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Occurrence of drought in the State of Paraná

Ocorrência de estiagem no Estado do Paraná

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Highlights

August is the month with the highest occurrence of drought in the state of Paraná.
The northwest region is the most prone to drought in the state.
Winter is the season most affected by drought.

Abstract

The influence of global climate change on agriculture and its consequential impact on the loss of productive potential in various Brazilian regions are widely recognized. This study aims to assess the prevalence of drought by examining the relationship between actual evapotranspiration and potential evapotranspiration (ETa/PET) in the state of Paraná. Daily meteorological data on precipitation and air temperature were sourced from the meteorological stations of the Paraná Rural Development Institute IAPAR-EMATER (IDR-Paraná) over the period from 1976 to 2020. This data collection covered six distinct regions within the state: central, south, north, coast, northwest, and southwest. Potential evapotranspiration data were estimated using the method Thornthwaite (1948), while ETa data were derived from the Climatological Water Balance model proposed by Thornthwaite and Mather (1955). Drought conditions were defined as instances when ETa/PET < 0.6, evaluated on annual, quarterly, monthly, and decade (10-day) scales. The month of August and the last decade of this month were found to be the period with the highest frequency of drought occurrences across the state. The northwest region demonstrated the highest susceptibility to drought, followed by the north, south, southwest, and coastal regions.

Key words: Climate Anomaly. Climate change. Extreme event.

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Resumo

É notório que as alterações climáticas globais têm causado impactos sobre a agricultura induzindo perdas de potencial produtivo em diversas regiões brasileiras. O objetivo deste trabalho foi avaliar a ocorrência de estiagem através da relação evapotranspiração real e evapotranspiração potencial (ETR/ETP) no estado do Paraná. Foram utilizados dados diários de precipitação pluvial e temperatura do ar, coletados pelas estações meteorológicas do Instituto de Desenvolvimento Rural do Paraná IAPAR-EMATER (IDR-Paraná), no período de 1976 a 2020 para as regiões: Central, Sul, Norte, Litoral, Noroeste e Sudoeste do estado. Os dados de ETP foram estimados a partir do método estabelecido por Thornthwaite (1948) e os de ETR obtidos pelo Balanço Hídrico Climatológico proposto por Thornthwaite e Mather (1955), sendo considerado como estiagem quando a razão entre ETR/ETP apresentou valor <0,6 em escala Anual, trimestral, mensal e decendial. Foi possível observar que o mês de agosto e o seu terceiro decêndio como o de maior ocorrência de estiagem em todo o estado. Sendo a região Noroeste a mais sujeita a ocorrência de estiagem, seguida da região Norte, Sul, Sudoeste e Litoral.
Palavras-chave: Anomalia Climática. Mudanças climática. Evento extremo.

Introduction

According to the latest estimates from the National Supply Company (Companhia Nacional de Abastecimento [CONAB], 2022), Brazil achieved a record-breaking grain harvest in 2022, producing 272.5 million tons (mil t) across 73.8 million hectares (mil ha). Notably, the southern region, despite facing meteorological challenges, was alone responsible for 67.2 mil t from 22 mil ha, with the state of Paraná contributing 36.6 mil t from 10.6 mil ha. CONAB also reports an increase of approximately 1.22 mil t of grains compared to the previous harvest, with particular emphasis on the growth in corn and wheat production.

However, climate change has become a major cause for concern in this agricultural landscape (Cintra et al., 2020). Despite the country's substantial agricultural potential, extreme weather events such as excessive rainfall and droughts have led to significant drops in productivity. Most regions in Brazil are experiencing an uptick in the frequency and duration of these extreme events, particularly during crucial phases of major agricultural crops (Félix et al., 2020; Nóbrega & Santiago, 2016). As a result, even with producers adhering to the standards outlined by the Agricultural Climate Risk Zoning (ZARC), they remain vulnerable to meteorological unpredictability (Evangelista et al., 2022; Massignam et al., 2015).

Another challenge lies in quantifying and predicting the likelihood of these events occurring (Silva Lima et al., 2018), especially during the agricultural harvest seasons. This is because traditional agrometeorological tools rely on historical averages and often struggle to detect extreme events (Bonfim et al., 2021). One potential solution is to identify the atmospheric demand of the local environment and the water behavior of the region through the plant's evapotranspiration.

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This can be accomplished by employing potential evapotranspiration (PET) or reference evapotranspiration (ETo), which is characterized as the simultaneous release of water from both the soil and plants into the atmosphere in areas without water deficiency (Franco et al., 2019). The measurement of PET involves considering the amount of water on a vegetated surface per gram, encompassing the entire area and without any water restrictions in place. As highlighted by Pereira et al. (2007), PET indicates the atmospheric evapotranspiration demand of a specific location over a defined time frame. Quantifying PET solely requires meteorological data, and its values can be tailored to the unique conditions of each vegetation type and soil moisture level under investigation through empirical or deterministic methods (Primo et al., 2018; Fança et al., 2021).

On the other hand, actual evapotranspiration (ETa), while rooted in the same principle as PET, takes into account whether there are water restrictions in place. When water restrictions are absent, the ETa value matches that of PET. However, if water restrictions exist, ETa reflects water loss from a surface under standard conditions where the proper development of crops might be impaired (Paula, 2018). According to Lins et al. (2017), understanding the concept of ETa is crucial for managing river basins and irrigation. This is particularly true when conducting meteorological and hydrological modeling in a region—particularly in those characterized by low precipitation levels and water scarcity.

Therefore, this study aims to determine the occurrence of drought in the state of Paraná by examining the ETa/PET ratio, which provides insights into situations where plants may be at risk of experiencing drought conditions by considering both water availability and atmospheric demand.

Material and Methods

The research was conducted in six locations within the state of Paraná, situated in the southern region of Brazil. The climate in these areas exhibits characteristics of both subtropical Cfa, characterized by hot summers with concentrated summer precipitation and the absence of a distinct dry season, and Cfb, a temperate climate featuring mild summers and no well-defined dry season. The elevation in these locations varies from 0 to 1300 m above sea level (Nitsche et al., 2019).

For the study, daily data encompassing rainfall and air temperature spanning from 1976 to 2020 were sourced from the meteorological station network operated by the Paraná Rural Development Institute IAPAR-EMATER (IDR – Paraná) in the six different locations, each representing distinct climatic mesoregions (Table 1). To enhance data quality and address gaps in information, additional data from the Paraná Environmental Technology and Monitoring System (SIMEPAR), the National Water and Sanitation Agency (ANA), and the National Institute of Meteorology (INMET) were integrated, creating a comprehensive daily database spanning the 45-year period under examination.

Table 1
Representativeness of the mesoregions of Paraná and period evaluated

Municipality	Mesoregion	Precipitation (mm)	Air temperature (ºC)
Guarapuava	Central	1976-2020	1976-2020
Lapa	South	1976-2020	1988-2020
Londrina	North	1976-2020	1976-2020
Morretes	Coast	1976-2020	1976-2020
Paranavaí	Northwest	1976-2020	1976-2020
Pato Branco	Southwest	1976-2020	1978-2020

To calculate the relationship, the methodology employed replicates the approach outlined by Ferreira (2016). It hinges on the ratio between actual evapotranspiration (ETa), which takes into account whether the grass/plant is subject to water deficit, and potential evapotranspiration (PET), where water deficit is not a consideration. In essence, this method quantifies the correlation between the amount of water lost by the plant on a typical day (ETa) and the quantity of water that would be lost by the plant under ideal conditions of soil water availability (PET).

Potential evapotranspiration data were estimated using the Thornthwaite (1948) method established in 1948, while ETa data were derived from the Climatological Water Balance model proposed by Thornthwaite and Mather (1955). These calculations were carried out using Excel™ spreadsheets following the model presented by Rolim et al. (1998). An available soil water capacity (AWC) of 75 mm was assumed (Farias et al., 2001).

The ratio between ETr and PET serves as the basis for calculating the accuracy coefficient, also known as the Water Requirement Satisfaction Index (WHSI). This index quantifies the maximum evapotranspiration demand of a crop in relation to the available water in the soil from either irrigation or precipitation. Values span from 0 to 1, with a value of 1 indicating that the plant's water demand has been fully met, while a value of 0 signifies that the plants are experiencing drought conditions (Willmott, 1981; Farias et al., 2001).

For each crop, a specific WHSI threshold is employed. Given that soybeans, corn, and wheat are the primary crops in Paraná, an average WHSI value of 0.6 was adopted based on the work of Sales et al. (2017). Consequently, the occurrence of drought was determined when the average ETa/PET ratio fell below 0.6, assessed on an annual, quarterly, monthly, or ten-day scale.

Results and Discussion

To pinpoint periods of drought, monthly and seasonal analyses were conducted for each region.

In the central region, none of the months throughout the year exhibited prolonged drought conditions over the assessed period (Figure 1). Specifically, in January, February, March, October, November, and December, instances of WHSI values lower than 0.7 were scarce. Typically, throughout all years, the WHSI remained consistently around 0.8. However, from April to September, this ratio displayed more significant fluctuations between years, particularly in the month of August.

