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EVAPOTRANSPIRAÇÃO DE REFERÊNCIA AO LONGO DO ESTADO DE MINAS GERAIS COMO GUIA PARA A GESTÃO REGIONALIZADA DA IRRIGAÇÃO

ANGÉLICA CARVALHO CUNHA[1]; CÉSAR DE OLIVEIRA FERREIRA SILVA[2]; RODRIGO LILLA MANZIONE[3] E FERNANDO FERRARI PUTTI[4]

[1] Departamento de Engenharia de Biossistemas, Faculdade de Ciências e Engenharia, Universidade Estadual Paulista, Rua. Domingos da Costa Lopes, nº 780, Jardim Itaipu, 17602-496, Tupã, São Paulo, Brasil, angelicaccunha10@gmail.com.

[2] Departamento de Engenharia Rural, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista", Avenida Universitária, n° 3780, Altos do Paraíso, 18610-034, Botucatu, São Paulo, Brasil, cesaroliveira.f.silva@gmail.com.

[3] Departamento de Engenharia de Biossistemas, Faculdade de Ciências e Engenharia, Universidade Estadual Paulista, Rua. Domingos da Costa Lopes, nº 780, Jardim Itaipu, 17602-496, Tupã, São Paulo, Brasil, lilla.manzione@unesp.br.

[4] Departamento de Engenharia de Biossistemas, Faculdade de Ciências e Engenharia, Universidade Estadual Paulista, Rua. Domingos da Costa Lopes, nº 780, Jardim Itaipu, 17602-496, Tupã, São Paulo, Brasil, fernando.putti@unesp.br.

1 RESUMO

Minas Gerais é o terceiro estado brasileiro com maior área irrigada, sendo assim é de suma importância o manejo da irrigação para garantir o uso sustentável dos recursos hídricos. Uma das formas de se calcular a quantidade hídrica necessária na irrigação é por meio da estimativa da evapotranspiração de referência (ETo). Os valores de evapotranspiração são influenciados por diversos fatores climatológicos, como: radiação solar, temperatura, deficiência de pressão de vapor, logo, os valores de evapotranspiração tendem a diferir de acordo com cada região. Assim, o presente estudo propõe a elaboração de um mapa de evapotranspiração de referência média para o estado de Minas Gerais como base para gestão hídrica para a agricultura. Os dados foram fornecidos pelo Instituto Nacional de Meteorologia (INMET), utilizando Estações Meteorológicas Automáticas (EMAs) localizadas em 49 cidades do estado de Minas Gerais. Por meio das análises realizadas, pôde-se observar que, em mesorregiões caracterizadas por maior seca, como o norte do estado, os índices de evapotranspiração foram maiores do que em mesorregiões mais úmidas, que apresentam maiores níveis de precipitação, como as Regiões Centro, Sul e Triângulo Mineiro. Devido a sua característica úmida, a região do bioma Mata Atlântica obteve menores valores de ETo em relação aos biomas do Cerrado e Caatinga.

Palavras-chave: gestão hídrica, manejo da irrigação, modelagem de dados.

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REFERENCE EVAPOTRANSPIRATION THROUGHOUT THE STATE OF MINAS GERAIS AS A GUIDE FOR REGIONALIZED IRRIGATION MANAGEMENT

2 ABSTRACT

Minas Gerais is the third Brazilian state with the largest irrigated area, so irrigation management is of paramount importance to ensure the sustainable use of water resources. One way of

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calculating the water quantity needed for irrigation is by estimating reference evapotranspiration (ETo). Evapotranspiration values are influenced by several climatological factors, such as solar radiation, temperature, vapor pressure deficiency; therefore, evapotranspiration values tend to differ according to each region. Thus, this study proposes the use of a medium reference evapotranspiration map of Minas Gerais as a basis for water management in agriculture. The data were provided by the National Institute of Meteorology (INMET), using Automatic Meteorological Stations (EMAs) located in 49 cities in the state of Minas Gerais. Through the analysis conducted, it was observed that, in mesoregions characterized by greater drought, such as the north of the state, evapotranspiration rates were higher than in more humid mesoregions, which present higher levels of precipitation, such as the Central, Southern, and *Mineiro* Triangle Regions. Due to its humid characteristic, the region of the Atlantic Forest biome had lower ETo values compared to the Cerrado and Caatinga biomes.

