ea engenharia agrícola
Journal of the Brazilian Association of Agricultural Engineering

Engenharia Agrícola

ISSN: 1809-4430 (on-line)
www.engenhariaagricola.org.br

Doi:http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v38n2p173-179/2018

CLIMATE CHANGE AND RURAL WORKERS THERMAL COMFORT: HISTORICAL AND FUTURE IMPACTS

André L. N. Amaro[1], Tadayuki Yanagi Junior[2*], Sílvia de N. M. Yanagi[1], Gabriel A. E S. Ferraz[1], Alessandro T. Campos[1]

[2*] Corresponding author. Universidade Federal de Lavras/ Lavras - MG, Brasil. E-mail: yanagi@deg.ufla.br

KEYWORDS

human biometeorology, human thermal comfort, THI, time series

ABSTRACT

The aim of the present research was to propose a bioclimatic mapping to classify the thermal comfort and discomfort of rural workers within the state of Minas Gerais, considering historical and future scenarios. Monthly historical series (1976-2014) of minimum, mean and maximum temperature-humidity index (THI), determined through the values of air temperature (minimum, mean and maximum) and relative humidity from 48 weather stations located in the state of Minas Gerais were used to analyze the trends through Mann-Kendall and linear regression assays. The bioclimatic mapping of human comfort, obtained via geostatistical analysis, was developed as a function of the minimum, medium and maximum THI for the historical period (1976-2014) and future scenario (2024). Results indicate an overall trend of increasing in thermal discomfort conditions throughout the mesoregions of the state of Minas Gerais during the weather seasons, being more incisive in summer and spring.

INTRODUCTION

Climate change can generate negative impacts on human beings, especially workers in some agribusiness activities that require higher metabolic activity. Impacts of the thermal environment on humans have been widely studied because of the harmful effects on performance and health (Ou et al., 2014) and, under extreme conditions, leading to death (Loughnan et al., 2010).

Under heat stress conditions, humans present changes in physiological parameters, such as increases in heart rate, body temperature, blood pressure, and sweat production (Shen & Zhu, 2015). Heat-related disorders such as sunstroke, cramps and exhaustion have also been reported (Zheng et al., 2012). Extreme conditions of cold stress also cause health problems (McMichael et al., 2006).

Indexes of the thermal environment have been used to generate bioclimatic maps applied to the analysis of the effect of the external environment on humans (Park et al., 2014). Among the various indexes, the temperature and humidity index (THI) (Thom, 1959) has been widely used to classify the level of thermal comfort of humans, in view of the easy obtaining of meteorological data used as input into the equation.

In this context, the goal of the present study was to propose a bioclimatic zoning to classify the thermal comfort and discomfort of rural workers in the State of Minas Gerais, using the temperature and humidity index (THI), considering a historical period and a future scenario.

MATERIAL AND METHODS

For the development of bioclimatic zoning of human comfort for the State of Minas Gerais, it was used data from 48 weather stations located in the State of Minas Gerais belonging to the National Institute of Meteorology (INMET) (Figure 1). The database is composed of the monthly average values of minimum, medium and maximum dry-bulb temperatures ($t_{db,min}$, $t_{db,mean}$ and $t_{db,max}$, respectively) and air relative humidity (RH).

---

[1] Universidade Federal de Lavras/ Lavras - MG, Brasil.
Received in: 8-25-2017
Accepted in: 11-20-2017