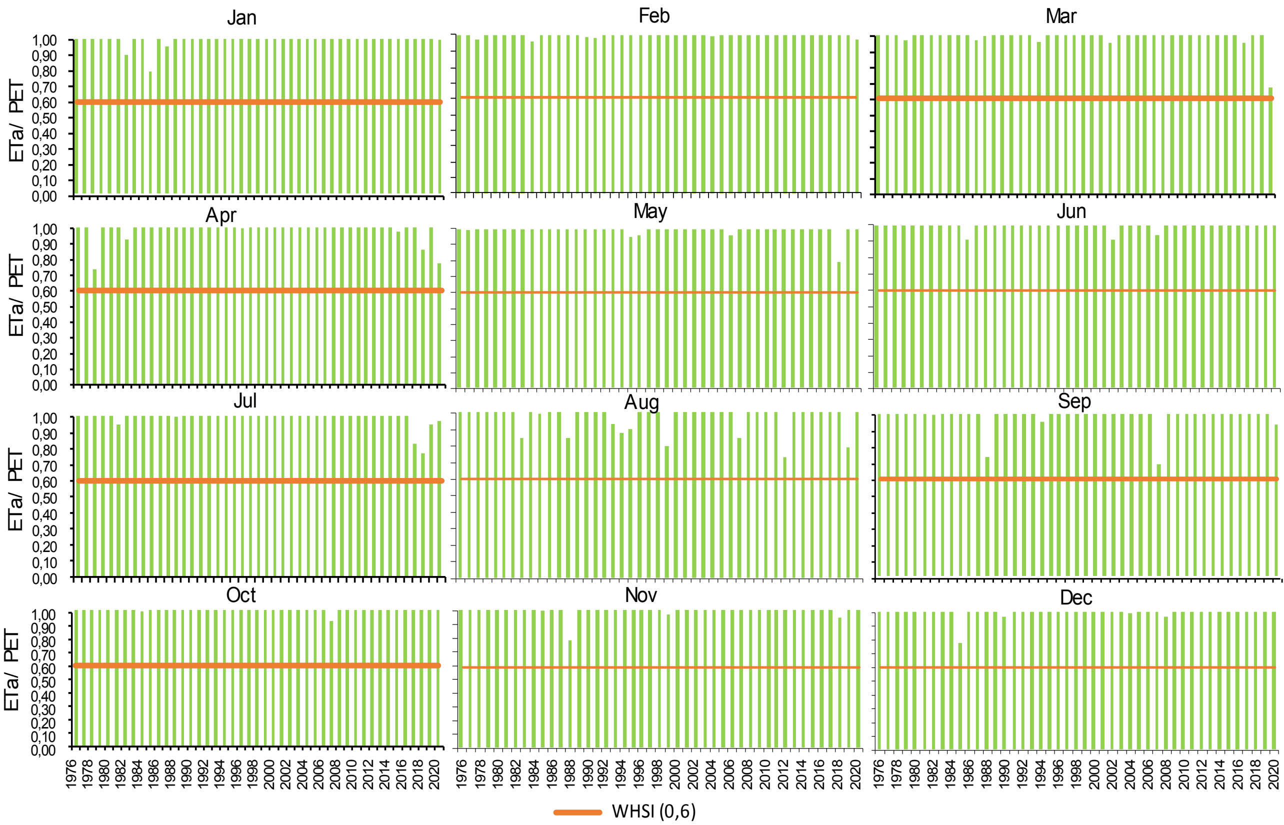

Figure 1. Monthly ETR/ETP ratio in the central region.

Regarding the means of seasons of the year (Figure 2), no drought events were detected across any of the seasons. Nevertheless, during the winter, there were fluctuations in WHSI values ranging between 0.9 and 1.0 over the entire assessed period. In the fall, there was a gradual decline in WHSI values observed in the central region during the last five years of the historical series, although this decline did not reach the threshold indicative of drought.

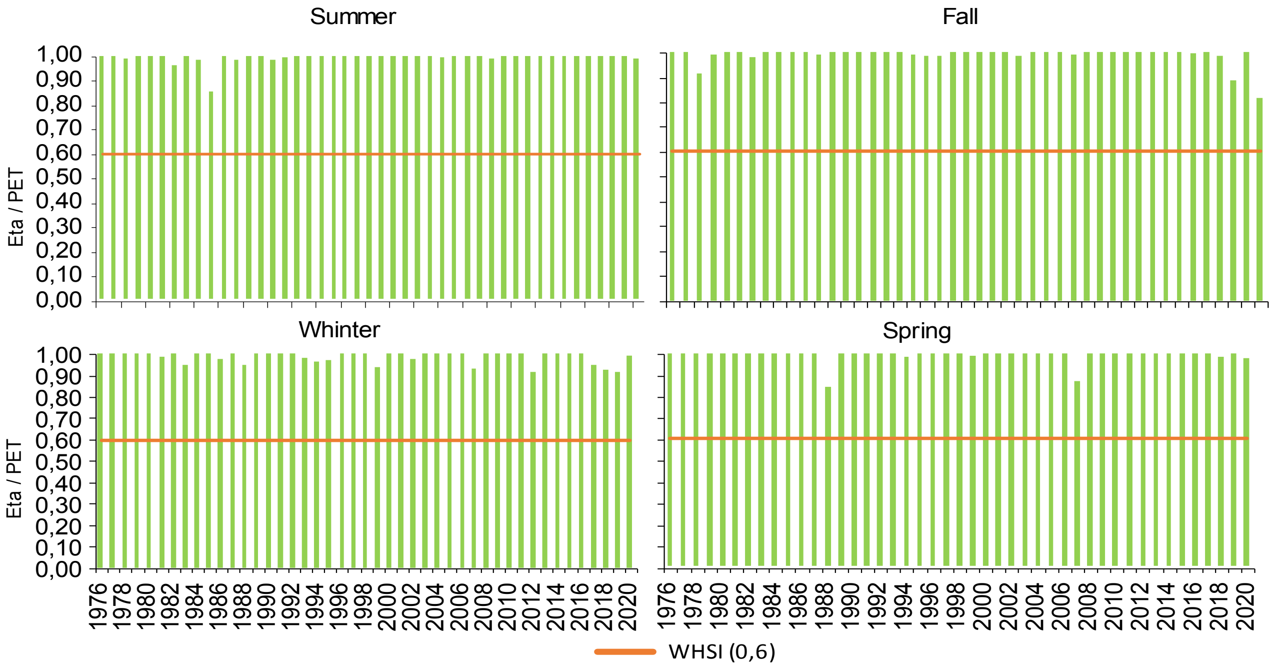

Figure 2. ETa/PET ratio across seasons of the year in the central region.

The decade (10-day interval) analysis (Figure 3) revealed that WHSI values below 0.6 occurred in some years, but these events were not readily discernible when examining monthly means for the region. Notably, in the 3rd and 4th decades of JAN3, FEB1, and MAY1, these values dipped below the drought threshold. Between March and June, despite WHSI values fluctuating multiple times, there was no recurring pattern of drought impact on plants during these months. Conversely, the decades of August and September exhibited the most substantial fluctuations in WHSI values from one year to the next, indicating that these months experienced the driest conditions.

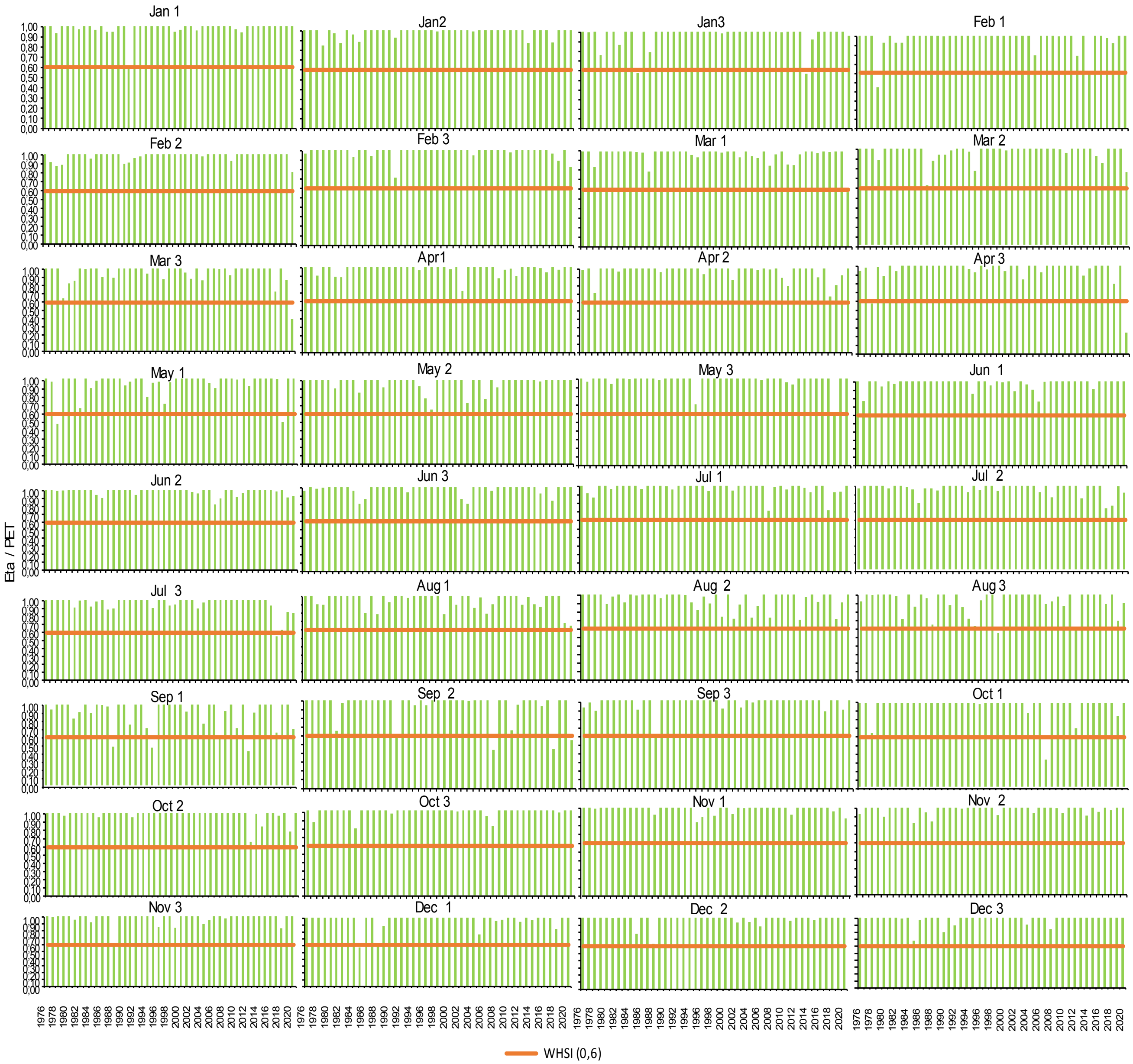

Figure 3. Decade ETa/PET ratio in the central region.