Keywords: water management, irrigation management, data modeling.

3 INTRODUCTION

Located in the Southeast Region of Brazil, the state of Minas Gerais has a tropical climate. Owing to the specific characteristics of each region of the state, such as changes in altitude, the climate is subdivided into subdivisions ranging from highland tropical to humid tropical. A semiarid climate is present in the extreme north of Minas Gerais due to the low rainfall in this area of the state. The average annual temperatures in Minas Gerais are above 18°C in all regions except the highest plateaus in the center-south region, where the average winter temperatures are below 18°C (NATIONAL INSTITUTE OF METEOROLOGY, 2019).

Minas Gerais accounts for a large portion of the country's agricultural economy. In 2017, agribusiness accounted for 33.54% of the state's gross domestic product (GDP) and 13.59% of Brazil's GDP. Coffee cultivation is predominant in Minas Gerais, which ranks as the Brazilian state with the greatest coffee production, accounting for approximately 50% of the country's total (CENTER FOR ADVANCED STUDIES IN APPLIED ECONOMICS, 2019; FEDERATION OF AGRICULTURE AND LIVESTOCK OF THE STATE OF MINAS GERAIS, 2020). From January to July 2020, Minas Gerais' agribusiness sector posted a surplus of US$4.54 billion, a 10% increase compared with the same period the previous year, driven by strong export performance. Minas Gerais was responsible for exporting 7.6 million tons of agricultural products to 162 countries, an increase of 31.4% in the accumulated volume exported (FEDERATION OF AGRICULTURE AND LIVESTOCK OF THE STATE OF MINAS GERAIS, 2020).

Irrigation is frequently needed to maintain the viability of crop cultivation in areas affected by water scarcity. In Minas Gerais, the months from April to September are characterized by low rainfall, so producers rely on irrigation techniques, especially during this period.

However, irrigation is characterized as the activity that demands the most water in Brazil and worldwide. In Brazil, irrigation accounts for 46% of the water withdrawn from water bodies and 67% of the consumption flow, placing the country among those with large irrigated areas (NATIONAL WATER AND SANITATION AGENCY, 2017). Given this scenario, it is important to manage water resources properly and maintain sustainable consumption to avoid overuse, since excessive water consumption for irrigation, in addition to environmental problems, can also negatively affect crops (CUNHA; GABRIEL FILHO; PUTTI, 2019).

Minas Gerais is the third Brazilian state with the largest irrigated area (NATIONAL WATER AND SANITATION AGENCY, 2017), being responsible for 16% of the country's irrigated area and 40% of the Southeast Region, contributing to the region having 39% of Brazil's irrigated area.

Given the importance of the sustainable use of water resources in irrigation, it is essential to be aware of the causes that lead to water loss in crops, and one of these causes is evapotranspiration (CUNHA *et al*., 2021).

To aid in the management of surface and groundwater resources, modeling techniques have been employed to identify the variability and uncertainty associated with hydrological elements. Because the data are abstract from the reality encountered, mathematical and statistical models have been used to describe hydrological phenomena (MANZIONE, 2018).

In Minas Gerais, water management is governed by the State Water Resources Policy, which was proposed by Law No. 13,199/1999. This policy ensures that current and future water users control the quantity used, quality, and satisfactory regime. In addition to the policy, there are also management instruments and tools that aim to support and direct the work of the Water Resources Management System (INSTITUTO MINEIRO DE GESTÃO DAS ÁGUAS, 2019).

Spatial distribution maps with the spatial distributions of meteorological variables provide an important basis for climate studies in these regions (XU *et al.*, 2006). Thus, the mean reference evapotranspiration maps generated via the empirical Bayesian kriging method can assist in the management of water resource use.

