CLIMATE CHANGE IN THE TRIÂNGULO MINEIRO REGION – BRAZIL

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ABSTRACT: In the summer of 2013/2014 the Brazil's Southern region dealt with a severe crisis in water supply. Recent studies have shown that the low volume of rainfall was caused by an anomalous atmosphere blocking condition. Would this anomaly be a regional effect caused by climate change? To answer this question this study aims to analyze the pattern of temperature, rainfall and relative humidity in the Triângulo Mineiro region, located at the Middle Eastern part of Brazil. Temperature (maximum, average and minimum), rainfall and relative humidity data for the weather stations of the Uberaba (1961 – 2015) and Capinópolis (1971 – 2015) cities were submitted to a Mann-Kendall statistical test (MK) in order to investigate trends. The results showed significant positive trends in temperature for both stations. Likewise, the MK test identified a significant negative trend in rainfall and relative humidity for the month of October, thereby suggesting a delay in the return of the rainy season (spring/summer). Analysis of covariance (ANCOVA) showed that there is a relationship between the reduction of rainfall and relative humidity, and the increase in temperature. The rainy season delay severely affects the water resources availability, and combined with expansion of crop areas, population growth, and the increase in temperatures, which leads to the increase in evapotranspiration, worsens the water stress in the Triângulo Mineiro region.

Keywords: Statistical Testing; Mann-Kendall; water resources; Uberaba city; Capinópolis city.

MUDANÇAS CLIMÁTICAS NA REGIÃO DO TRIÂNGULO MINEIRO - BRASIL

RESUMO: No verão de 2013/2014 a região sudeste do Brasil enfrentou uma grave crise de abastecimento. Trabalhos recentes demonstraram que a falta de chuvas foi consequência de condições anômalas de bloqueios atmosféricos. No entanto, seria essa anomalia uma manifestação regional dos efeitos das mudanças climáticas? O trabalho analisa o comportamento das temperaturas, precipitações e umidade relativa para a região do Triângulo Mineiro – MG – Brasil, buscando evidências de mudanças climáticas. Dados de temperatura (máxima, média e mínima), precipitações e umidade relativa para Uberaba (1961-2015) e Capinópolis (1971-2015) foram submetidos ao teste de Mann-kendall (MK) para verificação de suas respectivas tendências. Os resultados apontaram tendências significativas de aumento para as temperaturas (máximas, médias e mínimas) em ambos os locais. O MK também demonstrou tendências significativas de redução das chuvas e da umidade relativa nos meses de outubro, sugerindo atraso no retorno da estação chuvosa (primavera/verão). A análise de covariância (ANCOVA) mostrou que existe uma relação entre a redução das precipitações pluviométricas e da umidade relativa com o aumento das temperaturas. O atraso na estação chuvosa afeta severamente a disponibilidade de recursos hídricos e, combinado com a expansão das áreas cultivadas, o crescimento populacional e o aumento das temperaturas leva ao aumento da evapotranspiração, acentuando o estresse hídrico na região do Triângulo Mineiro.

Palavras-chaves: Testes estatísticos; teste de Mann-Kendall; recursos hídricos, Uberaba, Capinópolis.

1. INTRODUCTION

In the past 60 years, mankind has been more responsible for changes in ecosystems than over any other period of time in human history (RICHARDSON et al., 2009). In regards for climate change, the Fifth Assessment Report (AR5) reinforced evidences on climate change previously published in the AR4, pointing out the unequivocal warming of the climatic system and, since the fifties, the observed changes are unprecedented (IPCC, 2013).

To the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013), as the averaged Earth's surface temperature increases, the temperature and precipitation extreme events over continents in middle and tropical regions, most likely, will become more frequent and intense by the end of the twenty first century.

Research on this theme has demonstrated that greenhouse gas emissions (GARREAUD et al., 2009; KELLER, 2009; RUZMAIKIN et al., 2015) and other aspects of climate change are reaching the IPCC projections upper limits (EASTERLING et al., 1997; VINCENT et al., 2005; ALEXANDER et al., 2006; SILLMANN & ROECKNER, 2008; ORLOWSKY & SENEVIRATNE, 2012; CHOI et al., 2014; SHARMAA & BABELB, 2014; BARBU et al., 2015; GUAN et al., 2015; HU et al., 2015; PARAK et al., 2015; ALEXANDER, 2016 and RAO et al., 2016). In addition, the climate change key indicators are showing values beyond the natural variability in the Earth system, i.e. increases in averaged Earth's average surface temperature, global average sea level and temperature, Greenland and Antarctic ice sheets shrinking, and ocean acidification.