For the southern region of Paraná, the months of January to March displayed relatively minor fluctuations in WHSI values (Figure 4), with only a few years featuring distinct drought episodes. In contrast, the months of April and May exhibited several identified drought events, especially in May, characterizing it as the month with the highest risk of drought in the region. August also displayed year-to-year fluctuations, although WHSI values never dipped below 0.7. Meanwhile, for the other months, a consistent WHSI value of around 1.0 was noted, irrespective of the year.

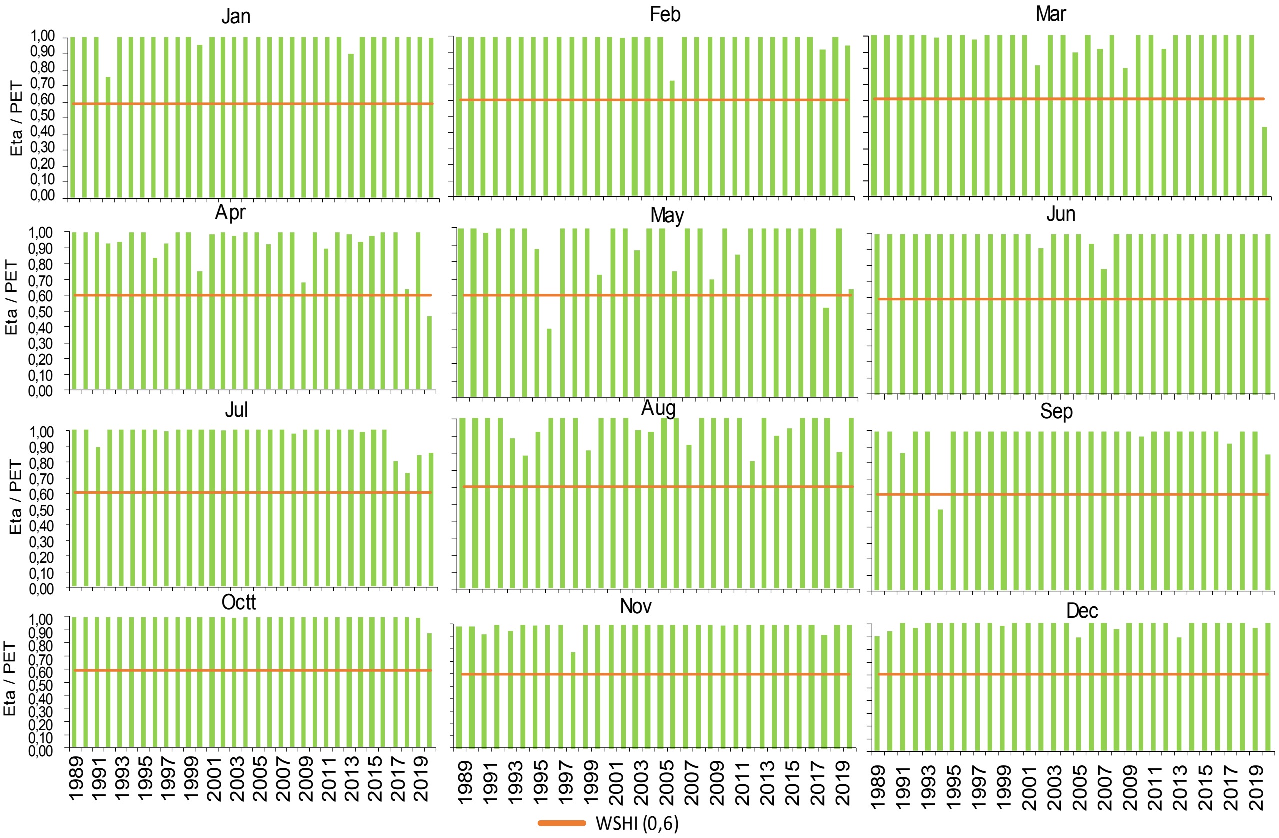

Figure 4. Monthly ETR/ETP ratio in the south region.

When examining the various seasons (Figure 5), it becomes evident that drought events are rare in the region during spring, summer, and winter. A similar pattern is observed in the fall season, although there is greater fluctuation in WHSI values, which reached at least 0.7.

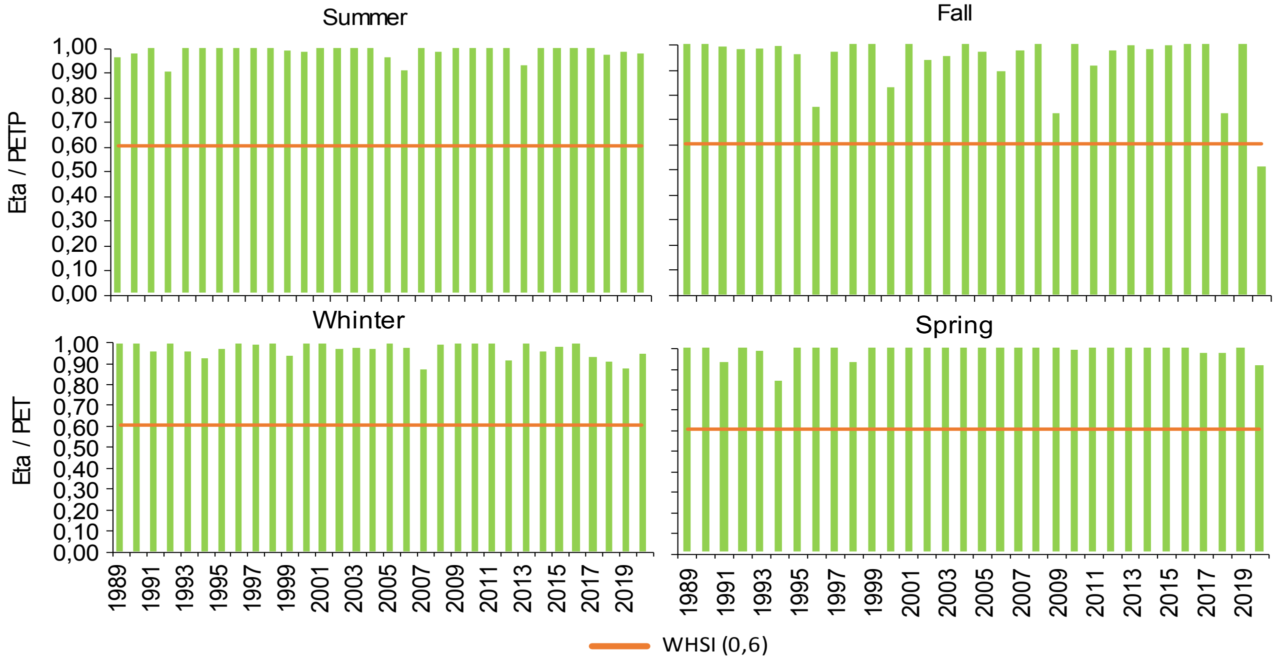

Figure 5. ETa/PET ratio across seasons of the year in the south region.

Regarding the decade averages for the region (Figure 6) October consistently records WHSI values above 0.6, with November and December displaying periods characterized by lower likelihoods of drought. However, during the decades from MAR3 to SEP2, the historical series reveals a substantial number of drought occurrences. April, May, and August stand out, showcasing significant year-to-year fluctuations and instances of WHSI values falling below 0.6 in the region's historical data.

