ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

VARIABILIDADE TEMPORAL DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA PARA A MESORREGIÃO METROPOLITANA DE BELÉM-PA

LILIANE DA SILVA VIANA[1]; MARYJANE DINIZ DE ARAÚJO GOMES[2]; ÉLVIS DA SILVA ALVES[3]; ALEX PAULO MARTINS DO CARMO[4]; VERA QUEIROZ DE SOUZA[5]; LAILSON DA SILVA FREITAS[6]

[1]Engenheira Agrônoma, Instituto Federal do Pará – Campus Castanhal – PA – BR 316, Km 61, Saudade II, CEP: 68740-970, Castanhal – PA, Brasil, Email: liliane.agro.viana@gmail.com
[2]Professora, Instituto Federal do Pará – Campus Castanhal – PA – BR 316, Km 61, Saudade II, CEP: 68740-970, Castanhal – PA, Brasil, Email: gomes-mary@hotmail.com
[3]Doutor em Engenharia Agrícola, Brasil, Email: elvistv@gmail.com
[4]Doutorando em Produção Vegetal, Universidade Estadual do Norte Fluminense Darcy Ribeiro– Campos dos Goytacazes – RJ, Av. Alberto Lamego, 2000, Parque Califórnia, CEP: 28013-602, Campos dos Goytacazes – RJ, Brasil, Email: alex.taa97@gmail.com
[5]Graduanda em Agronomia, Instituto Federal do Pará – Campus Castanhal – PA – BR 316, Km 61, Saudade II, CEP: 68740-970, Castanhal – PA, Brasil, Email: veraqueirozsouza95@gmail.com
[6]Mestrando em Produção Vegetal, Universidade Estadual do Norte Fluminense Darcy Ribeiro– Campos dos Goytacazes – RJ, Av. Alberto Lamego, 2000, Parque Califórnia, CEP: 28013-602, Campos dos Goytacazes – RJ, Brasil, Email: lailsonfreitas222@gmail.com

1 RESUMO

A evapotranspiração de referência (ETo) é diretamente influenciada por variáveis climatológicas e seu estudo é importante para a agricultura irrigada, pois evidencia a quantidade de água que se desloca para a atmosfera, possibilitando compreender a demanda hídrica das culturas. Neste sentido, o objetivo do trabalho foi estimar, através de análise geoestatística, a variabilidade temporal da ETo para a região metropolitana de Belém, PA. O estudo foi realizado com base em dados climatológicos da estação convencional de Belém em um período de 12 anos, obtidos do Banco de Dados Meteorológicos para Ensino e Pesquisa (BDMEP) do Instituto Nacional de Meteorologia (INMET). A ETo foi calculada pelo *software* REF-ET 4.1.22, a estatística descritiva por meio de uma planilha eletrônica e a análise geoestatística pelo *software* $GS^{+®}$. A ETo na região metropolitana de Belém, aumentou gradativamente a partir de 2007, sendo influenciada pelas mudanças climáticas que ocorrem nessa região. Constatou-se, nos doze anos avaliados, que apenas três apresentaram moderado índice de dependência temporal (IDT) e os demais, forte IDT. Analisando os mapas de distribuição temporal, foi possível constatar que os meses de maior demanda evapotranspirativa foram agosto, setembro, outubro e novembro e que houve um incremento anual de 1,0 mm dia^{-1} da ETo.

Palavras-chave: Geoestatística, irrigação, agroclimatologia, temperatura.

VIANA, L. S.; GOMES, M. D. A.; ALVES, E. S.; CARMO, A. P. M.; SOUZA, V. Q.; FREITAS, L. S.
TEMPORAL VARIABILITY OF REFERENCE EVAPOTRANSPIRATION FOR THE METROPOLITAN MESORREGIÃO OF BELÉM-PA

Recebido em 21/12/2020 e aprovado para publicação em 03/10/2021
DOI: http://dx.doi.org/10.15809/irriga.2022v27n1p111-123

2 ABSTRACT

The reference evapotranspiration (ETo) is directly influenced by climatological variables and its study is important for irrigated agriculture since it shows the amount of water that moves into the atmosphere, making it possible to understand crop water demand. this sense, this work aimed to estimate, through geostatistical analysis, the temporal variability of ETo for the metropolitan region of Belém, PA. The study was conducted based on climatological data from the conventional station of Belém for 12 years, obtained from the Meteorological Database for Teaching and Research (BDMEP) of the National Institute of Meteorology (INMET). The ETo was calculated using the REF-ET 4.1.22 software, descriptive statistics through an electronic spreadsheet, and geostatistical analysis by the GS + ® software. The ETo in the metropolitan region of Belém, PA, increased gradually from 2007, being influenced by the climatic changes that occur in this region. In the twelve years evaluated, it was found that only three had a moderate temporal dependency index (IDT) and the others had a strong IDT. Analyzing the temporal distribution maps, it was possible to verify that the months of greatest evapotranspirative demand were August, September, October, and November and that there was an annual increase of 1.0 mm day^{-1} of ETo.

Keywords: Geostatistics, irrigation, agroclimatology, temperature.