Minas Gerais is home to many river basins. Many of Brazil's river basins, such as the São Francisco, Paraná, and Leste River basins, originate from the state. Minas Gerais produces an average of 58.6 million hectares of water. The main basins that make up the state's hydrographic network are the Doce, Grande, Jequitinhonha, Mucuri, Paraíba do Sul, Paranaíba, Pardo, and São Francisco river basins (MINEIRO INSTITUTE OF WATER MANAGEMENT, 2019; MINAS GERAIS, 2019). The São Francisco basin is the largest in Minas Gerais, draining an area equivalent to half the state, encompassing the North, Northwest, Central, West, and Metropolitan Belo Horizonte mesoregions (GUIMARÃES; DOS REIS; LANDAU, 2010).

On the basis of the characteristics of Minas Gerais, this work aimed to use an average reference evapotranspiration map of the state as a basis for water resource management for agriculture.

4 MATERIALS AND METHODS

An automatic meteorological station collects, every minute, meteorological data (temperature, humidity, atmospheric pressure, precipitation, wind direction and speed, and solar radiation) that represent its location. Every hour, this information is integrated and made available for transmission via satellite or cell phone to the headquarters of the National Institute of Meteorology (INMET) in Brasília. All the received data are validated through quality control and stored in a database (NATIONAL INSTITUTE OF METEOROLOGY, 2011).

The INMET network of automatic meteorological stations (EMAs) is-located in 49 cities in the state of Minas Gerais (Tables 1--3). Throughout the state, there are 68

EMAs, but it was necessary to disregard 19, since they presented failures and a lack of data, characterized by equipment failures, maintenance periods or recent construction, automatically resulting in little data.

Table 1. Automatic meteorological stations in the state of Minas Gerais – Part 1.

City name	Latitude (S)	Longitude (W)	Altitude (m)	Data period	Data number	Actual data	Loss (%)
1. Red Waters	-15,751	-41,457	754	09/2007 - 12/2018	4132	3758	9.05
2. Aimorés	-19,532	-41,090	288	12/2008 – 12/2018	4167	2696	35.30
3. Almenara	-16,166	-40,687	189	11/2007 – 12/2018	5861	3445	41.22
4. Araxa	-19,605	-46,949	1,018	05/2008 – 12/2018	5857	3640	37.85
5. Scene-beard	-21,228	-43,767	1,169	07/2003 – 12/2018	5869	4870	17.02
6. Belo Horizonte - Pampulha	-19,883	-43,969	854	10/2006 – 12/2018	4466	4345	2.71
7. Buritis	-15,524	-46,435	894	11/2007 – 12/2018	4214	3514	16.61
8. Caldas	-21,918	-46,382	1,077	11/2006 – 12/2018	4417	4107	7.02
9. Campina Verde	-19,539	-49,518	559	07/2006 – 12/2018	4553	3877	14.85
10. Cape-line	-17,705	-42,389	932	09/2007 – 12/2018	4140	3853	6.93
11. Cara-tinga	-19,735	-42,137	609	05/2007 – 12/2018	4240	3885	8.37
12. Chapada Gaucha	-15,300	-45,617	873	06/2007 – 12/2018	4313	3584	16.90
13. Conception of Alagoas	-19,985	-48,151	573	07/2006 – 12/2018	4550	4032	11.38
14. Curvelo	-18,747	-44,453	669	12/2006 – 12/2018	4397	4239	3.59

Table 2. Automatic meteorological stations in the state of Minas Gerais – Part 2.