In Brazil, evidence on climate change (temperature and rainfall) is being widely presented and discussed. Studies on trends have shown a decrease in rainfall in the southern part of Amazon related to deforestation process (PAIVA & CLARKE, 1995), an increase in rainfall in the northern part of Amazon due to warming water of the Atlantic Ocean (MARENGO & ALVES, 2005), a decrease in rainfall in the southern and southeastern part of Brazil (FOLHES & FISCH, 2006; OBREGON & MARENGO, 2007 and BLAIN, 2009), an increase in magnitude of rainfall extreme events in the Twentieth Century in the southern and southeastern part of Brazil (HAYLOCK et al., 2006; OBREGON & MARENGO, 2007; MARENGO & CAMARGO, 2002; BLAIN, 2009; BORSATO & SOUZA FILHO, 2010; SANCHES et al., 2013, 2014; SILVA DIAS et al., 2013; VALVERDE & MARENGO, 2014), an increase in temperature observed in many cities in Brazil (VINCENT et al., 2005; HAYLOCK et al., 2006; OBREGON & MARENGO, 2007; MARENGO & CAMARGO, 2008), an increase in number of warm air masses in the Middle-South of Brazil (BORSATO & SOUZA FILHO, 2010).

The recent water shortage which took place in the southeastern part of Brazil in 2013 and 2014 due to the decrease in rainfall drew the water resources managers' and Brazilian society attention to the water availability issue. Research presented in (COELHO et al, 2015a, 2015b; LUIZ SILVA et al., 2015; NOBRE et al., 2016) thoroughly analyzed the drought climatology events and the ocean-atmosphere dynamic related to the years 2013-2014. The authors' research demonstrated that the anomalous water shortage was due to an atmospheric blocking condition triggered by the development of an anticyclone over the central region of Brazil for a longer period, thereby impeding frontal systems passage over the southern part of Brazil. The presence of this anticyclone increased temperature, decreased rainfall and relative air humidity in the region.

Furthermore, the occurrence of these and other extreme events causes enormous damages and impacts to agriculture, water resources, renewable energy, human health, ecosystems and biodiversity, coastal zones, cities and industry (NOBRE et al., 2016; YAZID & HUMPHRIES, 2015). Thereby, it is of value to study climate change in micro scales in order to assist decision makers in facing extreme events, such as, heat surges, storms, floods etc. mitigating impacts on society, mainly on those groups that are most vulnerable (DUCAN et al., 2013).

In this regard, this study aims to analyze the pattern of temperature (maximum, average and minimum values), rainfall and relative humidity in the Triângulo Mineiro region, located in the middle eastern part of Brazil as a means to search for climate change at the small scale. The paper is organized as follows: section 2 presents the data sources and the statistical methods employed; section 3 presents the results and discussion; finally, section 4 the conclusions, where the main findings are highlighted.

2. MATERIALS AND METHODS

2.1. STUDY AREA

The Triângulo Mineiro region is 52.760 km2 in area and located between 18° S and 20.5° S, and 51° W and 47.5° W (Figure 1). The eastern area limit encompasses part of the administrative region of the Alto Paranaíba (BATEZELLI et al., 2005; IBGE, 2016). The region landscape is characterized by tabular surfaces with gradual reduction of elevations to the west, varying between 750m and 350m. Its geological structure is formed by sedimentary and volcanic terrain Mesozoic, of the Paraná Basin (IBGE, 2016; NOVAIS, 2011).

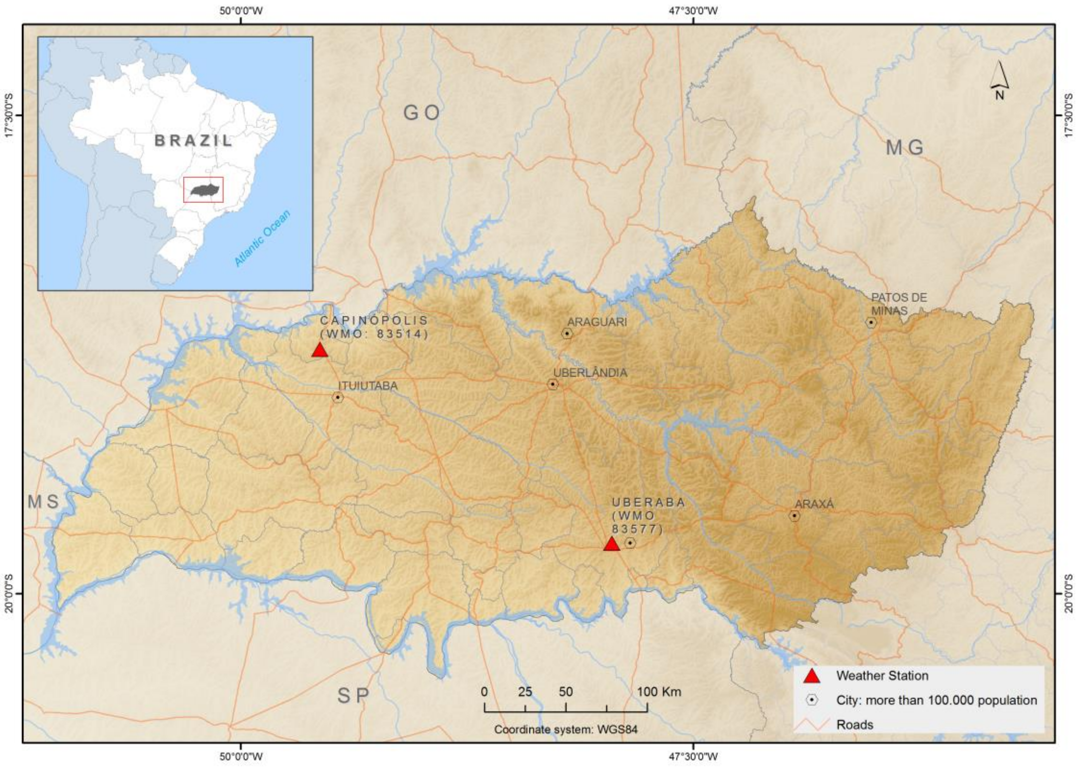


Figure 1 - Location of Triângulo Mineiro and weather stations in Uberaba and Capinópolis cities.