3 INTRODUCTION

Climatological studies are necessary due to the climate changes that have been occurring over the years, as evidenced by the increase in the average global temperature due to the increase in the concentration of greenhouse gases, especially carbon dioxide [CO_2] (RENATO *et al.*, 2018). These surveys deserve frequent attention with respect to the conservation and preservation of the environment, taking into account that climate change affects all existing biota.

Reference evapotranspiration (ETo) is an important climate variable, and its estimation is fundamental for understanding the hydrological cycle of a region since ETo directly affects the water balance on the Earth's surface (CABRAL JÚNIOR; BEZERRA, 2018; ARAÚJO; MEDEIROS; FRANÇA, 2020). For Araújo, Medeiros and França (2020), additional studies on evapotranspiration and records in different regions of tropical countries are useful to provide more evidence and help in understanding the variability and trend of global evapotranspiration.

In agricultural food production, water and energy represent the largest inputs consumed, especially in irrigated agriculture (AHMAD; KHAN, 2016). In this context, ETo represents the amount of water that moves into the environment, enabling the calculation of the amount of water that must be replaced for crops to meet their water needs. It can also contribute to studies aimed at managing the rational use of this natural resource.

For irrigation planning and hydrological and environmental modeling, practical applications of ETo data are necessary, which can be evaluated in a distributed and temporal manner (VILANOVA; SIMÕES; TRANNIN, 2012). The study of the spatial and temporal characteristics of ETo, in addition to being an important tool as a climate indicator, is extremely fundamental for the efficient use of water resources, whether they are intended for use in the sectors of agricultural production, energy production, and human consumption, among others (CABRAL JÚNIOR; BEZERRA, 2018).

ETo estimation can be performed via several equations, the most widespread being the Penman–Monteith equation, which is considered the standard method by the *Food and Agriculture Organization (FAO) of the United Nations*, as it involves a greater number of climatic variables, producing satisfactory values for the climatic conditions of a given region (ALLEN *et al*., 1998; SARAIVA; BONOMO; SOUZA, 2017; BOEIRA *et al*., 2020).

Using geostatistics, it is possible to reliably infer the evolution of climate attributes, as observed by Pereira, Santos, and Neves (2020), who studied the spatial and temporal variability of precipitation over a 19-year period for the state of Mato Grosso, Brazil, via geostatistical techniques. Conde *et al*. (2016) stated that ETo expresses a strong index of temporal dependence in a comparison of studies carried out between regions of Cuba and Brazil.

Studies on the spatial and temporal variability of soil and climate attributes are being carried out using geostatistics, an efficient tool for supporting management decisions on the basis of the structure of variability obtained from maps (GUEDES, 2009).

For Conde *et al.* (2016), the interpretation of ETo variations is facilitated when these variables are presented as thematic maps, allowing for agile decision-making in agricultural zoning and adequate irrigation management.

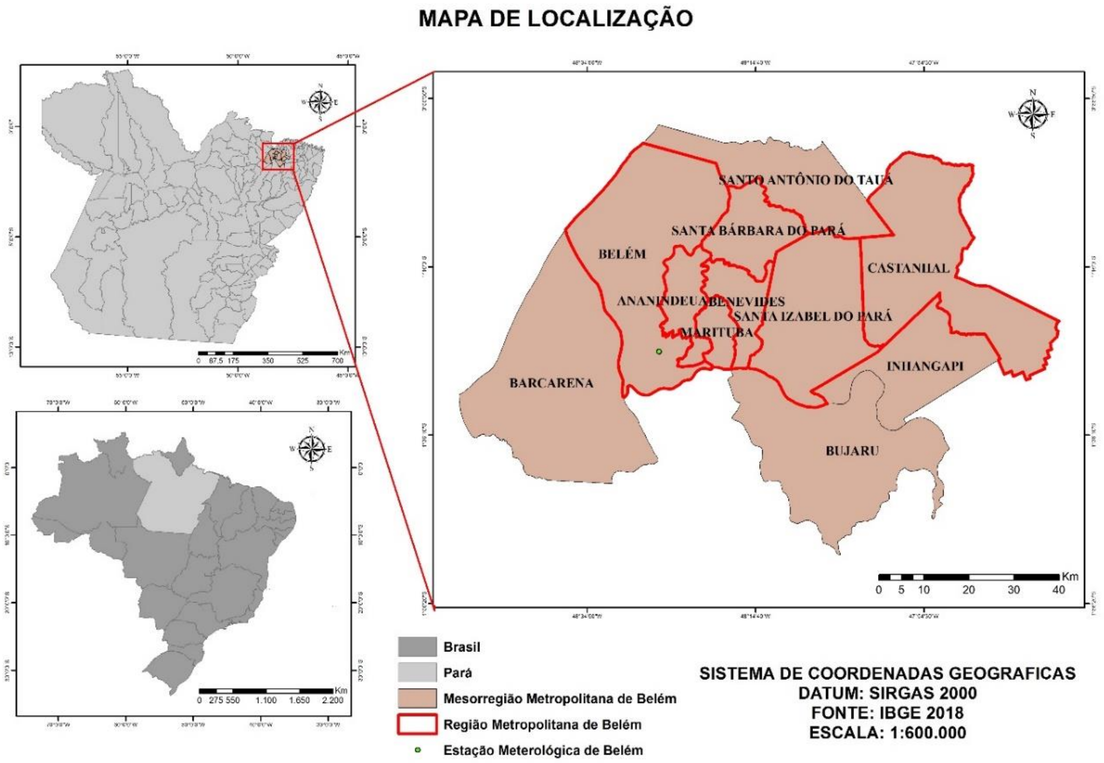
Therefore, it is important to develop studies that analyze the existence of temporal dependence in reference evapotranspiration and estimate the degree of this dependence through geostatistics to identify the influence of climatic variables on evapotranspiration. Thus, the objective of this study was to analyze the temporal variability in reference evapotranspiration for the metropolitan region of Belém, Pará, over a 12-year period.