City name	Latitude (S)	Longitude (W)	Altitude (m)	Data period	Data number	Actual data	Loss (%)
15. Day-mantina	-18,231	-43,648	1,359	06/2007 – 12/2018	4228	3761	11.05
16. Pains of Indaiá	-19,481	-45,593	721	06/2007 – 12/2018	4232	3564	15.78
17. Espi-nosa	-14,912	-42,808	565	11/2007 – 12/2018	4066	3769	7:30
18. Forest	-19,885	-44,416	754	06/2008 – 12/2018	3840	3792	1.25
19. Ant	-20,454	-45,453	878	08/2006 – 12/2018	4520	4345	3.87
20. Governor Valadares	-18,830	-41,977	198	05/2007 – 12/2018	4235	3925	7.32
21. Guanhães	-18,786	-42,942	853	06/2007 – 12/2018	4231	3782	10.61
22. Chief Guard	-17,561	-47,199	997	07/2007 – 12/2018	4192	3863	7.85
23. Ibirité (Rola Moça)	-20,031	-44,011	1,199	06/2008 – 12/2018	3861	3623	6.16
24. Itaobim	-16,575	-41,485	272	09/2007 – 12/2018	4136	3714	10.20
25. Ituiu-taba	-18,952	-49,525	540	05/2006 – 12/2018	4617	4204	8.95
26. John Pinheiro	-17,784	-46,119	877	07/2007 – 12/2018	4196	3876	7.63
27. Judge of Fora	-21,769	-43,364	937	05/2007 – 12/2018	4238	3893	8.14
28. Keep it	-18,780	-40,986	255	08/2007 – 12/2018	4171	3884	6.88
29. Mary of Faith	-22,314	-45,373	1,281	12/2006 – 12/2018	4413	4235	4.03
30. Mocam-binho	-15,085	-44,016	454	11/2007 – 12/2018	4069	3737	8.16
31. Montal-vânia	-14,408	-44,404	520	06/2007 – 12/2018	4207	3670	12.76
32. Monte Verde	-22,861	-46,043	1,545	12/2004 – 12/2018	5126	4015	21.67
33. Muriaé	-21,104	-42,375	283	08/2006 – 12/2018	4507	4118	8.63
34. White Gold	-20,556	-43,756	1,048	07/2006 – 12/2018	4540	4235	6.72

Table 3. Automatic meteorological stations in the state of Minas Gerais – Part 3.

City name	Latitude (S)	Longitude (W)	Altitude (m)	Data period	Data number	Actual data	Loss (%)
35. Pass Four	-22,395	-44,961	1,017	06/2007 – 12/2018	4234	3618	14.55
36. Steps	-20,745	-46,633	782	07/2006 – 11/2018	4550	3418	24.88
37. Sponsorship	-18,996	-46,985	978	08/2006 – 12/2018	4515	4011	11.16
38. Sacrament	-19,875	-47,434	913	08/2006 – 12/2018	4518	4307	4.67
39. Salt Flats	-16,160	-42,310	487	09/2007 – 12/2018	4127	3909	5.28
40. Saint John of the King	-21,106	-44,250	930	06/2006 – 12/2018	4589	3950	13.92
41. Saint Romanus	-16,362	-45,123	490	06/2007 – 12/2018	4203	3868	7.97
Ai-morés Mountains	-17,798	-40,249	212	08/2006 – 12/2018	4516	3992	11.60
43. Teófilo Otoni	-17,892	-41,515	467	08/2006 – 12/2018	4512	3827	15,18
44. Timothy	-19,573	-42,622	493	02/2006 – 12/2018	4696	3986	15.12
45. Three Marys	-18,200	-45,459	931	08/2006 – 12/2018	4511	4327	4.08
46. Uberlandia	-18,917	-48,255	875	03/2003 – 12/2018	5858	4853	17,16
47. Unai	-16,554	-46,881	641	06/2007 – 12/2018	4217	3972	5.81
48. Var-ginha	-21,566	-45,404	950	07/2006 – 12/2018	4555	4180	8.23
49. Viçosa	-20,762	-42,864	698	09/2005 – 12/2018	4856	4255	12.38

The EMAs began operations at different times, so the data period varied across cities, resulting in varying amounts of data. Tables 1--3 present the amount of data used in the study, the collection period, and the percentage of null values. The data actually used in the analyses are lower than the total collected data, as data were lost because of data collection system failures, instrument defects, data capture issues, and other factors.