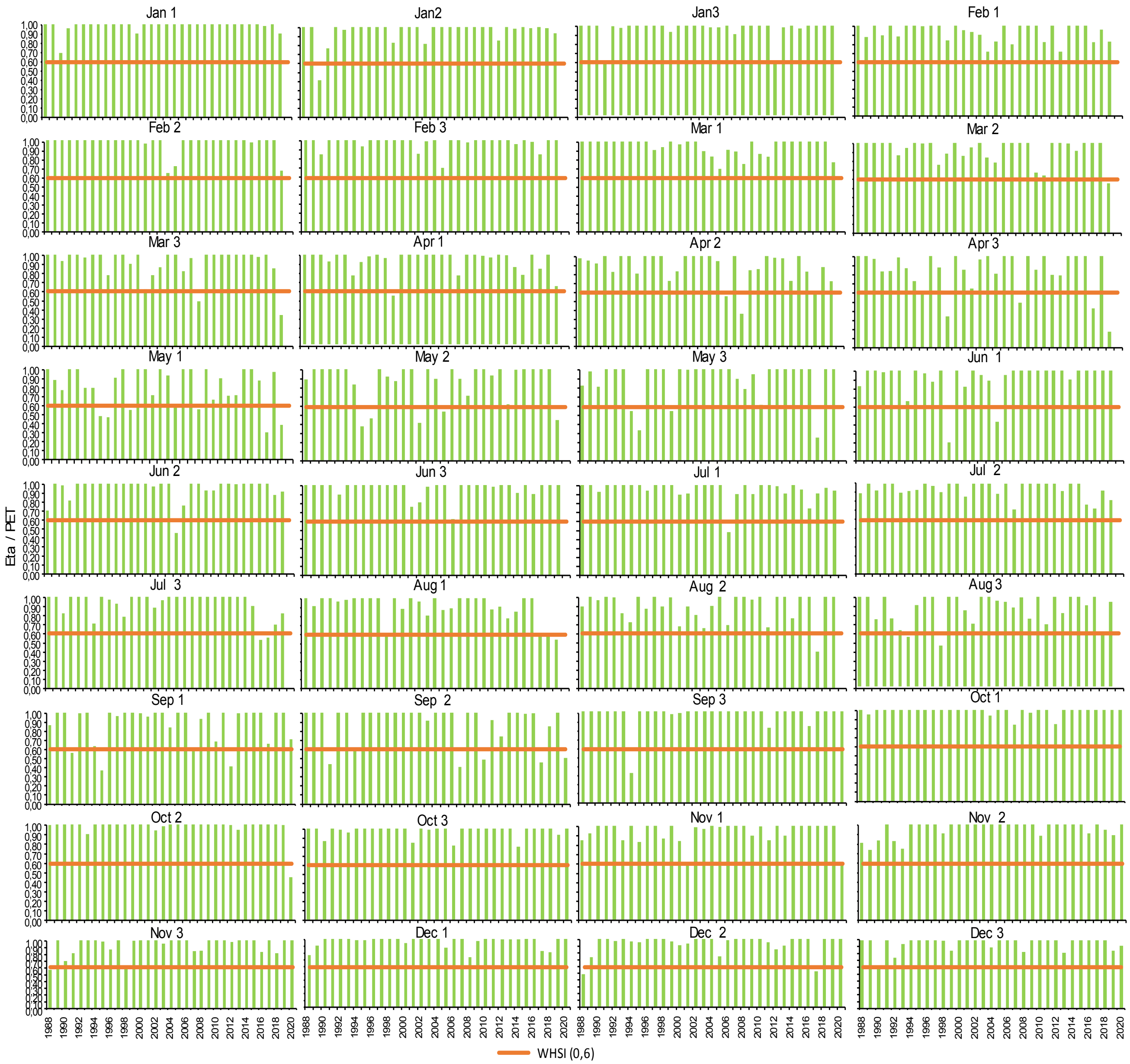

Figure 6. Decade ETa/PET ratio in the south region.

In the northern region, the months of January to March (Figure 7) did not experience drought events, although there was greater year-to-year fluctuation compared to the previously discussed regions. On the other hand, the months of July, August, and September witnessed the highest frequency of drought occurrences, especially in August. Given the variability in the planting dates of agricultural crops in the state, this period often coincides with a fallow period for Asian soybean rust, as well as the conclusion of the winter crop harvest. Consequently, this drought may have favorable aspects as it helps protect harvested grains and avoids damage (Dias, 2018; Becker et al., 2015).

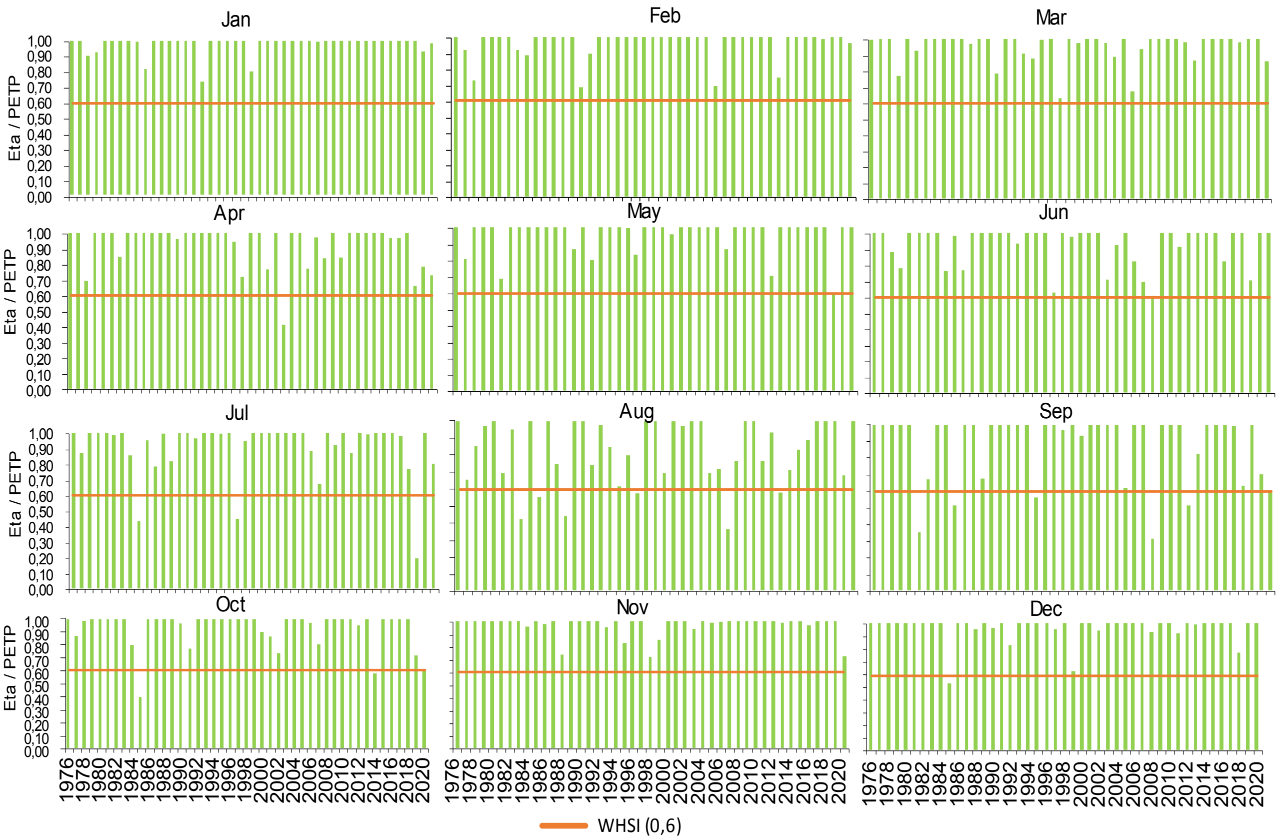

Figure 7. Monthly ETR/ETP ratio in the north region.

However, the end of September marks the restart of soybean planting. Drought during this period is known to be detrimental to the initial growth of the crop, affecting seed germination and establishment (Barbosa, 2017). Furthermore, November and December also recorded relatively low occurrences of drought events, although there were infrequent years in which the average WHSI remained above 0.7.

Analyzing the seasons in the northern region (Figure 8), winter exhibited the most substantial fluctuation in WHSI values and the highest number of events below the year-to-year average. Spring and fall followed in terms of fluctuation. Summer, in contrast, remained consistently humid with a high ETr/PET ratio across the evaluated periods. No droughts were recorded during this season, and the lowest mean WHSI value recorded was 0.75.