4 METHODOLOGY

4.1 Characterization of the study region

The study was conducted via climatological data from the conventional station in Belém, Pará (WMO code 82191), which is part of the metropolitan region of Belém, the capital of the state of Pará. The selected data covered a 12-year period (2007--2018) and were obtained from the Meteorological Database for Teaching and Research (BDMEP) of the National Institute of Meteorology (INMET). The geographic coordinates of the meteorological station are latitude -1.43° and longitude -48.43°, with an altitude of 10 meters.

Figure 1. Location map of the Belém Metropolitan Region. Source: Prepared by the authors.



The Belém Metropolitan Region is formed by seven municipalities: Ananindeua, Belém, Benevides, Castanhal, Marituba, Santa Barbará do Pará and Santa Izabel do Pará. These municipalities comprise a territorial area of 3,566.203 km², with an estimated population of 2,275,032 inhabitants and a population density of 637.9 inhabitants/km² (IBGE, 2010). According to the Köppen climate classification (1931), the region has a humid tropical climate defined as Afi, characterized by abundant rainfall throughout the year with an average annual precipitation above 2000 mm. Regardless of the month, the monthly precipitation in the region is greater than 60 mm, in addition to the absence of a defined dry period.

4.2 Determination of the study variable

The method chosen to analyze the reference evapotranspiration was the Penman–Monteith method (ALLEN *et al*., 1998), which, according to the FAO, is the method that best estimates ETo, uses grass as standard vegetation and provides a mathematical description of physical processes together with physiological and aerodynamic parameters (ALENCAR; SEDIYAMA; MANTOVANI, 2015).

ETo via the Penman–Monteith method, FAO 56, is expressed by Equation (1).

$$ETo = \frac{0{,}408 * \Delta * (Rn - G) + \gamma * \frac{900}{T+273} * U2 * (es - ea)}{\Delta + \gamma * (1 + 0{,}34 * U2)} \quad (1)$$

where ETo is the reference evapotranspiration (mm d^{-1}); Rn is the net radiation at the crop surface (MJ m^{-2} d^{-1}); G is the soil heat flux density (MJ m^{-2} d^{-1}); T is the air temperature at 2 m height (°C); U_2 is the wind speed at 2 m height (m^{-1}); es is the saturation vapor pressure (kPa); e a is the partial vapor pressure (kPa); Δ is the slope of the saturation vapor pressure curve (kPa $°C^{-1}$); and γ is the psychrometric coefficient (kPa $°C^{-1}$).

After the data were tabulated and processed, the ETo calculation was performed via REF-ET 4.1.22 *software* (ALLEN, 2016).

4.3 Data organization and statistical analysis

The data from the studied series were subjected to the Shapiro–Wilk normality test and subsequently organized via Microsoft Excel® spreadsheets, in which the standard deviation (S) and coefficient of variation (CV) were calculated. The standard deviation is a measure that expresses the degree of dispersion of a dataset, and the CV is a measure of dispersion that quantifies, in relative terms (%), how far the values are from the mean.

4.4 Geostatistical analysis

Geostatistical analysis was performed by kriging with the purpose of verifying the existence and estimating the degree of temporal dependence between observations on the basis of the assumption of stationarity of the intrinsic hypothesis, which is estimated via Equation 2.

$$y^{*}(h) = \frac{1}{2N(h)_0} \sum_{i=1}^{N(K)} (Z(x_i) - Z(x_i + h)^2) \quad (2)$$

where y* (h) is the estimated semivariance of the experimental data and N (h) is the number of pairs of measured values Z(xi), Z(xi+h) separated by a vector h, where N (h) is the number of samples separated by a distance h, and Z represents the measured values; therefore, it depends on both magnitude and direction (VIEIRA *et al*., 1983).

The estimation was performed via the geostatistical program GS $^{+}$ 7 (ROBERTSON, 2009). The variograms were adjusted, and the values referring to the reach (a), nugget effect (Co) and plateau (Co + C) were obtained.

For theoretical models, four theoretical functions are found that fit the variogram models: a) linear; b) spherical; c) exponential; and d) Gaussian (STURANO, 2015).

The degree of temporal dependence was analyzed via the temporal dependence index (TDI) proposed by Zimback (2001), according to Equation 3.

$$IDT = \frac{C}{C_o + C} \times 100 \quad (3)$$

where IDT is the time dependence index, C is the structural component, and Co is the nugget effect.