According to the Köppen climate classification system, the predominant climate in the region is the Aw type (Tropical Savanna). The annual average temperature ranges from 22C to 26C and the annual rainfall varies from 1,100 mm to 1,750 mm with the dry season lasting throughout the winter period (May, June and July) (NOVAIS, 2011; SÁ JUNIOR, 2009). The savanna ecoregion called Cerrado forms the natural land use composed of savanna forest, wooded savanna, park savanna, gramineous-woody savanna, savanna wetlands and gallery forests. Currently, it represents 20 % of the natural conditions (NOVAIS, 2001; SÁ JUNIOR, 2009; IBAMA, 2016).

Important urban areas are located in the region (Uberlândia – 662,362 hab., Uberaba – 322,126 hab., Araguari - 116,267 hab. and Ituiutaba - 103,333 hab.) (IBGE, 2016), which present a high demographic growth rate and, therefore presenting a high demand on water resource for water supply. It is a region with raising livestock and mining activities (limestone, diamond, clay and aggregates), which also highlights the expansion of the biofuel cane ethanol sector with sugarcane crops replacing, gradually, soybean crops and degraded pastures (NOVAIS, 2011). In 1997 cane croplands occupied roughly 100,000 hectares in the Triângulo Mineiro region. In 2003, these areas occupied roughly 150,000 hectares (BRITO & REIS, 2012). In 2010, however, the cane croplands areas increased to roughly 650,000 hectares (IBGE, 2016), thereby marking the biofuel production boom.

2.2. DATA AND METHODOLOGY

Rainfall and temperature data were acquired from the Meteorological Database for Research and Teaching (BDMEP in Portuguese), belonging to the National Institute of Meteorology (INMET in Portuguese). The acquired data were organized into monthly average maximum temperature (Tmax), monthly average temperature (Tmean), monthly average minimum temperature (Tmin), monthly average relative humidity (RH) and monthly rainfall at the weather stations of Uberaba city (station number WMO 83577), at the elevation of 737 m above the sea level, from 1961 to 2015 and Capinópolis city (station number WMO 83514), at the elevation of 650 m above sea level, from 1970 to 2015. Thereafter, the monthly rainfall data were summed across quarters (seasonal data): December, January and February (DJF) – Summer; March, April and May (MAM) – Autumn; June, July and August (JJA) – Winter; and September, October and November (SON) – Spring.

To fulfill the proposed objective, trends in temperature, relative humidity and rainfall data (both stations) were investigated by means of parametric (linear regression) and non-parametric (Mann-Kendall) tests.

The seasonal as well as the monthly data were subjected to the parametric and non-parametric tests. The Mann-Kendall (MK) test is a non-parametric statistical test used for trend analysis of long term time-series and recommended by the World Meteorological Organization (WMO) (ALEXANDER, 2016; HAYLOCK et al., 2006; BLAIN, 2009).

According to the MK test, the null hypothesis (H_0) represents the time series stability, in which realizations (X_n) must be independent and identically distributed. The alternative hypothesis (H_A) represents a monotonic trend in the time series. Thus, the MK statistic test is defined according to:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\,(X_j - X_k) \quad (1)$$

Where,

$$sgn\left(X_j - X_k\right) = \begin{bmatrix} 1;\, for\ X_j - X_i > 0 \\ 0; for\, X_j - X_i = 0 \\ -1; for\, X_j - X_i < 0 \end{bmatrix} \quad (2)$$

The mean of S (E[S]) is zero and its variance is given by:

$$VAR(S) = \frac{n(n-1).(2n+5)}{18} \quad (3)$$

The statistic S is approximately normal distributed, therefore a transformation to the reduced variable, Z, is applied:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & if \quad S < 0 \end{cases} \qquad (4)$$

If S equals to zero there is no trend, if it is different from zero there is a monotonic trend. In order to evaluate the trend significance, a certain confidence interval has to be chosen. Taking into account a 95% confidence interval, i.e., a significance level p equals to 0.05, the Z values must lie out of the interval ranging from -1.96 to 1.96.

Thereafter, a covariance analysis (ANCOVA) was applied to the data as a means of verifying the relationships and significant trends in temperature, rainfall and relative humidity.

3. RESULTS AND DISCUSSION

3.1. ANNUAL DATA ANALYSIS

The analysis of annual average maximum, annual average and annual average minimum temperatures for the weather stations of Uberaba and Capinópolis cities (Figure 2) shows upward trends during the analyzed period. The MK test results (Table 1) indicate the observed trends are statistically significant, which are consistent with the results observed by (EASTERLING et al. 1997; ALEXANDER et al., 2006; ALEXANDER, 2016).