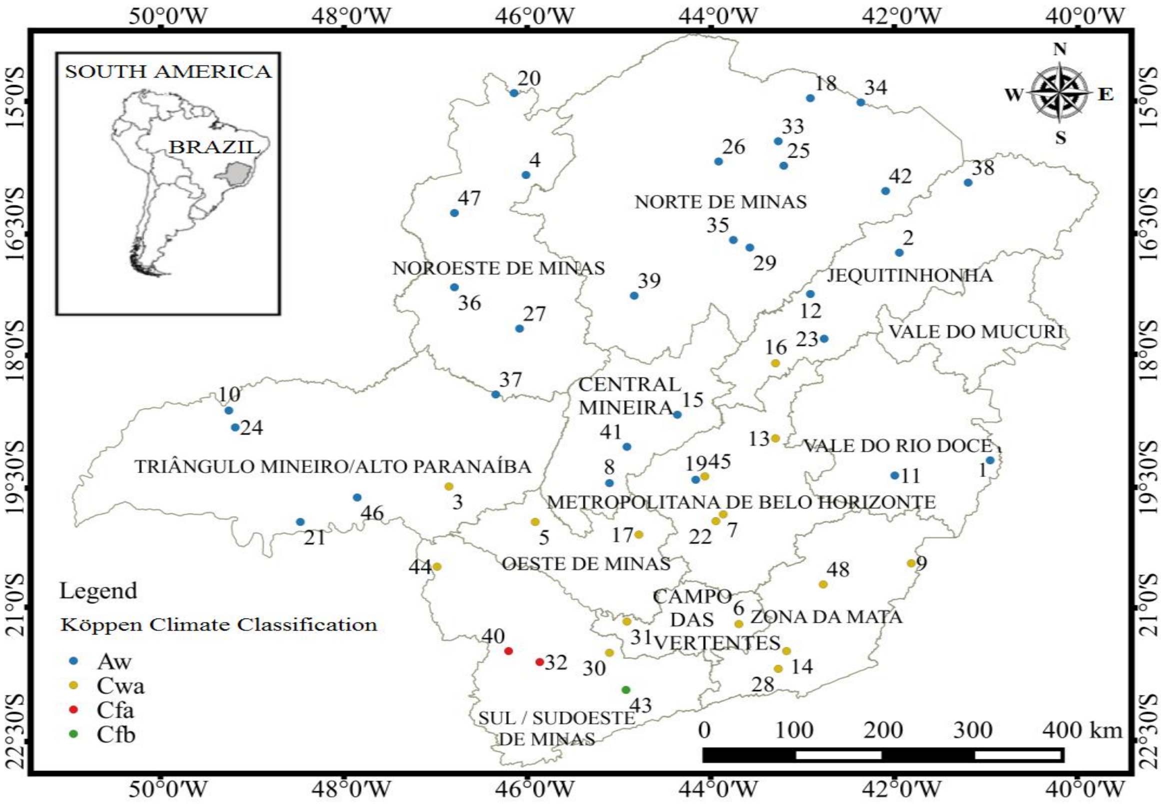

FIGURE 1. Location of the weather stations used in the present study.

The State of Minas Gerais has an area of approximately 7% of the Brazilian territory, with 582,586 km² and wide climatic variability (Tonietto et al., 2006). The average values of annual precipitation vary from 700 to 1,100 mm in the driest regions (north, northeast and east) and from 1,200 to 1,500 mm in the rainier regions (South, Triângulo Mineiro, northwest and Serra do Espinhaço and Mantiqueira) (Mello & Viola, 2013). In the lower regions of north and east of the State, the monthly average temperatures reach 27°C, while in the higher regions are observed temperatures around 13°C.

The weather stations used in this study are listed in Table 1, and the historical series of $t_{db,min}$, $t_{db,mean}$, $t_{db,max}$ and RH were of 39 years, covering the period from 1976 to 2014.

TABLE 1. Conventional weather stations and their respective elevation.

N°	Station	Elev. (m)	N°	Station	Elev. (m)	N°	Station	Elev. (m)
1	Aimorés	83	17	Divinópolis	788.35	33	Mocambinho	452
2	Araçuaí	289	18	Espinosa	596.64	34	Monte Azul	625
3	Araxá	1.024	19	Florestal	749	35	Montes Claros	652
4	Arinos	519	20	Formoso	840	36	Paracatu	712
5	Bambuí	661	21	Frutal	544	37	Patos de Minas	940
6	Barbacena	1.126	22	Ibirité	815	38	Pedra Azul	648.91
7	Belo Horizonte	915	23	Itamarandiba	1.097	39	Pirapora	505
8	Bom Despacho	695	24	Ituiutaba	560	40	Poços de caldas	1.15
9	Caparaó	843	25	Janaúba	516	41	Pompéu	691
10	Capinópolis	620.6	26	Januária	474	42	Salinas	471
11	Caratinga	610	27	João Pinheiro	760.36	43	São Lourenço	953
12	Carbonita	736	28	Juiz de Fora	940	44	São S. do Paraiso	820
13	C do Mato Dentro	652	29	Juramento	648	45	Sete Lagoas	732
14	Coronel Pacheco	435	30	Lambari	878	46	Uberaba	737
15	Curvelo	672	31	Lavras	919	47	Unaí	460
16	Diamantina	1.296	32	Machado	873	48	Viçosa	712