The Penman–Monteith FAO model (Allen *et al., 1998)* was used to estimate evapotranspiration via Equation 1:

$$ETo = \frac{0{,}408\Delta(H-G) + \gamma \frac{900}{T+273} u_2 \,(es-ea)}{\Delta + \gamma\,(1+0{,}34\, u_2)} \qquad (1)$$

where ETo is the reference evapotranspiration, mm day $^{-1}$; H is the global solar radiation, MJ m ^{2} d $^{-1}$; G is the soil heat flux, MJ m ^{2} d $^{-1}$; T is the daily mean air temperature at 2 m height, °C; u_2 is the wind speed at 2 m height, ms $^{-1}$; e_s is the vapor saturation pressure, kPa; e_a is the current vapor pressure, kPa; $e_s - e_a$ is the vapor saturation deficit, Δ is the slope of the vapor pressure *versus* temperature curve, kPa °C $^{-1}$; γ is the psychrometric constant, kPa °C $^{-1}$; and 0.408 corresponds to $\frac{1}{\lambda}$, where λ is the latent heat of vaporization of water equal to 2.45 MJ kg $^{-1}$ and 900 is a coefficient for the reference crop.

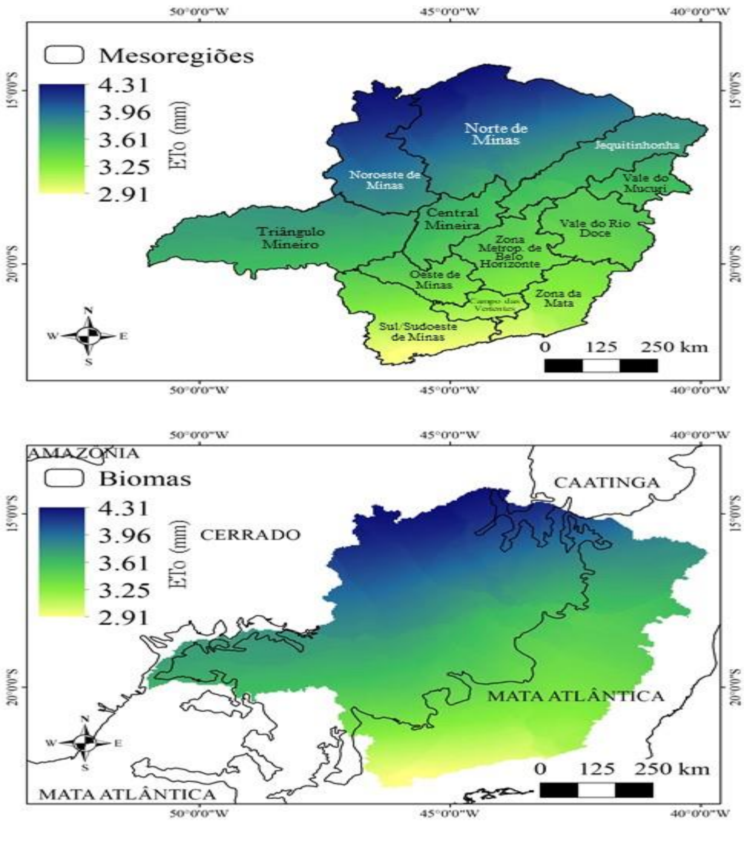
From the reference evapotranspiration (ETo) data obtained from the EMAs, a map was generated for the entire state of Minas Gerais via the empirical Bayesian kriging method available in ArcGIS 10.6 software.

5 RESULTS AND DISCUSSION

Owing to its geographic location, relief, continentality, and biome and phytophysiognomies, the state of Minas Gerais experiences diverse thermodynamic conditions, resulting in varied rainfall patterns. The North and Jequitinhonha Valley mesoregions experience low rainfall. The Central and South mesoregions of the state have higher precipitation levels than the North mesoregions do (GUIMARÃES; DOS REIS; LANDAU, 2010).

Figure 1 presents a map created via the empirical Bayesian kriging method to present the average reference evapotranspiration estimated via the Penman–Monteith FAO method (Allen *et al.*, 1998) on the basis of the data from the automatic stations presented in Tables 1--3.

Figure 1. Spatial distribution of reference evapotranspiration throughout the state of Minas Gerais by the empirical Bayesian kriging method using 49 automatic stations with geographic divisions of mesoregions and biomes.



Rainfall in Minas Gerais varies according to the relief and geographic position, being approximately 650 mm in the north of the state and 2100 mm in the south/southwest region (GUIMARÃES; DOS REIS; LANDAU, 2010).