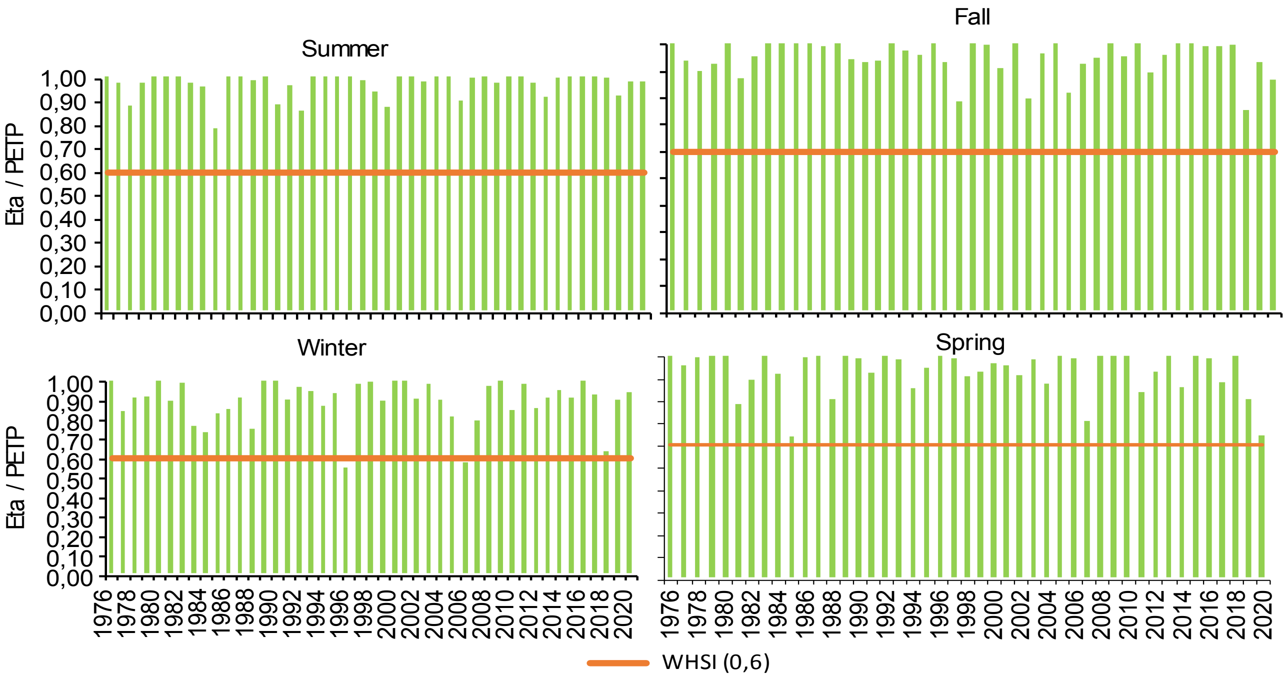

Figure 8. ETa/PET ratio across seasons of the year in the north region.

In examining the average of the decades (Figure 9), all decades within the year included episodes in which the WHSI value dropped below 0.6, with particular emphasis on the last two decades of August and the first two of September, where these events recurred from year to year. The first decade of January, the first decade of February, and those from November to December were the exceptions, with a higher number of events featuring a higher ETa/PET ratio closer to 1.0, thus avoiding deficit conditions.

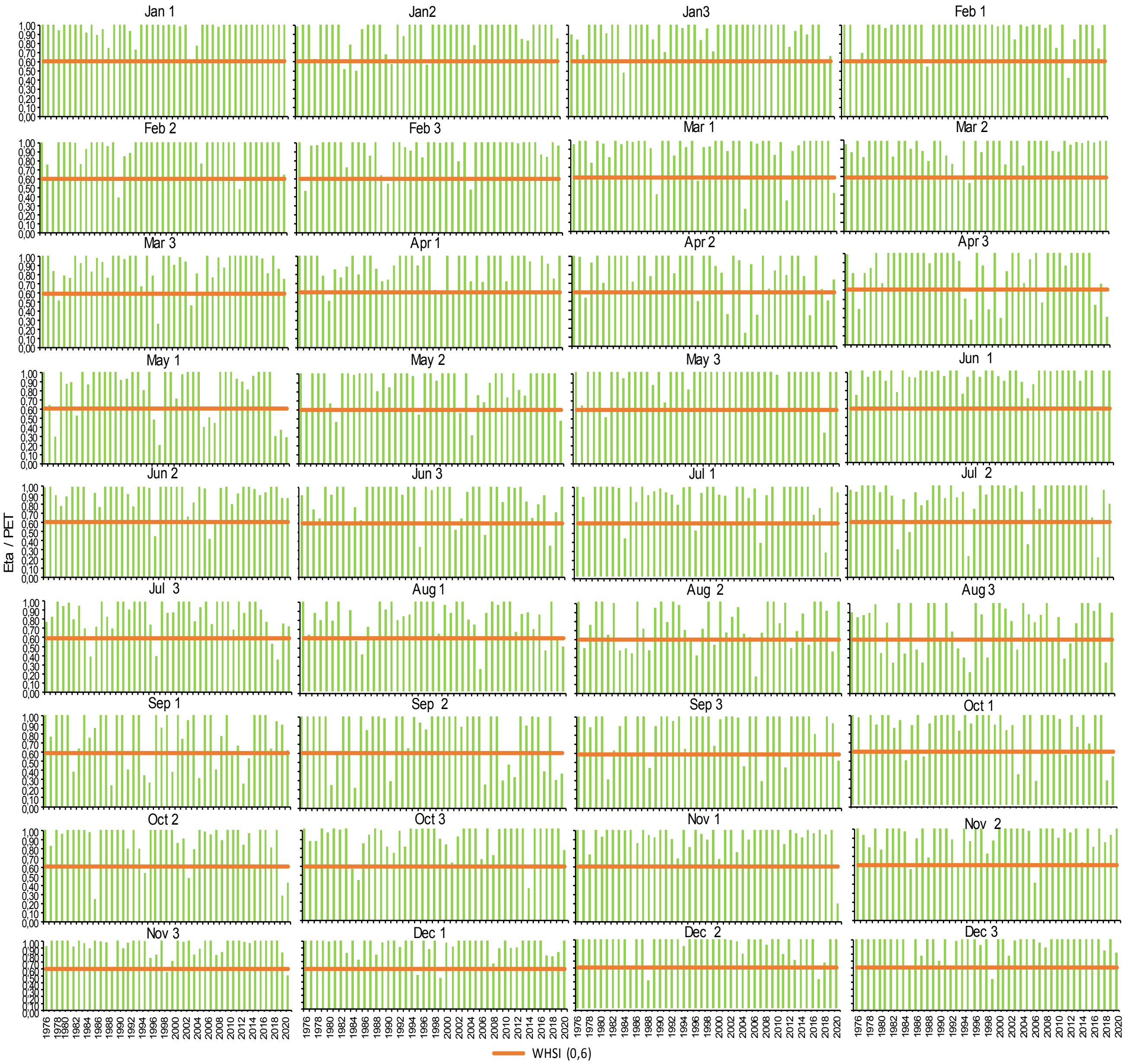

Figure 9. Decade ETa/PET ratio in the north region.

On the coast of Paraná, the majority of months exhibited a notably high ETa/PET ratio (Figure 10). However, there were only sporadic occurrences in the months of May, June, and July, ranging from 0.5 to 0.8. In the remaining months, the WHSI value consistently hovered around 1.0 from year to year.

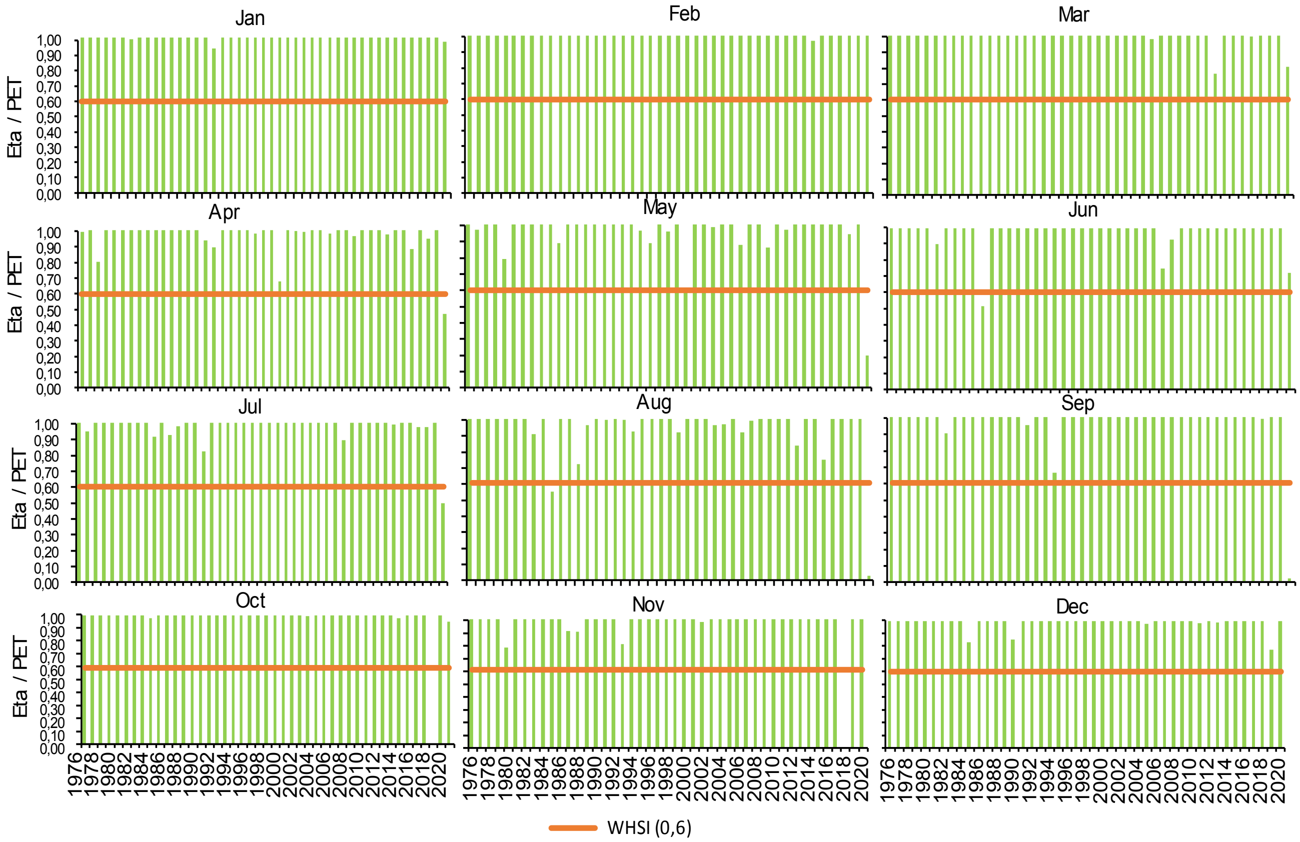

Figure 10. Monthly ETR/ETP ratio in the coastal region.