N - number of the weather station; Elev - station elevation

THI was calculated through the (Equation 1) (Thom, 1958), based on $t_{db,min}$, $t_{db,mean}$, $t_{db,max}$ (°C) and dew point temperature (t_{dp}), that was determined by (Equation 2) (Vianello & Alves, 2012) as a function of the actual water vapor pressure (e, hPa).

$$\mathrm{THI} = t_{db} + 0,36 \cdot t_{dp} + 41,5 \tag{1}$$

where,

THI – temperature and humidity index (THI, dimensionless);

t_{db} – air dry-bulb temperature, °C;

t_{dp} – air dew-point temperature, °C,

$$t_{dp} = (186,4905 - 237,3 \log e)/(\log e - 8,2859) \tag{2}$$

where,

e – actual water vapor pressure, hPa.

Historical series trend analysis

The trends of the historical series of THI_{min}, THI_{mean}, THI_{max} over a period of 39 years, for each studied station, were verified using the non-parametric Mann-Kendall test (Mann, 1945; Kendall, 1975) proposed by Sneyers (1975), and the linear regression analysis, methodologies commonly used (Minuzzi, 2010, Ávila et al., 2014, Tian et al., 2016).

The non-parametric Mann-Kendall test considers that, since there is stability of the time series (Hypothesis H_0), the succession of values occurs independently and the probability distribution remains unchanged (simple random series).

A time series will present a tendency of increase or decrease of a certain variable if the value of the Mann-Kendall coefficient is positive (MK> 0) or negative (MK <0), respectively. For this purpose, the Z test should be applied at the 5% level of significance, which provides $Z_{0.975}$ = 1.96. It is rejected H_0 if the Mann-Kendall test, $|MK| > Z_{1-\alpha/2}$, is greater than 1.96, indicating a significant trend in the data time series (AVILA et al., 2014). The S statistic was determined by (Equation 3), where n is the number of observations, Xj and Xi are the sequential values of the data and sgn (ϕ) is the signal function. The signal function assumes a value of 1 if $\phi > 0$; 0 if $\phi = 0$; and -1 if $\phi < 0$.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}\,(X_j - X_i) \tag{3}$$

According to Kendall (1975), assuming the hypothesis that the data are identically distributed and independent, the average and the variance of the Z statistic are given by (Equations 4 and 5), respectively. The m is the number of associated classification groups, each one associated with a ti, which corresponds to the THI values of the historical series of THI_{min}, THI_{mean} and THI_{max}.

$$E(S) = 0 \tag{4}$$

$$\mathrm{Var}(S) = \frac{n \cdot (n-1) \cdot (2 \cdot n + 5) - \sum_{i=1}^{m} ti \cdot (ti - 1) \cdot (2 \cdot ti + 5)}{18} \tag{5}$$

The value of Z can be calculated as follows:

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{\mathrm{Var}(s)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \dfrac{s+1}{\sqrt{\mathrm{Var}(s)}}, & \text{if } S < 0 \end{cases}$$

The linear regression analysis was applied to obtain trends through the parametric significance *t* test over the angular coefficient (β) (Longobardi & Villani, 2010). This test considered the linear regression between the random variable Y (THI series) and time (X). The trend for a period of 10 years (2024) was calculated using the adjusted linear equations, multiplying β by 10.

Bioclimatic zoning

The bioclimatic zoning was carried out through the interval maps of THI_{min}, THI_{mean} and THI_{max} for the State of Minas Gerais, considering the historical period from 1976 to 2014, and indicating trends for 2024, a decade after the end of the data historical series.

Statistical analysis and linear regression were performed by the R program (R Development Core Team, 2014). The creation of the maps was made by the ArcGIS for Desktop 10.4 program, through its extensions, Spatial Analyst and Geostatistical Analyst. The spatial dependence of the THI in the State of Minas Gerais was analyzed by means of the semivariogram adjustment using the OLS method, adjusting the spherical model, and the interpolation was carried out using ordinary kriging (Ferraz et al., 2015).