TDI values ≤ 25% indicate weak temporal dependence; values in the range of 25% < TDI < 75% indicate moderate temporal dependence; and TDI values ≥ 75% indicate strong temporal dependence.

The coefficient of determination (R^2) was also determined to explain each model in all the years studied.

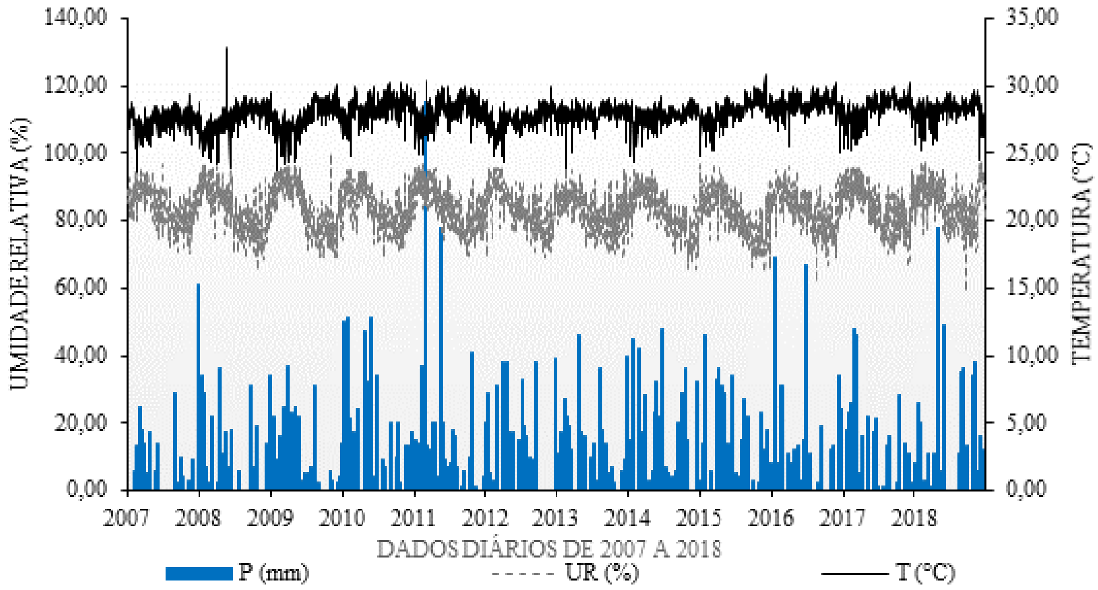
5 RESULTS AND DISCUSSION

5.1 Description of climatic characteristics during the 12-year study period

The average annual temperature over the 12 years (2007–2018) varied between 27.46 and 28.40°C, with an increase observed from 2010 onward (Figure 2). In that same year, a gradual reduction in relative humidity was observed, which can be explained by the reduction in rainfall in 2010, since, according to data collected at this station, 2010 had an annual rainfall of

3,065.30 mm, which resulted in a difference from that in the previous year of 398.3 mm.

Figure 2. Rainfall (P), relative humidity (RH) and temperature (T) measured daily at the Meteorological Station in the metropolitan region of Belém, PA



Source: Prepared by the authors

The significant increase in temperature in all months over the last 40 years in the city of Belém, Pará, with September being the month with the greatest trend, may be influenced by urbanization, which has altered the city's local microclimate (DIAS; VALENTE; FERNANDES, 2020). The authors also noted that El Niño and La Niña phenomena influence the precipitation regime in the city of Belém, where the extremes of flooding coincide with La Niña and drought with El Niño.

Climatological data influence ETo and may contribute to an increase in this variable. The results observed in this study corroborate those reported by Santos (2017), who, when evaluating climatic precipitation in the Belém Metropolitan Region via a 10-year database, reported that in 2010, there was a reduction in rainfall and an increase in soil exposure due to the reduction in vegetation cover.

In this sense, it can be inferred that the loss of water to the atmosphere through evaporation of water on the soil surface increased due to the reduction in vegetation cover and may thus have contributed to the significant increase in ETo, given that this variable represents the loss of water to the atmosphere through plant transpiration and evaporation of water present on the soil surface (JOSÉ *et al*., 2020).

Changes in climate variables over time are due to several associated factors and affect the ETo of a given location. According to Bolwerk and Ertzogue (2021), rising temperatures in the Legal Amazon may be directly correlated with progressive deforestation, the population density ratio per area, CO_2 concentrations, and especially the occurrence of fires. The same authors reported results indicating a strong inverse correlation between deforestation and rainfall.

The trend of rising temperatures combined with decreasing rainfall can interfere with the evapotranspiration process and, consequently, the water cycle (BOLWERK; ERTZOGUE, 2021). This statement corroborates the results of this study, in which it was possible to observe, throughout the data series, an increase in temperature and a decrease in rainfall.

5.2 Reference evapotranspiration

On the basis of the mean and median values for most of the analyzed periods, it is possible to conclude that ETo increased over the years (Table 1). This can be explained by deforestation, resulting primarily from growing urbanization and the increase in livestock farming in the Belém Metropolitan Mesoregion and surrounding areas.