According to Figure 1, the cities located in the São Francisco River basin region, especially those located further north of the basin, presented higher evapotranspiration values via the empirical Bayesian kriging method, with values between 3.96 and 4.31 mm. This occurred because the region has a climatic characteristic with a lower precipitation index and lower relative humidity than the other mesoregions studied. Lemos Filho *et al.* (2010) also reported greater water needs in the northern region of the state of Minas Gerais.

South of the state, bathed by the Rio Grande basin and the presence of the Atlantic Forest biome, it is a region with a high rainfall index and, automatically, high relative humidity; therefore, the evapotranspiration values obtained via the empirical Bayesian kriging method are significantly lower, at approximately 2.91 mm, as shown in Figure 1.

According to Kool (2014), evapotranspiration is influenced by several climatological factors, such as solar radiation, temperature, vapor pressure deficiency, and wind speed. Therefore, evapotranspiration values differ according to region. This difference can be observed in the results obtained in this study, since in mesoregions characterized by greater drought, such as the northern part of the state, evapotranspiration rates were higher than those in wetter mesoregions with higher precipitation levels, such as the Central, South, and Triângulo Mineiro regions.

Spatial distribution maps contribute to water management planning, providing important information, such as evapotranspiration values established by region, in which case ETo can be considered a driver of the hydrological cycle (XU *et al.*, 2006).

The cities of Monte Verde, Diamantina, Maria da Fé, Ibirité (Rola Moça), Barbacena, Caldas, Ouro Branco, Passa Quatro, Araxá, São João Del Rei, Patrocínio, Varginha, Juiz de Fora, Capelinha, Três Marias and Sacramento belong to the Central Mineira, South/Southwest and Triângulo Mineiro mesoregions, which have high altitudes, above 912 m, all presented low values of evapotranspiration by the empirical Bayesian kriging method, between 2.91 and 3.61 mm.

The lowest evapotranspiration rates obtained via empirical Bayesian kriging are found in the cities of Monte Verde, Caldas, Maria da Fé, and Passa Quatro, which have altitudes between 1,040 m ~~and~~ 1,500 m. All of these cities are located in the southern region of the state, and the biome of this region is the Atlantic Forest. In addition to high altitudes, these cities have higher precipitation levels and milder temperatures (GUIMARÃES; DOS REIS; LANDAU, 2010). In the study developed by Santos *et al.* (2017) in the state of Paraná, the lowest evapotranspiration rates were also associated with high altitudes.

The cities of Buritis, Chapada Gaúcha, Unaí, Espinosa, and Montalvânia presented the highest evapotranspiration values via the empirical Bayesian kriging method. The precipitation levels in these cities are low, and the altitudes between 512 m and 894 m are lower than those in other cities in the state. These cities are located in the northern and northwestern regions of the state and are located in the Cerrado and Caatinga biomes.

The region within the Atlantic Forest biome had the lowest ET values, characterized by a hot and humid climate. Because of the humid climate, the environment tends to retain more water, decreasing ETo values. The opposite occurs in the region within the Caatinga biome, which has a semiarid climate characterized as dry and hot. Under these conditions, the environment tends to lose more water, which increases ETo values.

6 CONCLUSION

The analysis of the evapotranspiration demand in the state of Minas Gerais indicated that ETo increases from the South Region to the North Region, with higher values in the North Region, reaching an evapotranspiration value of 4.31 mm according to the empirical Bayesian kriging method, whereas in the South Region, this value was only 2.91 mm.

Regions characterized by higher altitudes, higher precipitation levels and a humid climate tend to have lower ETo values than drier regions with lower altitudes.

Thus, the INMET station network for the state of Minas Gerais allowed the identification of water demand characteristics in the state's mesoregions; the interpolation of ETo serves as a guide for assessing water viability for crops on the basis of the quantification of crop evapotranspiration, which is a function of ETo.

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8 REFERENCES

ALLEN, RG; PEREIRA, LS; RAES, D.; SMITH, M. **Crop evapotranspiration** : Guidelines for computing crop water requirements. Rome : FAO, 1998. 300 p. (Irrigation and Drainage Paper , 56).