The zones of thermal comfort and discomfort for rural workers were defined considering that the rural workers exert moderate activities, with metabolic rate of 175 W, working stand-up, with movement of arms and legs and the use of light clothes, that is, with thermal resistance of 0.09°C W m^{-2} (Oliveira et al., 2006).

The thermal environments were classified as comfort (THI <74), hot (74≤THI <79), very hot (79≤THI<84) and extremely hot (THI≥84) (Lamberts et al., 1997; Oliveira et al., 2006). Thermal discomfort begins in the hot environment and can cause health problems and reduce rural workers’ performance. The very hot environment indicates danger and can cause serious effects to health and the extremely hot environment can cause very serious health risks.

RESULTS AND DISCUSSION

The spatial distribution of the average historical values (1976-2014) of THI_{min} and THI_{mean} indicate that the thermal environment in almost all seasons was classified as a comfort situation (THI <74), except for spring. At this season, the THI_{mean} in some parts of the mesoregion of the Triângulo Mineiro/Alto Paranaíba and part of the boarder of the mesoregions of the Northwest and North of Minas Gerais presented values in the interval between 74 and 79, characterizing the region as hot (Figure 2).

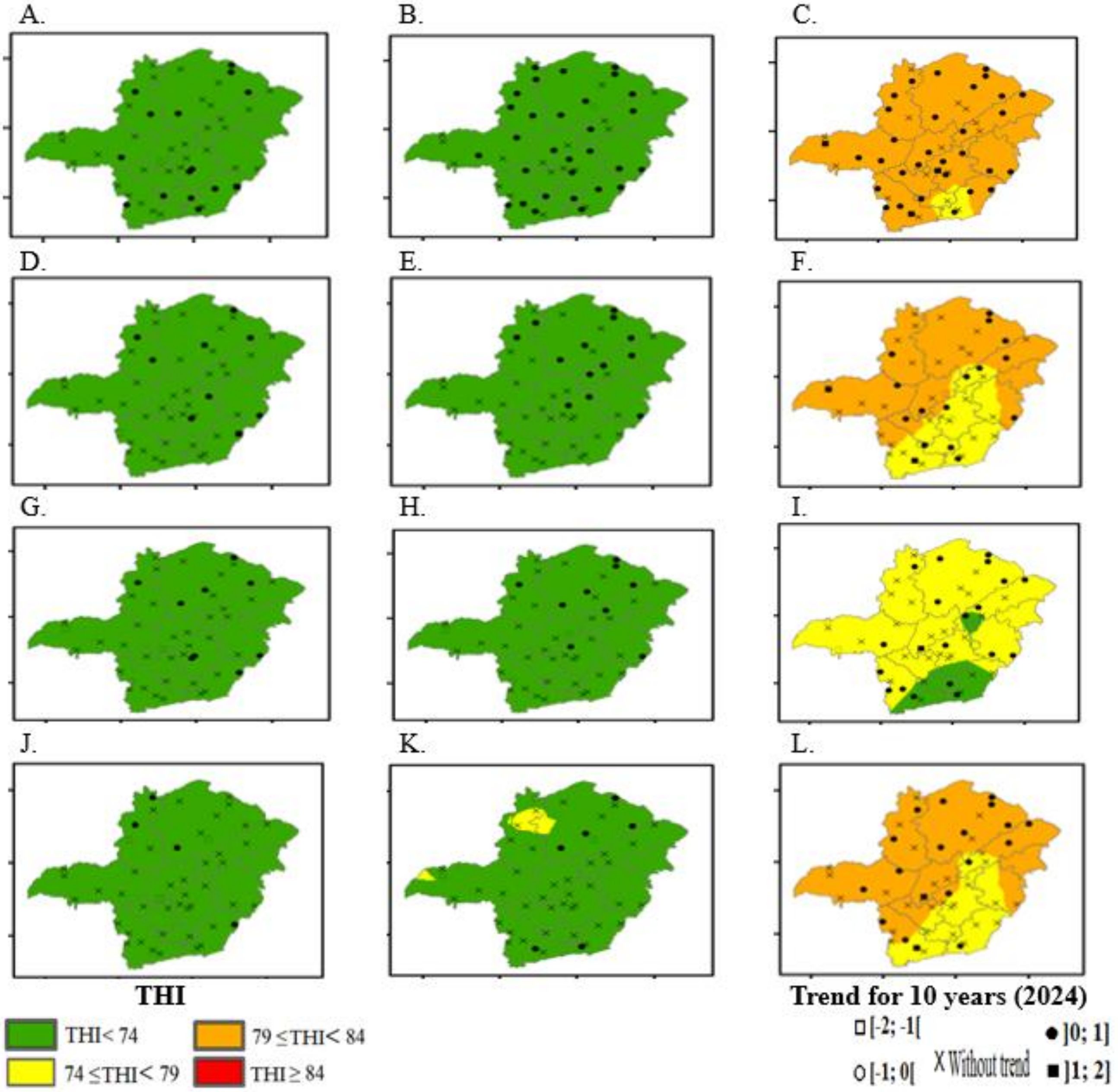

FIGURE 2. Variation of the minimum, medium and maximum temperature and humidity index (THI) (summer: (A), (B) and (C), respectively; fall: (D), (E) and (F), respectively; winter: (G), (H) and (I), respectively; spring: (J), (K) and (L), respectively), for the period from 1976 to 2014, in the evaluated municipalities of the State of Minas Gerais, and their THI trends for a decade (2024).