When we examine the seasonal patterns, we find that the differences were not particularly pronounced (Figure 11). During the summer, the lowest WHSI value recorded was 0.95 in only three out of the 45 years analyzed, with all others registering a ratio of 1.00. This implies that the crop's water requirements were consistently met during the summer. A similar pattern was observed in most years during the spring season. In contrast, during the winter and fall, there was greater fluctuation in values from year to year, particularly in the fall. However, even in these seasons, the WHSI remained above 0.75.

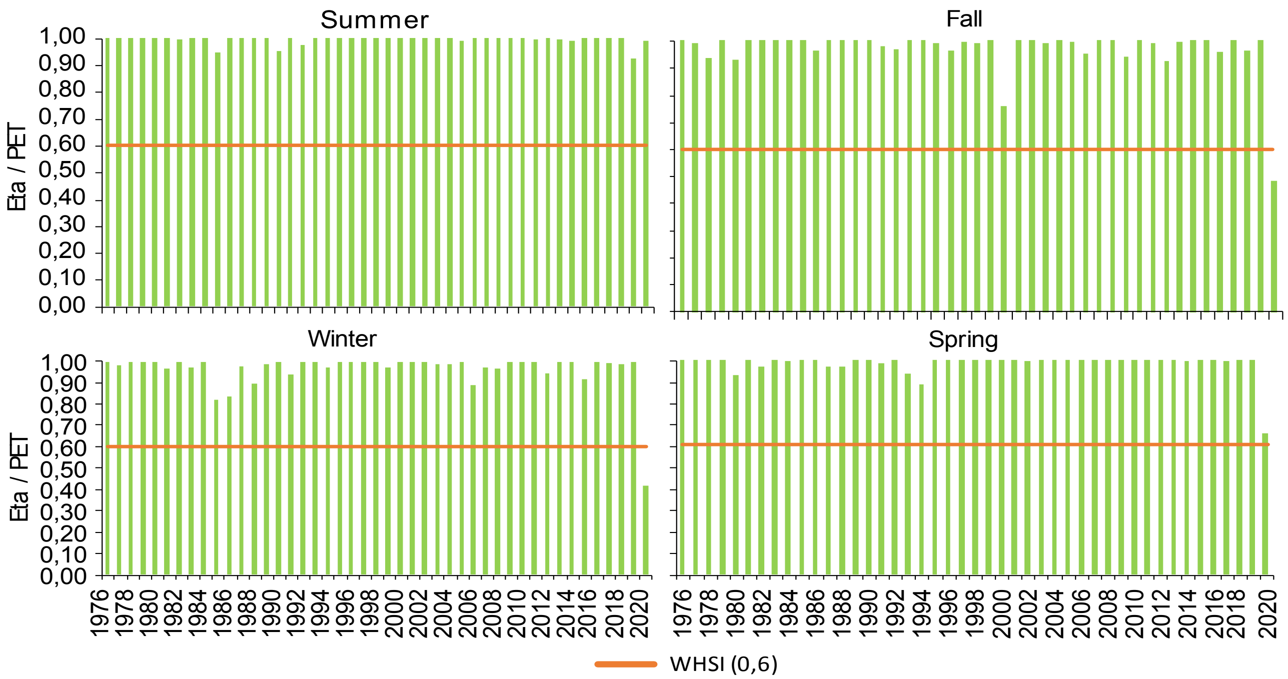

Figure 11. ETa/PET ratio across seasons of the year in the coastal region.

The decades of August and September were those with the highest frequency of years experiencing WHSI values below 0.6 (Figure 12). December witnessed such an occurrence in only one year, specifically within its last decade (DEC3). From the first decades of January through the second decade of April, the ETa/PET ratio consistently remained high, staying close to 1.0 with little year-to-year fluctuation.

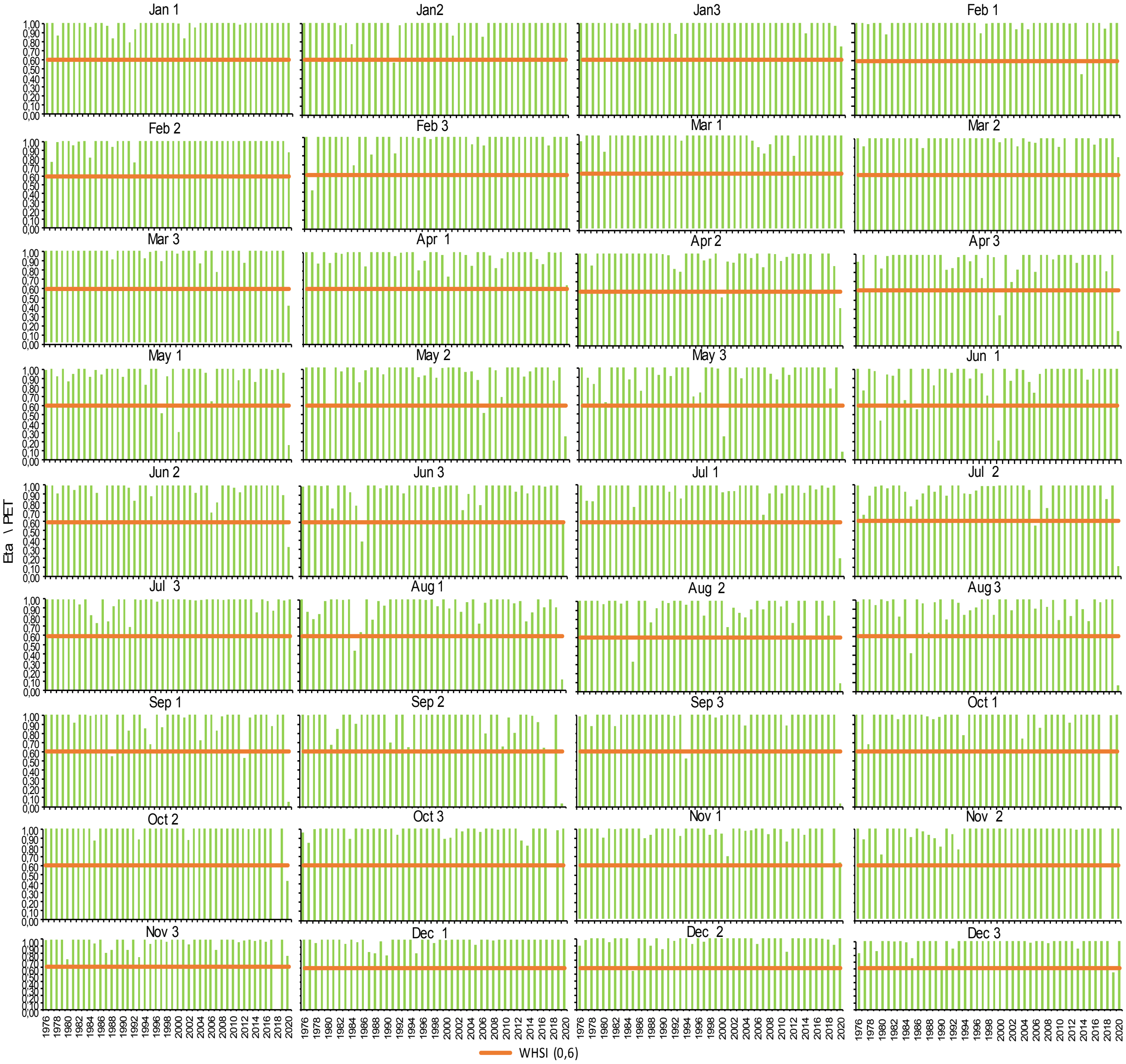

Figure 12. Decade ETa/PET ratio in the coastal region.

In the northwest region, May was the sole month where WHSI did not fall below 0.6 (Figure 13). On the other hand, June through September displayed the highest number of below-average WHSI records, exhibiting considerable year-to-year variation, with August standing out as a particularly drought-prone month. In contrast to other regions, October, November, and December witnessed more instances in which the ETa/PET ratios were closer to 0.6 than 1.0, signifying a heightened likelihood of drought compared to the other regions.