ISSN: 2237-8642 (Eletrônica)

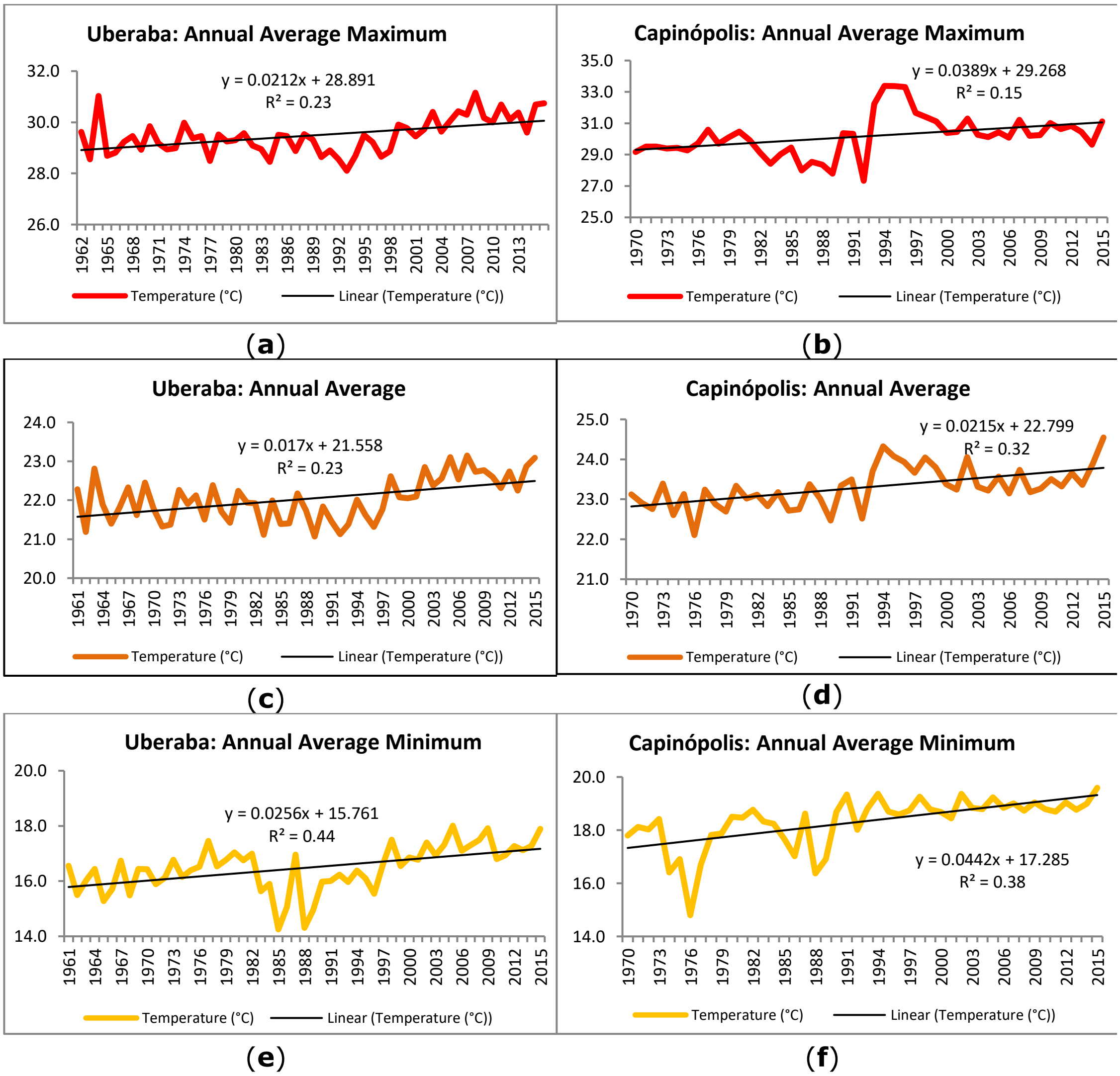


Figure 2 - Annual average maximum (a) (b), Annual average (c) (d) and Annual average minimum temperature (e) (f) trend for the weather stations of Uberaba and Capinópolis cities.

Table 1 - MK test Z values for the annual values of temperature at the significance level of 0.05.

Weather Station	TMax Annual	TMean Annual	TMin Annual
Uberaba	*3.83**	*3.46**	*4.40**
Capinópolis	*2.69**	*3.81**	*5.15**

* Significant at p=0.05.

Annual rainfall data and average relative humidity showed no significant trends by means of the MK statistic test application.

ISSN: 2237-8642 (Eletrônica)

3.2. SEASONAL DATA ANALYSIS

The seasonal data analysis showed significant trends during the analyzed period. For the weather station located in Uberaba city, average temperatures for summers (DJF), winters (JJA) and springs (SON) presented significant trends, as well as, winters and springs for the station in Capinópolis city. Regarding seasonal average temperatures, winters, springs and summers presented upward trends for both weather stations (Table 2).

Table 2 - MK test Z values for the seasonal temperature, rainfall and relative humidity data.