In relation to the average historical values of THI_{max}, it can be observed that only during the winter period (Figure 2I), part of the mesoregions of South/Southwest of Minas Gerais, Campos das Vertentes, Zona da Mata, West of Minas Gerais and Belo Horizonte Region, Jequitinhonha and Vale do Rio Doce presented comfort conditions (THI <74). The other mesoregions were classified as hot (74 ≤ THI <79) or very hot (79 ≤ THI <84) for winter and other seasons. The very hot areas have expanded throughout the seasons, from winter to summer and declining in fall (Figures 2C, 2F, 2I, 2L); similar to what was observed by Oliveira et al. (2006).

Thus, periods with thermal conditions classified as hot (74 ≤ THI <79) and very hot (79<THI≤ 84) were observed at all seasons in the State of Minas Gerais for THI_{max}, corroborating with Oliveira et al. (2006). Therefore, minor or serious health problems, in addition to the reduction in the performance of rural workers are expected. It is emphasized that, hourly variations of the THI can cause situations of thermal discomfort (Buriol et al., 2015), intensifying the discomfort.

The comfort classification verified for $THI_{mín}$ in the four seasons in the historical period (1976-2014) did not change in 2024 (Figure 3), although tendencies of increase and reduction of these values were observed (Figures 2A, 2D, 2G, 2J).

The reductions in the occurrence frequency of the condition classified as comfort for the THI_{mean} in the summer, fall, winter and spring seasons were 6.25%, 0.00%, 0.00% and 2.08%, respectively. These percentages of reduction were consequently added to the condition of the thermal environment classified as hot (Figure 3). Reduction on 6.25% of the situation classified as hot and increase of very hot situation was verified for THI_{max} (Figure 3A) in the summer season.

In the fall, it was observed the decrease of occurrences of THI_{max} values for comfort conditions of 2.09 (Figure 3B). Consequently, it was observed a 2.09% increase in the extremely hot classification for THI_{max} when comparing the 2024 scenario with the historical period (1979-2014).