NATIONAL WATER AGENCY (Brazil). **Irrigation Atlas** - Water Use in Irrigated Agriculture. Brasília, DF: ANA, 2017. Available at: http://arquivos.ana.gov.br/imprensa/publicacoes/AtlasIrrigacao-UsodaAguanaAgriculturaIrrigada.pdf. Accessed on: February 11, 2019.

CEPEA. **Minas Gerais agricultural GDP** . Piracicaba: USP, 2019. Available at: https://www.cepea.esalq.usp.br/br/pib-do-agronegocio-de-minas-gerais.aspx . Accessed on: October 21, 2020.

CUNHA, AC; GABRIEL FILHO, LRA; PUTTI, FF Evapotranspiration as an ally in the fight against water scarcity. *In:* PUTTI, FF; SILVA, ALC; GABRIEL FILHO, LRA **Sustainability in agricultural systems** . Tupã: ANAP, 2019. p. 35-57.

CUNHA, AC; GABRIEL FILHO, LRA; TANAKA, AA; GOES, BC; PUTTI, FF Influence Of The Estimated Global Solar Radiation On The Reference Evapotranspiration Obtained Through The Penman- Monteith FAO 56 Method. **Agricultural Water Management** , Amsterdam, v. 243, p. 106491, 2021.

FAEMG. **Agribusiness indicators** . Available at: http://www.faemg.org.br . Accessed on: October 22, 2020.

GUIMARÃES, DP; DOS REIS, RJ; LANDAU, EC **Rainfall indices in Minas Gerais** . Sete Lagoas: Embrapa Corn and Sorghum, 2010. (Research and Development Bulletin).

MINAS GERAIS INSTITUTE OF WATER MANAGEMENT. **Water Resources Plans** . Belo Horizonte. IGAM. Available at: http://www.igam.mg.gov.br/gestao-das-aguas/plano-de-recursos-hidricos . Accessed on: October 22, 2020.

NATIONAL INSTITUTE OF METEOROLOGY. **Climatological Normals of Brazil.** Brasília. INMET. Available at: https://portal.inmet.gov.br/normales . Accessed on: October 22, 2020.

KOOL, D.; AGAM, N.; LAZAROVITCH, N.; HEITMAN, JL; SAUER, T.J.; BEN-GAL, A. A review of approaches for evapotranspiration partitioning. **Agricultural and Forest Meteorology** , Amsterdam, v. 184, p. 56-70, 2014.

LEMOS FILHO, LCA; DE MELO, CR; DE FARIA, MA; DE CARVALHO, LG Spatial - temporal analysis of water requirements of coffee crop in Minas Gerais State , Brazil . **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grande, v. 14, n. 2, p. 165-172, Feb. 2010.

MANZIONE, RL Mapping of the dynamic characteristics of the water table of the Bauru Aquifer System as a tool for water resources management. **Geology USP** . Scientific Series, São Paulo , v. 18, n. 1, p. 227-240, 2018.

FEDERATION OF AGRICULTURE AND LIVESTOCK OF THE STATE OF MINAS GERAIS . **Agribusiness Indicators.** Belo Horizonte. FAPEMG. Available at: https://www.indi.mg.gov.br/agronegocio/. Accessed on: October 22, 2020.

SANTOS, LC; JOSÉ, JV; ALVES, DS; NITSCHE, PR; DOS REIS, EF; BENDER, FD Space-time variability of evapotranspiration and precipitation in the State of Paraná, Brazil. **Environment and Water Magazine** , Taubaté, v. 12, n. 5, p. 743-759, Oct. 2017.

Xu, C.; GONG, L.; JIANG, T.; CHEN, D.; SINGH, VP Analysis of spatial distribution and temporal trends of reference evapotranspiration and pan evaporation in Changjiang (Yangtze River) catchment. **Journal of Hydrology** , Amsterdam, vol . 327, p. 81-93, 2006.

9 ANNEX

Annex 1. The data used to calculate the ET of the 49 INMET stations for the state of Minas Gerais, Brazil, can be accessed through the following link: https://github.com/fernandoputti/Paper_Irriga_ETo_Minas_Gerais.git