		Uberaba	Capinópolis
TMax	**DJF**	*3.30**	1.56
	MAM	1.43	0.99
	JJA	*2.95**	*2.05**
	SON	*4.09**	*3.36**
TMean	**DJF**	*3.97**	*2.40**
	MAM	1.88	1.92
	JJA	*2.86**	*2.49**
	SON	*3.34**	*4.09**
TMin	**DJF**	*4.16**	*3.53**
	MAM	*3.20**	*3.24**
	JJA	*2.97**	*3.84**
	SON	*3.71**	*4.49**
Rainfall.	**DJF**	1.04	1.90
	MAM	1.72	0.23
	JJA	0.25	-0.39
	SON	-1.34	-1.26
RH	**DJF**	*-2.47**	-1.93
	MAM	0.88	*-3.17**
	JJA	-1.06	*-3.75**
	SON	*-2.18**	*-3.65**

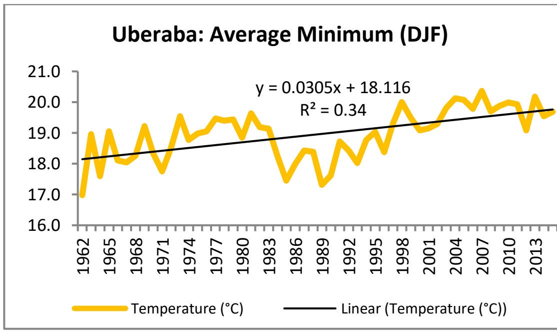
* Significant at p=0.05.

In respect to the average minimum temperatures (Figure 3), upward trends for both weather stations and seasons of the year were observed. These results agree with those of other studies in tropical regions (EASTERLING et al., 1997; VINCENT et al., 2005; ALEXANDER et al., 2006; SILMANN & ROECKNER, 2008; ORLOWSKY & SENEVIRATNE, 2012; SHARMAA & BABELB, 2014; BARBU et al., 2015; GUAN et al., 2015; HU et al., 2015; PARAK et al., 2015; ALEXANDER, 2016; OBREGON & MARENGO, 2007). The El Niño Southern Oscillation (ENSO) phenomenon in its negative phase (La Niña) resulted in a decrease in temperature in the years 1975-1976, 1984-1985 and 1988-1989 (Figure 3) (RAO & RADA, 1990). The southern part of South America is affected by the positive (El Niño) and negative phases of the ENSO. A decrease in rainfall and a decrease in temperature was observed for the negative phase (Figure 3) (RAO & RADA, 1990).

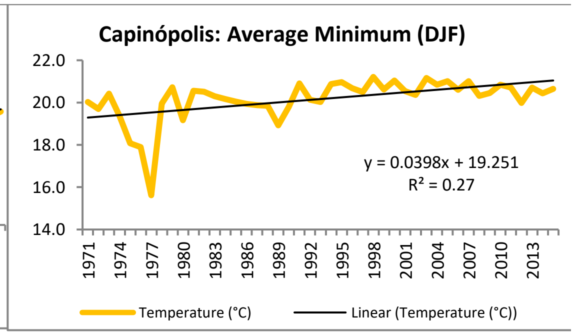
The downward trend found in average relative humidity data for the weather station in Uberaba city might be related directly to the observed increase in temperature during the warmer seasons (summer and spring).

Whereas for Capinópolis city, located at lower elevations and more inland, the downward trend was observed throughout the seasons, particularly, a significant downward trend for the winter, fall and spring.

Although the upward trend in temperature directly influenced the reduction of the relative humidity, it apparently did not show any influence on the seasonal rainfall. However, in both analyzed stations, downward trends in rainfall during spring were observed despite the fact they were not significant according to the MK test.



(a)



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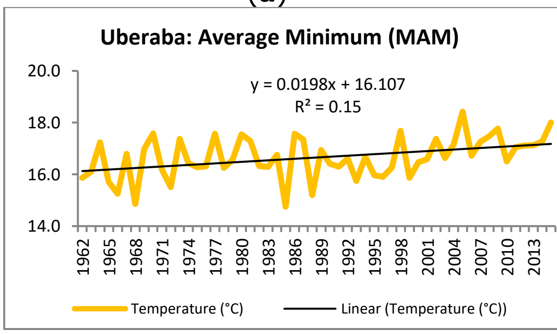
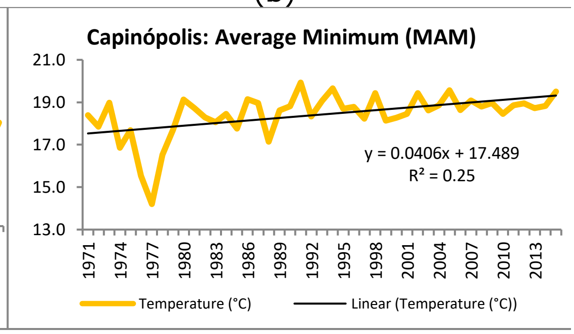


(c)