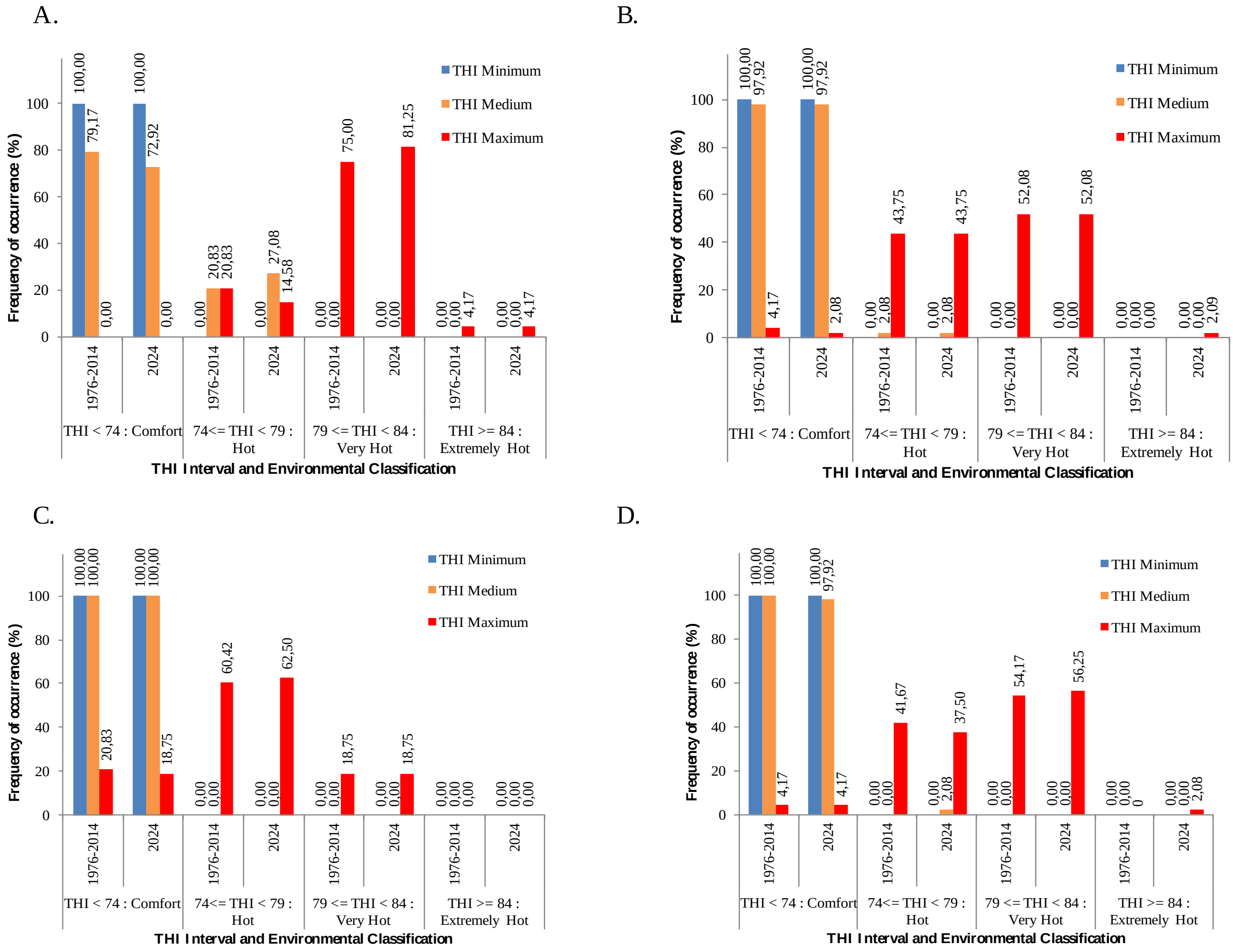

FIGURE 3. Variation of the occurrence frequency of THI_{min}, THI_{med} and THI_{max} in the seasons of (A) summer, (B) fall, (C) winter and (D) spring, for the period from 1976 to 2014 and for the year 2024, in the evaluated municipalities of the state of Minas Gerais

The trend analysis indicates, in general, the increase of the occurrence frequency of the hot classification in summer and spring for THI_{mean} and THI_{max}, when comparing the 2024 scenario with the historical period (1979-2014). So, it was verified the increase of the extremely hot condition in autumn and spring. This profile due to climatic changes increases human discomfort especially in summer, fall and spring, in which the sums of THI_{max} occurrences classified as very hot and extremely hot are 85.42%, 54.16% and 58.33 %, (Figure 3), respectively. The increase in human discomfort due to climate change was also verified by Potchter & Ben-Shalom (2013).

Zhang et al. (2014) recommended the upper limits of t_{db} and RH of 29.2°C and 50% (THI = 77.1) and 28.0°C and 70% (THI = 77.4) so that 90% of people can be satisfied in circulation spaces in a hot and humid area of China. The satisfaction level of 73% was obtained for t_{db} and RH of 31.0°C and 50% (THI = 79.5) and of 29.5°C and 70% (THI = 79.4).

Changes in the thermal environment are related to declining work capacity (Dunne et al., 2013) and to the increased incidence of cardiovascular diseases (Ezekowitz et al., 2013) and mental disorders (Vaneckova & Bambrick, 2013). The absence of actions to mitigate the thermal environment on humans can cause reduction of performance and increase of diseases, a situation that can be aggravated by climate changes.