Table 1. Statistical parameters for ETo determined in the Metropolitan Mesoregion of Belém, PA, between 2007 and 2018.

Year	n	Average	Median	Minimum	Maximum	s	CV	W
2007	365	4.11	4.08	2.18	5.42	0.44	10.77	0.99
2008	366	4.20	4.18	2.00	5.60	0.62	14.67	0.99
2009	365	4.22	4.19	2.21	5.94	0.68	16.22	0.98
2010	365	4.30	4.28	2.72	5.48	0.45	10.57	0.99
2011	365	4.32	4.32	2.81	5.32	0.45	10.38	0.98
2012	366	4.32	4.29	2.40	5.46	0.46	10.69	0.98
2013	365	4.41	4.41	3.00	5.55	0.37	8.29	0.98
2014	365	4.36	4.33	2.43	5.75	0.57	13.07	0.99
2015	365	4.50	4.45	3.00	5.84	0.51	11:30	0.99
2016	366	4.35	4.32	2.34	5.66	0.48	10.93	0.98
2017	365	4.40	4.40	2.90	5.92	0.53	12.05	0.99
2018	365	4.39	4.41	2.26	6.00	0.52	11.77	0.99

n: data used; s: standard deviation; CV: coefficient of variation; W: Shapiro–Wilk test statistic
Source: Prepared by the authors

Studies conducted by the Amazon Deforestation Estimation Project (PRODES) indicate that Pará is the state within the Brazilian Legal Amazon with the highest annual deforestation rates, accounting for 34% of the deforestation in this region (NATIONAL INSTITUTE FOR SPACE RESEARCH, 2019). Therefore, the gradual increase in evapotranspiration may be associated primarily with high deforestation rates because as the evaporative portion of the soil increases due to the lack of vegetation cover, a significant increase in local evapotranspiration occurs. However, a study correlating the deforestation rate in this area with the evapotranspiration found in this region is necessary.

Soil exposure can lead to an increase in evapotranspiration, since the evaporative portion of the soil will have a greater contribution to this variable. In this sense, the increase in evapotranspiration, evidenced mainly since 2010, corroborates the results showing that vegetation cover in municipalities of the Belém Metropolitan Mesoregion has been gradually decreasing (AZEVEDO; SOARES; TORRES, 2021). Santos (2017) observed the loss of vegetation cover in the Belém Metropolitan Mesoregion, as evidenced by the analysis of the standardized vegetation index (NDVI), which was calculated via images from the Landsat 7 satellite. Increasing deforestation was observed between 2000 and 2010, which led to a gradual increase in soil exposure.

Regarding the distribution of the data, the means and medians presented similar values, indicating a normal distribution, which was confirmed by the Shapiro–Wilk test (Table 1). Thus, in the analysis of the distribution of ETo values, which was carried out on the basis of the exploratory analysis of the data considered in the studied periods, the hypothesis of data normality was confirmed.

The results of the ETo estimation, according to the statistical analysis, presented a low dispersion in the study period (2007--2018). This is verified because the standard deviation is around the mean; that is, the values are very close to the mean; therefore, the samples are more homogeneous. Because the data used are from the same station (Belém, PA), the statistical analysis of the results that estimate the ETo has a similar dispersion, with no extrapolation in the results computed for the standard deviation and CV.

For the years 2007, 2010, 2011, 2012, 2013, 2015, 2016 and 2018, the CVs exhibited low variability (CV < 12%). In the remaining years, the CV showed medium variability.

Even with the CV value for the years that presented low variability, the year 2012 presented the greatest range (11.72 m, Table 2); thus, there was less temporal variability.

Table 2. Parameters of the adjusted models of the scaled semivariograms for reference evapotranspiration determined in Belém, PA, between 2007 and 2018.

Year	Model	R^2	Nugget effect (Co)	Level (Co + C)	Scope (THE)	Randomness E = (Co/C)	IDT (%)
2007	Exponential	0.90	0.05	0.23	9.75	1.29	77.3
2008	Spherical	0.96	0.08	0.43	10.00	1.23	81.1
2009	Spherical	0.99	0.05	0.50	7.74	1.12	89.2
2010	Exponential	0.99	0.02	0.21	5.73	1.12	89.7
2011	Exponential	0.97	0.06	0.24	10.00	1.34	75.0
2012	Spherical	0.98	0.07	0.26	11.72	1.37	73.0
2013	Exponential	0.93	0.02	0.14	5.22	1.21	82.9
2014	Spherical	0.99	0.05	0.40	11.03	1.14	87.5
2015	Spherical	0.98	0.04	0.28	5.93	1.18	84.7
2016	Spherical	0.98	0.10	0.25	10.70	1.61	62.2
2017	Spherical	0.98	0.08	0.34	10.95	1.32	76.0
2018	Spherical	0.93	0.14	0.29	10.19	1.99	50.2

Linear Regression; IDT: degree of temporal dependence; Range: distance within which the samples are correlated (m).
Source: Prepared by the authors

In geostatistics, more important than the normality of the data is the occurrence of the proportional effect, in which the mean and variance of the data are not constant in the study area, a fact that was not observed in this research since the semivariograms indicated well-established responses.