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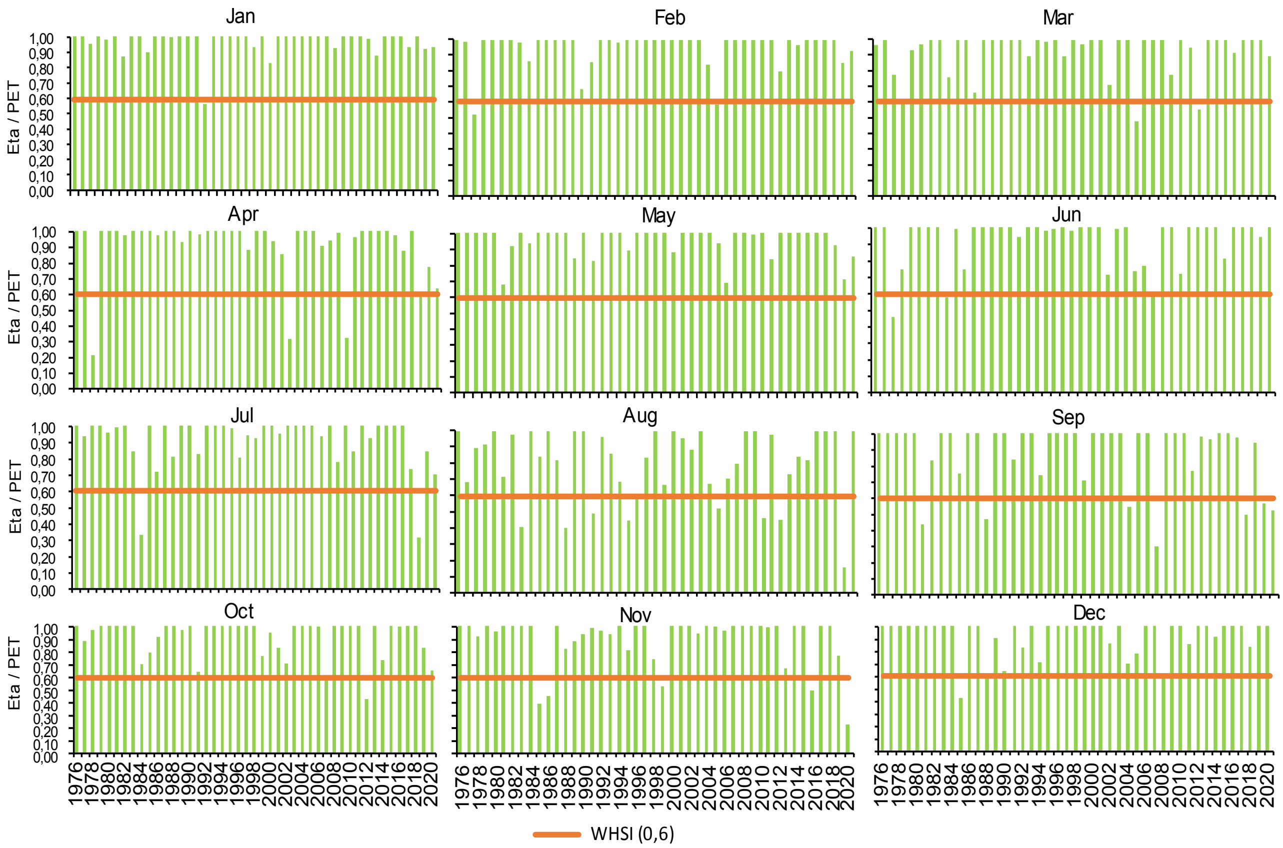

Figure 13. Monthly ETR/ETP ratio in the northwest region.

Regarding the seasons of the year (Figure 14), none of them exhibited records of drought years. Fall, winter, and spring exhibited the highest recurrence of events with an ETa/PET ratio close to 0.6, indicating a greater potential for drought occurrence. Conversely, summer, being the shortest season, displayed less year-to-year fluctuation.

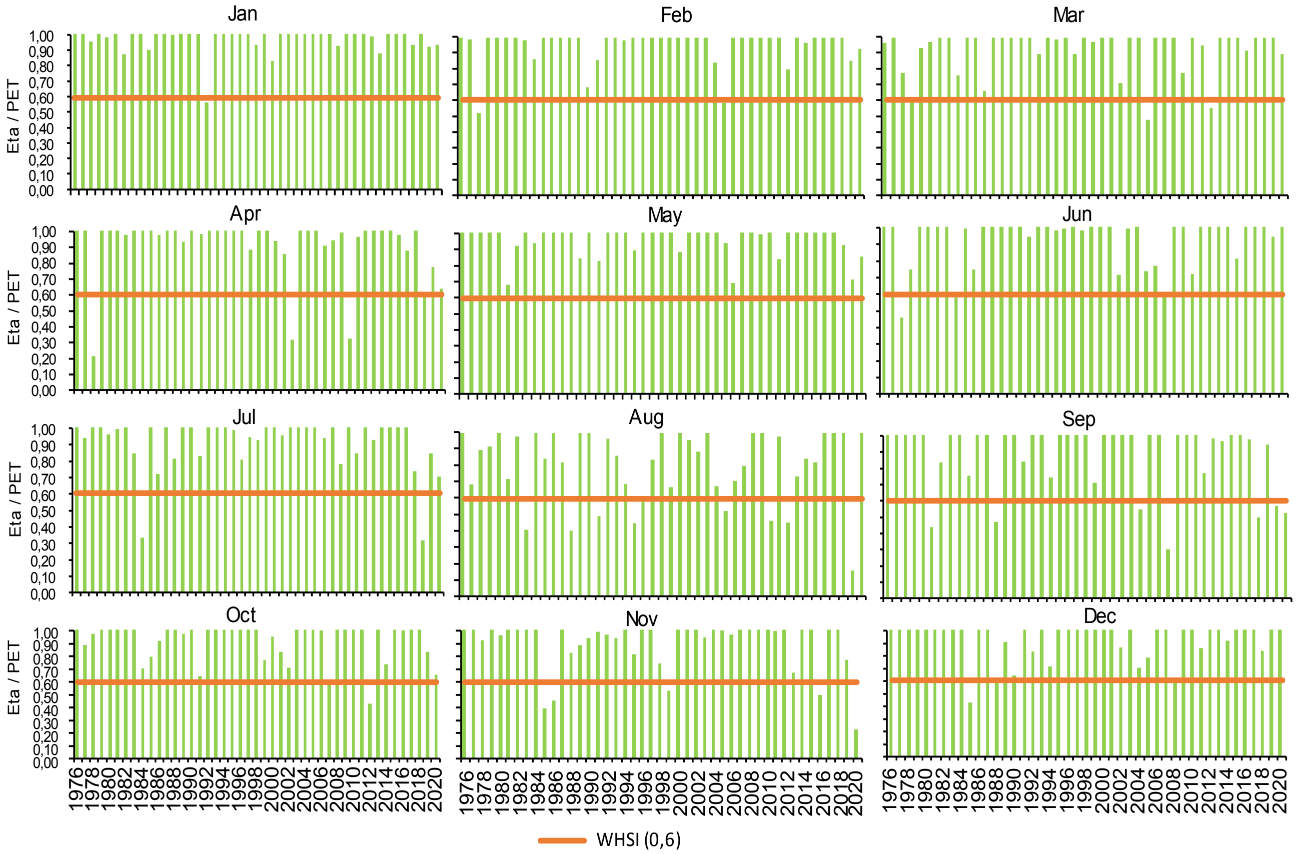

Figure 14. ETa/PET ratio across seasons of the year in the northwest region.

By analyzing the decades in the region (Figure 15), we observe that all of them featured years with a WHSI value close to or below 0.6. A prime example can be seen in the decades of August and the first decade of September, which displayed the greatest drought risk in the region. In other decades, there was substantial WHSI fluctuation from year to year, as observed in the decades of January and February, as well as those from November to December. A study conducted by Carmello (2017) found that certain years experienced reduced soybean productivity due to decreased precipitation during some of the January and February decades. These months coincide with critical stages of crop development, such as flowering and pod filling (Barbosa, 2017).