Given the current climatic conditions and trends to the future, strategies to mitigate the thermal effects of the environment on humans must be analyzed, such as the selection of surrounding vegetation (Lee et al., 2016), materials selection (Ragheb et al., 2016), the energy demand for heating or cooling (Van Hove et al., 2015), the design of the building, among others. This knowledge is essential for studies related to the reduction and adaptation to climate change (Hjort et al., 2016).

CONCLUSIONS

The bioclimatic zoning of the temperature and humidity index (THI) for the State of Minas Gerais indicated the occurrence of hot conditions (74 ≤ THI <79) when analyzing the THI_{mean} in the summer and fall and very hot conditions (79 <THI ≤ 84) and extremely hot conditions (THI>84) for THI_{max} throughout the year, except in the winter.

Trend analysis applied to the time series indicates worst conditions in 2024.

ACKNOWLEDGEMENTS

To the Federal University of Lavras (UFLA), FAPEMIG, CAPES and CNPq for financial support.

REFERENCES

Ávila LF, Mello CR, Yanagi SNM, Neto OBS (2014) Tendências de temperaturas mínimas e máximas do ar no Estado de Minas Gerais. Pesquisa Agropecuária Brasileira 49(4):247-256. DOI: 10.1590/S0100-204X2014000400002

Buriol GA, Estefanel V, Righi EZ, Bressan VC (2015) Conforto térmico para os seres humanos nas condições de ambiente natural em Santa Maria, RS, Brasil. Ciência Rural 45(2):223-230. DOI: http://dx.doi.org/10.1590/0103-8478cr20131537

Dunne JP, Stouffer RJ, Hohn JG (2013) Reductions in labour capacity from heat stress under climate warming. Nature Climate Change 3(6):563-566. DOI: http://dx.doi.org/10.1038/nclimate1827

Ezekowitz JA, Bakal JA, Westerhout CM, Giugliano RP, White H, Keltai M, Prabhakaran D, Tricoci P, Werf FV, Califf RM, Newby LK, Armstrong PW (2013) The relationship between meteorological conditions and index acute coronary events in a global clinical trial. International Journal of Cardiology 168(3):2315-2321. DOI: https://doi.org/10.1016/j.ijcard.2013.01.061

Ferraz GAS, Silva FM, Oliveira MS, Avelar RC, Sales RS (2015) Variabilidade espacial da dose de P2O5 e K2O para adubação diferenciada e convencional em lavoura cafeeira. Coffee Science 10(3):346-356.

Hjort J, Suomi J, Käyhko J (2016) Extreme urban-rural temperatures in the coastal city of Turku, Finland: Quantification and visualization based on a generalized additive model. Science of the Total Environment 569(1)507–517. DOI: https://doi.org/10.1016/j.scitotenv.2016.06.136

Kendall MG (1975) Rank correlation methods. London, Charles Griffin. 210p.

Lamberts R, Dutra L, Pereira FOR (1997) Eficiência energética na arquitetura. São Paulo, PW. 192p.

Lee H, Mayer H, Chen L (2016) Contribution of trees and grasslands to the mitigation of human heat stress in a residential district of Freiburg, Southwest Germany. Landscape and Urban Planning 148(1)37-50. DOI: https://doi.org/10.1016/j.landurbplan.2015.12.004

Longobardi A, Villani P (2010) Trend analysis of annual and seasonal rainfall time series in the Mediterranean area. International Journal of Climatology 30(10):1538-1546. DOI: https://doi.org/10.1002/joc.2001

Loughnan M, Nicholls N, Tapper N (2010) Mortality-temperature thresholds for ten major population centres in rural Victoria, Australia. Health & Place 16(6):1287-1290. DOI: https://doi.org/10.1016/j.healthplace.2010.08.008

Mann H B (1945) Nonparametric test against trend. Econometrika 13(1):245-259. DOI: 10.2307/1907187

McMichael AJ, Woodruff RE, Hales S (2006) Climate change and human health: present and future risks. The Lancet 367(9513):859-869. DOI: https://doi.org/10.1016/S0140-6736(06)68079-3