For the reference climate variable ETo, most of the years studied fitted the spherical model, except for the years 2007, 2010, 2011 and 2013, for which the exponential model was fitted.

The ETo presented the highest range value in 2012 and 2014 (11 days), and the lowest range was found in 2010, 2013, and 2015 (five days). From these data, it is possible to verify that those with the greatest ranges and, consequently, a greater distance (h) are represented by semivariograms that tend toward constant values. The range for

ETo was greatest in 2012 and 2014, implying that there was a greater temporal dependence of the data observed within the ETo during this period.

A small nugget effect is observed, indicating that the data did not present significant measurement errors, since this parameter represents the component of temporal variability that cannot be related to a specific cause (random variability). The values ranged from 0.02--0.14, approaching the ideal value of zero. According to Valente (1989), this effect reflects small-scale variation not detected by sampling due to measurement errors. Therefore, the data did not present significant measurement errors since values tended toward zero in all years.

The coefficients of determination (R^2) of the ETo from 2007--2018 (Table 2), which are greater than 0.90, demonstrate that the ETo calculated during all these years varied proportionally year to year, which satisfactorily represents the temporal variability of the meteorological parameters used in the calculations. These data favor the station criteria for the application of kriging.

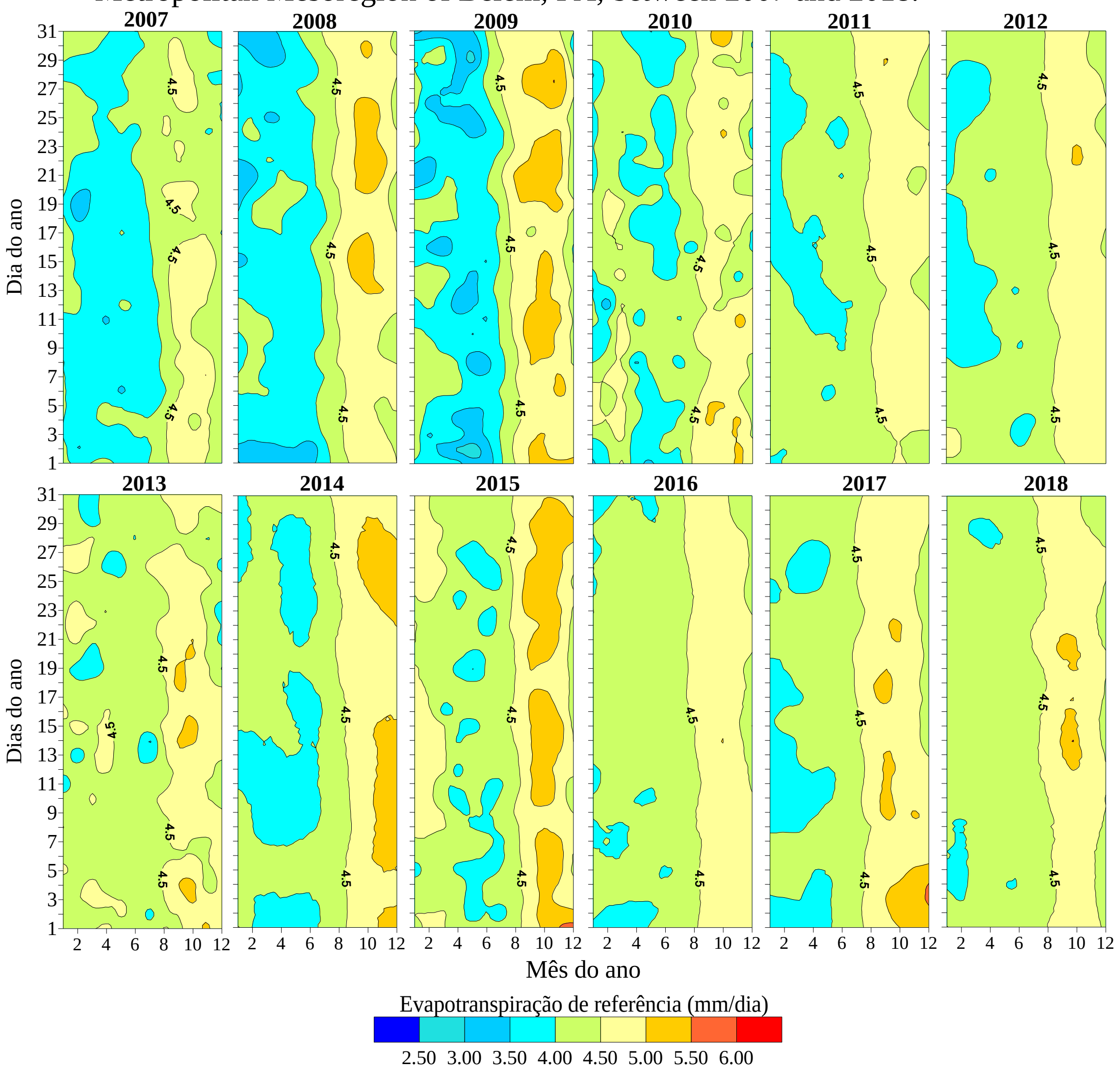
Kriging interpolation based on station criteria achieved the desired objectives, as the evapotranspiration calculated from the reference station was excellent (Table 2), indicating that kriging is a valid geostatistical technique for the spatialization of ETo, which is consistent with the work of Sartori *et al*. (2010). These sets of methods and procedures produced convincing results in the spatialization of ETo over time.