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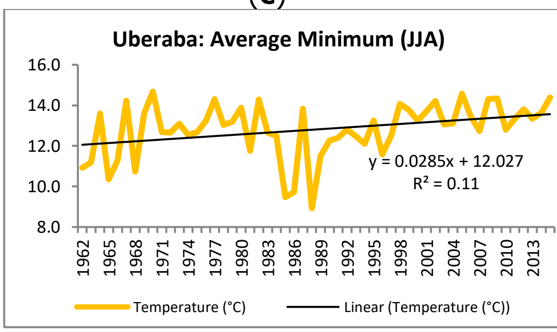

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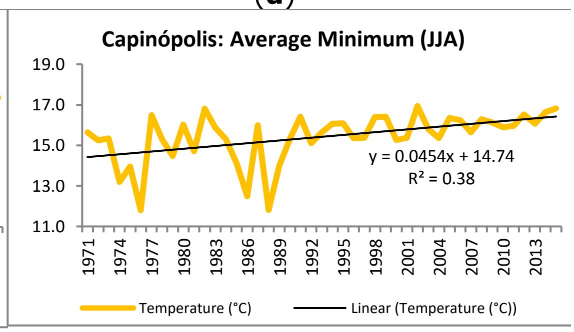
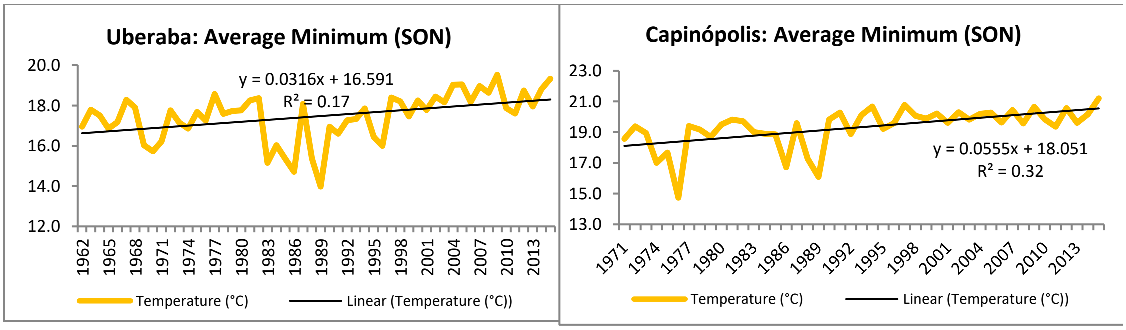


(f)



(g) (h)

Figure 3 - Seasonal average minimum temperature trends (Summer – DJF (a) (b); Fall – MAM (c) (d); Winter – JJA (e) (f) and Spring SON (g) (h)) for the weather stations in Uberaba and Capinópolis cities.

3.3. MONTHLY DATA ANALYSIS

Observing the monthly temperature, rainfall and relative humidity values, one can detect the increase in temperatures (for both cities) and its relationship with rainfall and relative humidity.

Table 3 - MK test Z values for monthly temperature, rainfall and relative humidity data.

	TMax	TMean	TMin	Rainfall	RH	TMax	TMean	TMin	Rainfall	RH
Jan	1,56	3,26*	3,56*	0,72	-0,73	1,42	1,38	2,14*	1,13	0,16
Feb	2,82*	2,82*	2,96*	-0,30	-1,69	0,82	1,11	3,19*	1,26	-0,78
Mar	0,61	0,86	2,48*	1,79	0,87	0,73	0,78	2,35*	0,58	-0,75
Apr	2,50*	1,67	2,39*	1,26	-0,06	2,10*	2,23*	3,64*	0,53	-1,91
May	0,20	0,55	1,52	1,11	-0,34	0,47	0,31	1,94	0,28	-2,37*
Jun	1,42	1,38	2,37*	-0,18	0,13	0,92	1,26	3,32*	0,30	-2,25*
Jul	2,99*	2,53*	2,56*	0,77	-0,64	1,92	2,05*	3,49*	0,62	-2,55*
Aug	2,02*	1,19	0,49	-0,23	-1,23	1,55	1,50	2,19*	1,42	-3,27*
Sep	1,26	1,12	1,99*	0,89	-0,19	2,83*	3,05*	4,05*	0,06	-3,08*
Oct	3,50*	3,54*	3,12*	-1,96*	-3,30*	2,85*	3,54*	3,74*	-2,25*	-3,37*
Nov	2,95*	2,73*	3,54*	-0,19	-0,68	2,51*	3,32*	2,95*	0,19	-1,76
Dec	3,85*	4,38*	4,71*	-0,06	-2,44*	2,18*	3,60*	4,37*	0,46	-2,40*

* Significant at p=0.05.

Although, there were significant upward trends in maximum and average temperatures for some months and for both stations, the minimum temperatures presented a higher significant change (Table 3). The upward trend in minimum temperatures (TMin) was observed in all the months for Uberaba weather station, except for the months of May and August. Whereas for Capinópolis weather station, the upward trend was not significant only for the month of May. These results are consistent with the research of Marengo & Camargo (2008), Borsato & Souza Filho (2010), Guan et al (2015), Hu et al (2015), Alexander (2016) and Caloiero (2016).

The MK test for the monthly rainfall and relative humidity data showed significant downward trends for the month of October (Figure 4).