Mello CR, Viola MR (2013) Mapeamento de chuvas intensas no estado de Minas Gerais. Revista Brasileira de Ciência do Solo 37(1):37- 44. Available in: http://www.redalyc.org/articulo.oa?id=180225736009

Minuzzi RB (2010) Tendências na variabilidade climática de Santa Catarina, Brasil. Revista Brasileira de Engenharia Agrícola e Ambiental 14(12):1288-1293. DOI: http://dx.doi.org/10.1590/S1415-43662010001200006

Oliveira LMF, Yanagi junior T, Ferreira E, Carvalho LG, Silva MP (2006) Zoneamento bioclimático da região Sudeste do Brasil para o conforto térmico animal e humano. Engenharia Agrícola 26(3)823-831.

Ou CQ, J YANG , Ou QQ, Liu HZ, Lin GZ, Chen PY, Qian J, Guo YM (2014) The impact of relative humidity and atmospheric pressure on mortality in Guangzhou, China. Biomedical and Environmental Sciences 27(12):917-925. DOI: https://doi.org/10.3967/bes2014.132

Park S, Tuller SE, Jo M (2014) Application of Universal Thermal Climate Index (UTCI) for microclimatic analysis in urban thermal environments. Landscape and Urban Planning 125(1):146-155. DOI: https://doi.org/10.1016/j.landurbplan.2014.02.014

Potchter O, Ben-Shalom HI (2013) Urban warming and global warming: Combined effect on thermal discomfort in the desert city of Beer Sheva, Israel. Journal of Arid Environments 98(1):113-122. DOI: https://doi.org/10.1016/j.jaridenv.2013.08.006

R Development Core Team. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing 2017. Available in: http://www.R-project.org/. Accessed: Jun 22, 2017.

Ragheb AA, El-darwish II, Ahmed S (2016) Microclimate and human comfort considerations in planning a historic urban quarter. International Journal of Sustainable Built Environment 5(1):156-167. DOI: https://doi.org/10.1016/j.ijsbe.2016.03.003

Shen D, Zhu N (2015) Influence of the temperature and relative humidity on human heat acclimatization during training in extremely hot environments. Building and Environment 94(1):1-11. DOI: https://doi.org/10.1016/j.buildenv.2015.07.023

Sneyers R (1975) Sur L' analyse statistique des séries d' observations. Genève, Organization Météorologique Mondial. 192p.

Thom EC (1958) Cooling degree: day air conditioning, heating, and ventilating. Transactions of the ASHRAE 55(1):65-72.

Thom EC (1959) The discomfort index. Weatherwise 12(1):57-60.

Tian Q, Prange M, Merkel U (2016) Precipitation and temperature changes in the major Chinese river basins during 1957–2013 and links to sea surface temperature. Journal of Hydrology 536(1):208-221. DOI: https://doi.org/10.1016/j.jhydrol.2016.02.048

Tonietto J, Vianello RL, Regina MA (2006) Caracterização macroclimática e potencial enológico de diferentes regiões com vocação vitícola de Minas Gerais. Informe Agropecuário 27(234):32-55.

Van Hove LWA, Jacobs CMJ, Heusinkveld BG, Elbers JA, Van Driel BL, Holtslag AAM (2015) Temporal and spatial variability of urban heat island and thermal comfort within the Rotterdam agglomeration. Building and Environment 83(1):91-103. DOI: https://doi.org/10.1016/j.buildenv.2014.08.029

Vaneckova P, Bambrick H (2013) Cause-specific hospital admissions on hot days in Sydney, Australia. PLoS ONE 8(1):1-9. DOI: https://doi.org/10.1371/journal.pone.0055459

Vianello RL, Alves, AR (2012) Meteorologia básica e aplicações. Viçosa, Universidade Federal de Viçosa, 2 ed. 460p.

Zhang Y, Zhang J, Chen H, Du X, Meng Q (2014) Effects of step changes of temperature and humidity on human responses of people in hot-humid area of China. Building and Environment 80(1):174-183. DOI: https://doi.org/10.1016/j.buildenv.2014.05.023

Zheng G, Zhu N, Tian Z, Chen Y, Sun B (2012) Application of a trapezoidal fuzzy AHP method for work safety evaluation and early warning rating of hot and humid environments. Safety Science 50(2):228-239. DOI: https://doi.org/10.1016/j.ssci.2011.08.042