The ETo in 2012, 2016, and 2018 presented moderate temporal dependence (IDT <75%), and in the remaining years, it presented strong temporal dependence (IDT ≥75%). Thus, the constructed geostatistical models allowed the incorporation of temporal dependence and were adequate for analyzing the ETo data ($R^2 \geq 0.90$). This shows that the number of sampled points was sufficient for making estimates through interpolation.

The absence of the pure nugget effect indicates the existence of temporal variability in the observed data, enabling the adjustment of the semivariograms for each specific model previously demonstrated in Table 2 in each year and verifying the existence of a temporal pattern.

The thematic maps (Figure 2) show that, in all years, the months with the highest evapotranspiration rates were August, September, October, November, and December, which are related to the hottest months of the year. This result can be explained by the climatic characteristics of the region, as the temperature and global solar radiation are more intense in these months, reaching averages of 28.5°C and 39.85 MJ m^2 d^{-1}, respectively.

Figure 2. Maps of the temporal distribution of reference evapotranspiration for the Metropolitan Mesoregion of Belém, PA, between 2007 ~~and~~ 2018.



Source: Prepared by the authors

The higher the temperature is, the greater the atmospheric demand for water. During the summer, there are fewer hours of sunlight due to the presence of atmospheric clouds, with lower wind speeds but high temperatures and high relative humidity (CONDE *et al*., 2016).

shows that, over the period evaluated (2007--2018), ETo increased by an average of 1.00 mm day $^{-1}$ per year. This represents a significant increase in terms of water loss to the atmosphere, resulting in an increase in the amount of water required for irrigation in cropping systems.

Kriging is an efficient interpolation method within geostatistics. In this work, we verify the temporal dependence of ETo, which manifests itself in semivariograms via adjacent samples. This allows us to estimate the value at any position within the field, without bias and with minimal variance. According to Vilanova, Simões, and Trannin (2012), kriging enables the generation of ETo maps in regions with few meteorological stations, producing good spatialization results. However, this tool must be used judiciously to validate the results, and a base meteorological station may be used.

This interpolation method generates values very close to the reference evapotranspiration variable. Kriging accurately represented ETo variations over the twelve years (2007--2018), as shown in Table 2 and Figure 2. This shows a year-to-year increase, becoming even more pronounced after 2010. This reflects considerable water loss to the atmosphere in the region covered by the Belém, Pará, meteorological station.

6 CONCLUSIONS

Geostatistics enabled the analysis of the temporal variability in ETo for the metropolitan region of Belém, PA, and identified the influence of climatic variables.

The ETo in the Belém Metropolitan Mesoregion, Pará, has gradually increased since 2007 and has been influenced by climate change. The average temperatures in the Belém metropolitan region are increasing, and rainfall patterns are changing each year, resulting in a reduction in average annual precipitation.

Using temporal distribution maps of reference evapotranspiration, it was determined that the months with the highest evapotranspiration demand in the Belém Metropolitan Mesoregion were August, September, October, and November. These months generally experience relatively high temperatures and relatively little rainfall.

7 REFERENCES

AHMAD, A.; KHAN, S. Water and energy scarcity for agriculture: is irrigation modernization the answer? **Irrigation and Drainage - Wiley Online Library** , v. 66, p. 34-44, 2016. DOI: https://doi.org/10.1002/ird.2021. Available at: https://onlinelibrary.wiley.com/doi/full/10.1002/ird.2021. Accessed on: 15 Jan. 2019.

ALENCAR, LP; SEDIYAMA, GC; MANTOVANI, EC Estimation of reference evapotranspiration (FAO standard ETo), for Minas Gerais, in the absence of some climatic data. **Agricultural Engineering** , Jaboticabal, v. 35, n. 1, p. 39-50, 2015.

ALLEN, RG; PEREIRA, LS; RAES, D.; SMITH, M. **Crop evapotranspiration** : Guidelines for computing crop water requirements . Rome: FAO, 1998. (Irrigation and Drainage Paper, 56).

ALLEN, R. G. **REF-ET** : Reference evapotranspiration calculator. Version 4.1.22. Moscow : University Idaho , 2016.

ARAÚJO, WR; MEDEIROS, RM; FRANÇA, MV; Spatialization of evapotranspiration in the Ipojuca River basin-PE, Brazil. **Journal of Biotechnology and Biodiversity** , Gurupi , v. 8, n. 3, p. 205-218, 2020.

AZEVEDO, SD; SOARES, LFA; TORRES, LM Surface temperature and land use and cover in municipalities of the metropolitan region of Belém/PA. **Ibero-American Journal of Environmental Sciences** , Aracajú, v. 12, n. 1, p. 214-222, 2021.