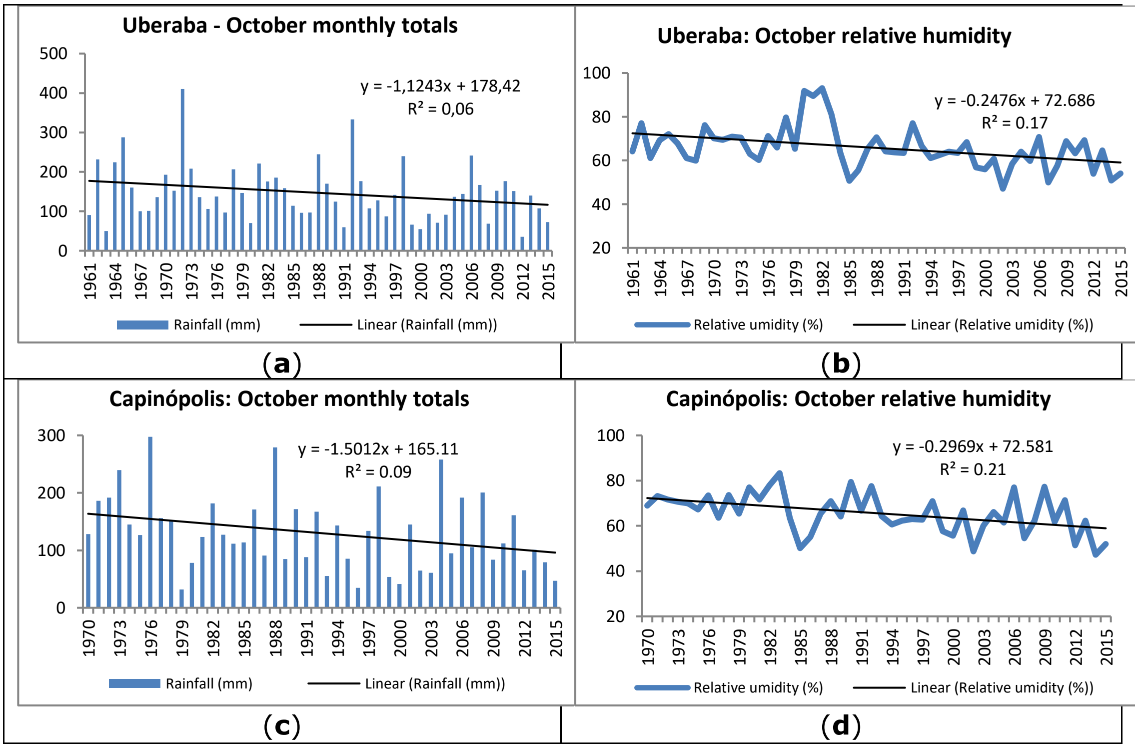


Figure 4 - Monthly rainfall and relative humidity for the month of October. Uberaba city weather station (a) (b) and Capinópolis city weather station (c) (d).

ANCOVA evaluates the difference between means of two or more groups, considering the relationship between a quantitative covariate and the response variable (MARDIA et al., 1994). ANCOVA application suggest a direct relationship between the increase in temperatures (average maximum, average and average minimum) and the decrease in rainfall and relative humidity for the month of October in both stations (Figure 5). The values of F confirm the covariance between temperatures, rainfall and relative humidity (Table 4 and 7).