BOLWERK, DA; ERTZOGUE, MH Climate change and/or sociocultural changes in the Legal Amazon. **Ibero-American Journal of Environmental Sciences** , Aracajú, v. 12, n. 1, p. 203-2013, 2021.

BOEIRA, LS; BARBARA NETO, M.; NEVES, LA; TERRA, VSS; COLLARES, GL Reference evapotranspiration by the Penman–Monteith method in 50 years for the microregion of Pelotas-RS. **Irriga** , Botucatu, v. 25, n. 3, p. 537-548, 2020.

CABRAL JÚNIOR, JB; BEZERRA, BG Analysis of reference evapotranspiration and aridity index for Northeast Brazil. **Northeast Geosciences Journal** , Caicó, v. 4, n. 1, p. 71-89, 2018.

CONDE, EC; BRITO, RR; MONTENEGRO, RJV; ROMÁN, RMS Temporal behavior of reference evapotranspiration in municipalities of São Paulo and provinces of Cuba. **Irriga** , Botucatu, v. 21, n. 2, p. 365-383, May/June 2016.

DIAS, LC; VALENTE, AMC; FERNANDES, LL Analysis and correlation of climatological variables with climate phenomena and urbanization in the city of Belém, in the state of Pará, northern Brazil. **Research, Society and Development** , Vargem Grande Paulista , v. 9, n. 8, p. e972986790, 2020.

GUEDES, OF **Spatial and temporal variability of harvest maps and soil attributes in a direct seeding system** . 2009. Dissertation submitted as a partial requirement for the degree of Master in Tropical and Subtropical Agriculture, Area of Concentration in Management of Agro-environmental Resources at the Agronomic Institute of Graduate Studies - IAC. Campinas, 2009. 97 p.

IBGE. **Demographic Census** . Brasília, DF: IBGE, 2010. Available at: https://cidades.ibge.gov.br/brasil/al/belem/panorama . Accessed on: February 28, 2019.

NATIONAL INSTITUTE FOR SPACE RESEARCH . **Prodes Digital Project** : Mapping Amazon Deforestation with Satellite Images. São José dos Campos: INPE, 2019. Available at: http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes/pdfs/Metodologia_Prodes_Deter_revisada.pdf. Accessed on: January 15, 2019.

JOSÉ, JV; PEREIRA, LB; LEITE, HMF; SANTOS, LC; BARROS, THS; LEITE, KN Empirical methods for estimating evapotranspiration in an equatorial tropical climate. **Research, Society and Development** , , Vargem Grande Paulista , v. 9, n. 10, p. e4099108563, 2020.

KÖPPEN, W. **Climatology** . Mexico City: Economic Culture Fund, 1931.

PEREIRA, TD; SANTOS, BC; NEVES, GZF Rainfall variability in the state of Mato Grosso in the time series from 1998 to 2017. **Geonorte Magazine** , Manaus – AM, v.11, n.37, p.39-56, 2020.

RENATO, NS; SEDIYAMA, GC; SILVA, JB; PEREIRA, EG Photosynthetic model for simulating corn productivity under high temperature and CO2 conditions. **Journal of Agricultural Sciences** , Lisbon, v. 41, n. 4, p. 1067-1074, 2018.

ROBERTSON, GP **GS + Geostatistics for the environmental sciences** . Plainwell : Gamma Design Software, 2009.

SANTOS, MRS **Climatic precipitation in the metropolitan mesoregion of Belém and its socioenvironmental implications** . 2017. Dissertation (Master's in Environmental Sciences) – Institute of Geosciences, Federal University of Pará, Belém, 2017.

SARAIVA, GS; BONOMO, R.; SOUZA, JM Evaluation of geostatistical and deterministic interpolators of daily reference evapotranspiration for the state of Espírito Santo. **Agro@mbiente On-line Magazine** , Boa Vista, v. 11, n. 1, p. 21-30, 2017.

SARTORI, AAC; SILVA, AF; RAMOS, CMC; ZIMBACK, CRL Temporal variability and mapping of climate data from Botucatu-SP. **Irriga** , Botucatu, v. 15, n. 2, p. 131-139, Apr./Jun. 2010.

STURANO, JR. **Basic geostatistics handbook** . Rio Claro: Unesp, 2015.

VALENTE, JMGP **Geomathematics** : lessons in geostatistics . Ouro Preto: Gorceix Foundation , 1989. v. 8.

VIEIRA, SR; HATFIELD, TL; NIELSEN, DR; BIGGAR, JW Geostatistical theory and application to variability of some agronomical properties. **Hilgardia** , California, v. 51, no. 3, p. 1-75, 1983.

Geospatial interpolation of reference evapotranspiration (ETo) in data-scarce regions: a case study in southern Minas Gerais. **Revista Ambiente & Água** , Taubaté, v.7, n. 2, p. 179-194, 2012.

ZIMBACK, CRL **Spatial analysis of soil chemical attributes for fertility mapping purposes** . 2001. Professorship Thesis (Professorship in Soil Survey and Photopedology) – Faculty of Agricultural Sciences, São Paulo State University, Botucatu, 2001.