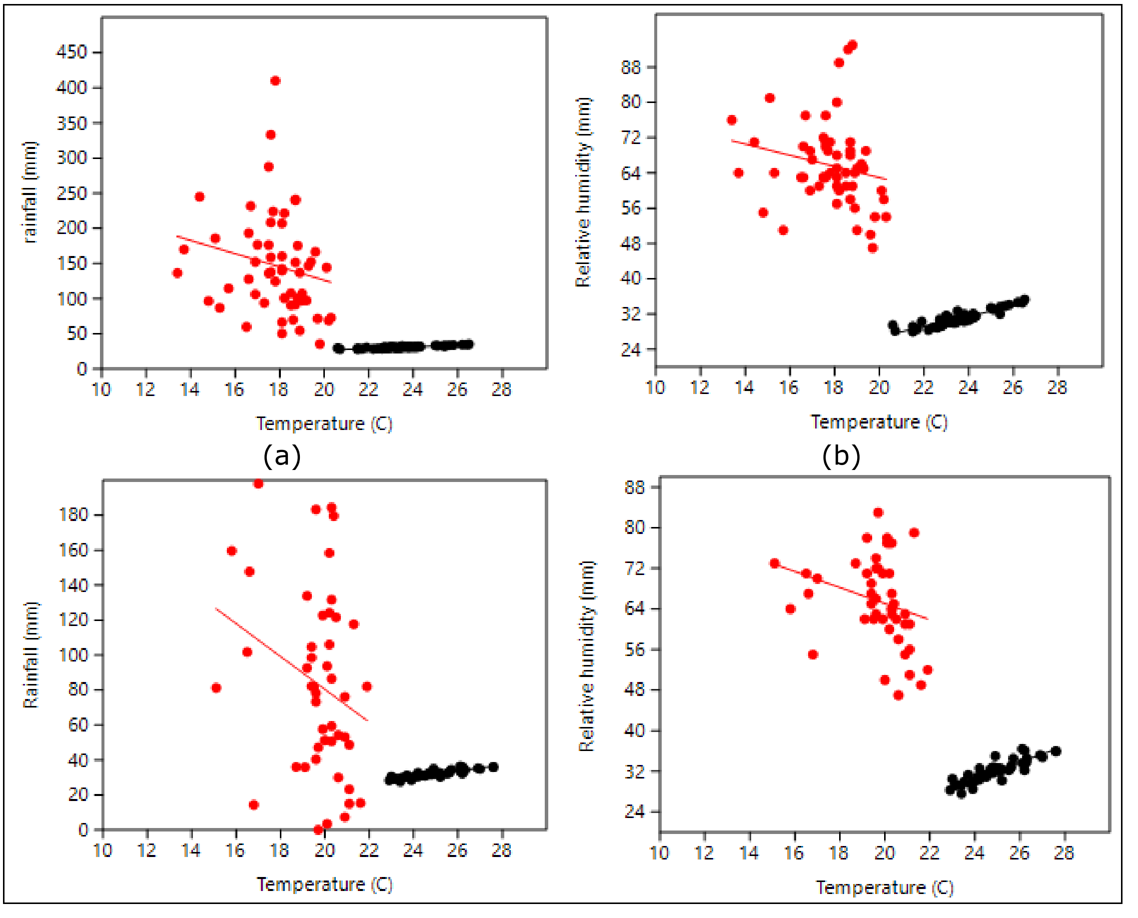


Figure 5 - ANCOVA of October temperature, rainfall and relative humidity data. Uberaba city weather station (a) (b) and Capinópolis city weather station (c) (d).

Table 4 - Test for equal means, adjusted for covariate - October temperature and rainfall data – Uberaba weather station.

	Sum of sqrs	df	Mean square	F	p (same)
Adj. mean:	40315,2	1	40315,2	*15,52*	*0,0001461*
Adj. error:	278020	107	2598,32		
Adj. total:	318335	108			

Homogeneity (equality) of slopes:	
F :	2,341
p (same)	0,129

ISSN: 2237-8642 (Eletrônica)

Table 5 - Test for equal means, adjusted for covariate – October temperature and relative humidity data – Uberaba weather station.

	Sum of sqrs	df	Mean square	F	p (same)
Adj. mean:	5903,24	1	5903,24	*123,7*	*1,469E-19*
Adj. error:	5106,27	107	47,7222		
Adj. total:	11009,5	108			

Homogeneity (equality) of slopes:	
F :	7,028
p (same)	0,009253

Table 6 - Test for equal means, adjusted for covariate – October temperature and rainfall data – Capinópolis weather station.

	Sum of sqrs	df	Mean square	F	p (same)
Adj. mean:	2975,27	1	2975,27	2,199	0,1416
Adj. error:	120423	89	1353,06		
Adj. total:	123398	90			

Homogeneity (equality) of slopes:	
F :	3,656
p (same)	0,05911

Table 7 - Test for equal means, adjusted for covariate – October temperature and relative humidity data – Capinópolis weather station.

	Sum of sqrs	df	Mean square	F	p (same)
Adj. mean:	4845,78	1	4845,78	*120,3*	*3,275E-18*
Adj. error:	3584,58	89	40,2762		
Adj. total:	8430,36	90			

Homogeneity (equality) of slopes:	
F :	11,08
p (same)	0,001273

The climatology of tropical regions in Brazil suggests that the return of the rainy season should occur in the middle of the month of October (SAMPAIO et al., 2006; REBOITA et al., 2010). Consequently, the downward trend in the monthly rainfall data suggests the delay in the rainy season is increasing the dry season period. Likewise, the downward trend in relative humidity, which was considered significant by the MK test, influences the dry season period since the temperatures (Tmax, Tmean and Tmin) for the month of October showed upward trends.

According to Borsato & Souza Filho (2010), the warming effect, which took place in the Paraná watershed, influenced the atmosphere dynamics at global and local scales. Thus, it is possible that the higher temperatures pattern at the end of the hydrological winter lead to a delay trend in the rainfall pattern in the Triângulo Mineiro region, thereby producing longer dry seasons.

4. CONCLUSIONS

As a way to contribute to the current discussion on climate change at small scales by means of the study of local and regional effects, this work studied the pattern of temperature, rainfall and relative humidity in the Triângulo Mineiro region.

The upward trend observed in temperature, as well as the decrease in rainfall and relative humidity, agrees with results from other studies on climate change in Brazil and South America.

It is worth noting that the decrease in rainfall and relative humidity is associated to the upward trend in temperature (maximum, average and minimum) for the month of October. The analysis carried out in this study suggests the increase in temperatures is affecting the decrease in rainfall and causing longer dry seasons. The rainy season delay combined with expansion of crop areas, population growth, and the increase in temperatures (which leads to an increase in evapotranspiration), severely affects the water resources availability and worsens the water stress.

Eventually, the results presented herein might contribute for public management in order to mitigate the climate change effects.

Acknowledgments: The authors thank FAPERGS (grant no. 002073-2551/13-1) and CNPq (grant no. 460329/2014-6) for financial support. The authors also thank the reviewers for their corrections and contributions.

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