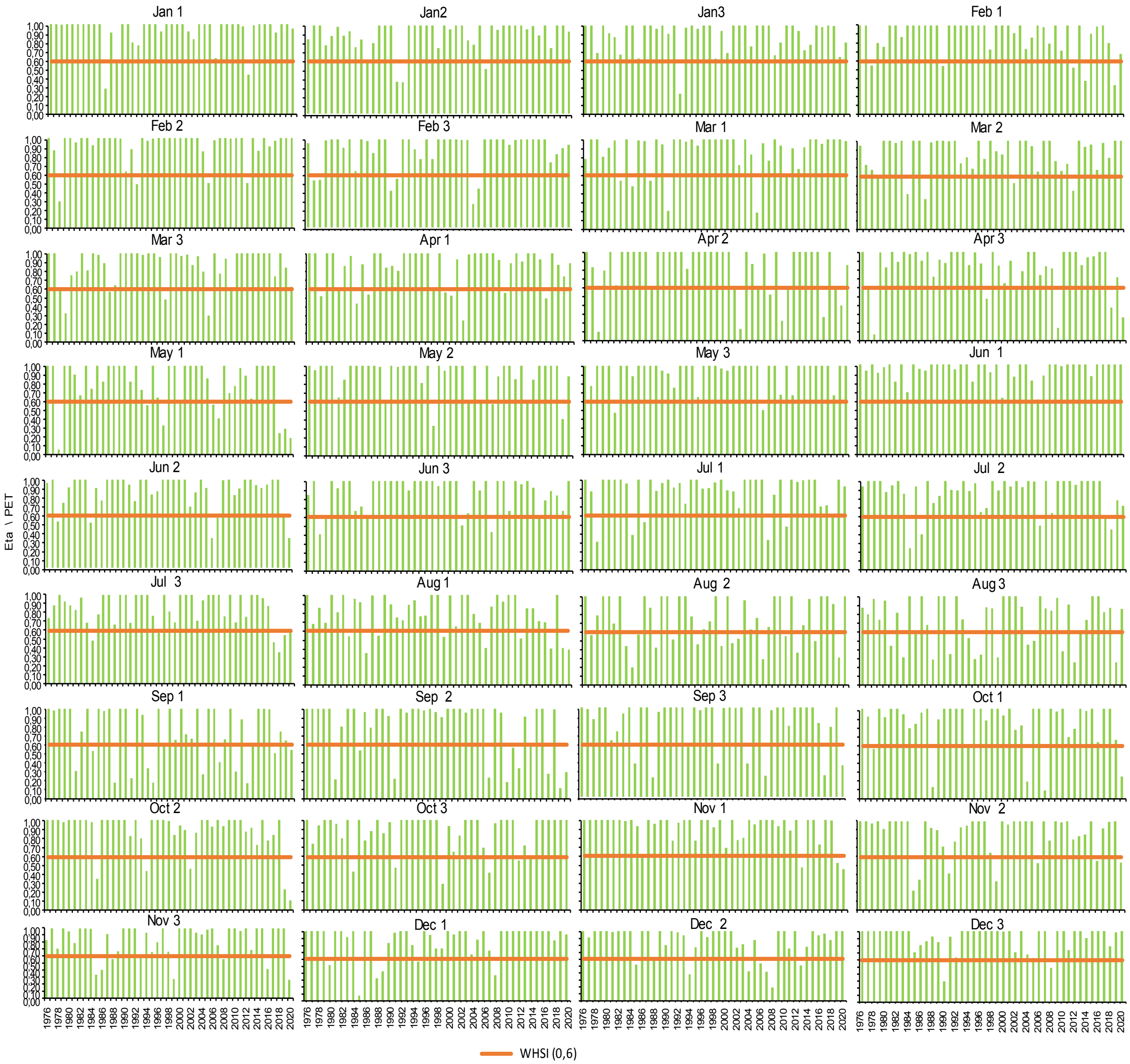

Figure 15. Decade ETa/PET ratio in the northwest region.

In the analysis of the monthly averages in the southwest region, all months consistently exhibited a high ETa/PET ratio, nearly always close to 1.00 (Figure 16). The only exception was June, where only two out of 45 years had an average value of 0.95. March and August displayed a greater year-to-year fluctuation in values, although there were few events with an average of 0.75, which does not constitute a drought.

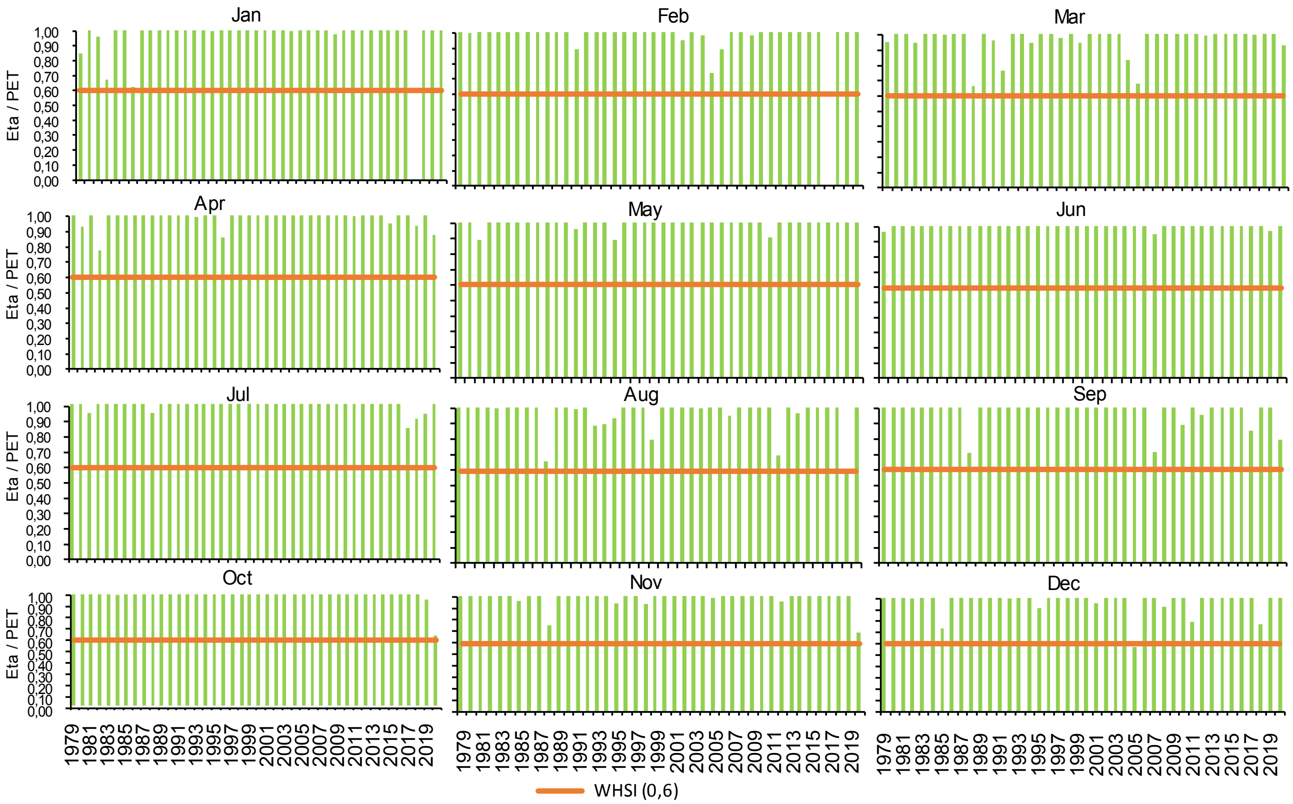

Figure 16. Monthly ETa/PET ratio in the south region.

As for the seasons of the year, no drought events were recorded in any of them (Figure 17). In the southwest region, occurrences with ETa/PET ratio lower than 1.00 were sporadic. In all seasons, the average remained around 0.8, well above the threshold for stress conditions for the plant.

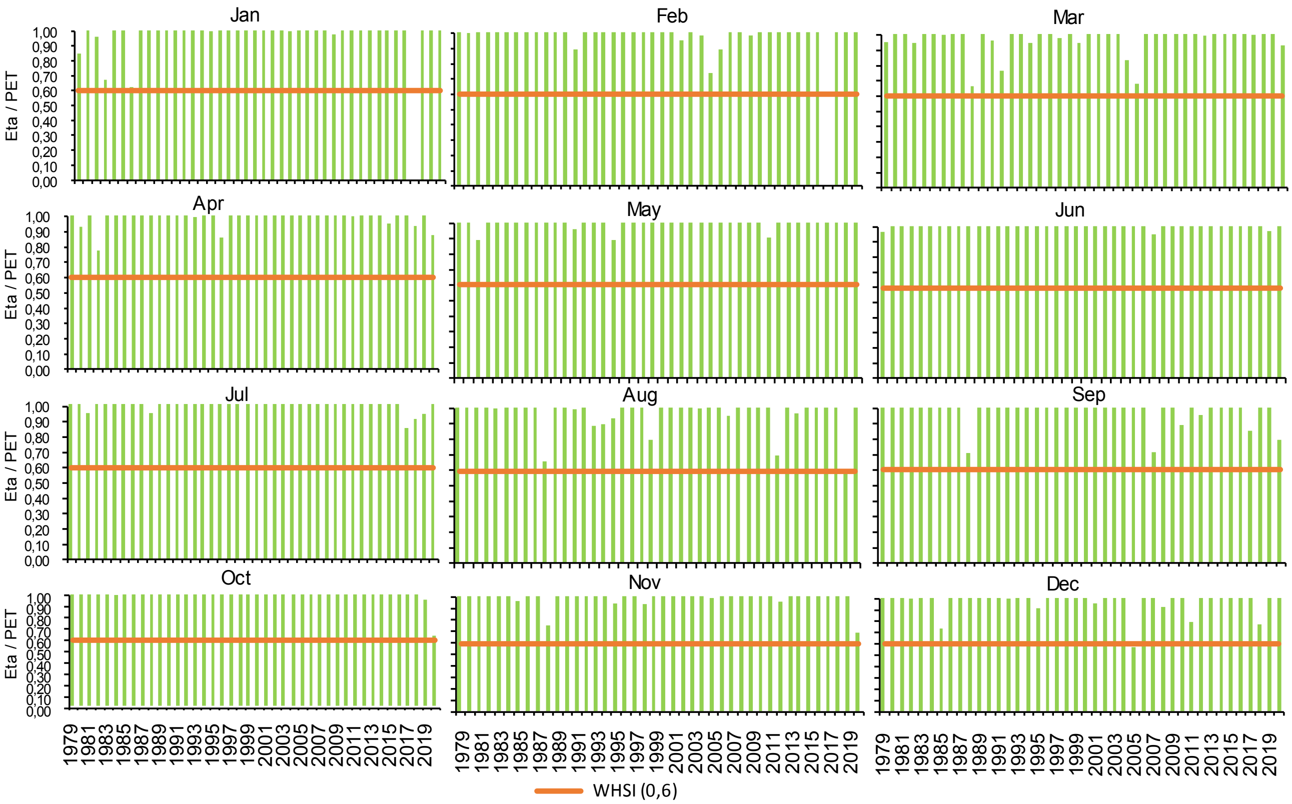

Figure 17. ETa/PET ratio across seasons of the year in the southwest region.

The first decades of March and September (Figure 18) were the ones with the most frequent drought years among those evaluated. Meanwhile, the decades of November, APR3, JUN1, JUN2, JUL1, JUL3, AUG1, AUG2, OCT2, and OCT3 were the only ones that did not witness any year with a WHSI value lower than 0.6, maintaining an average close to 0.75.

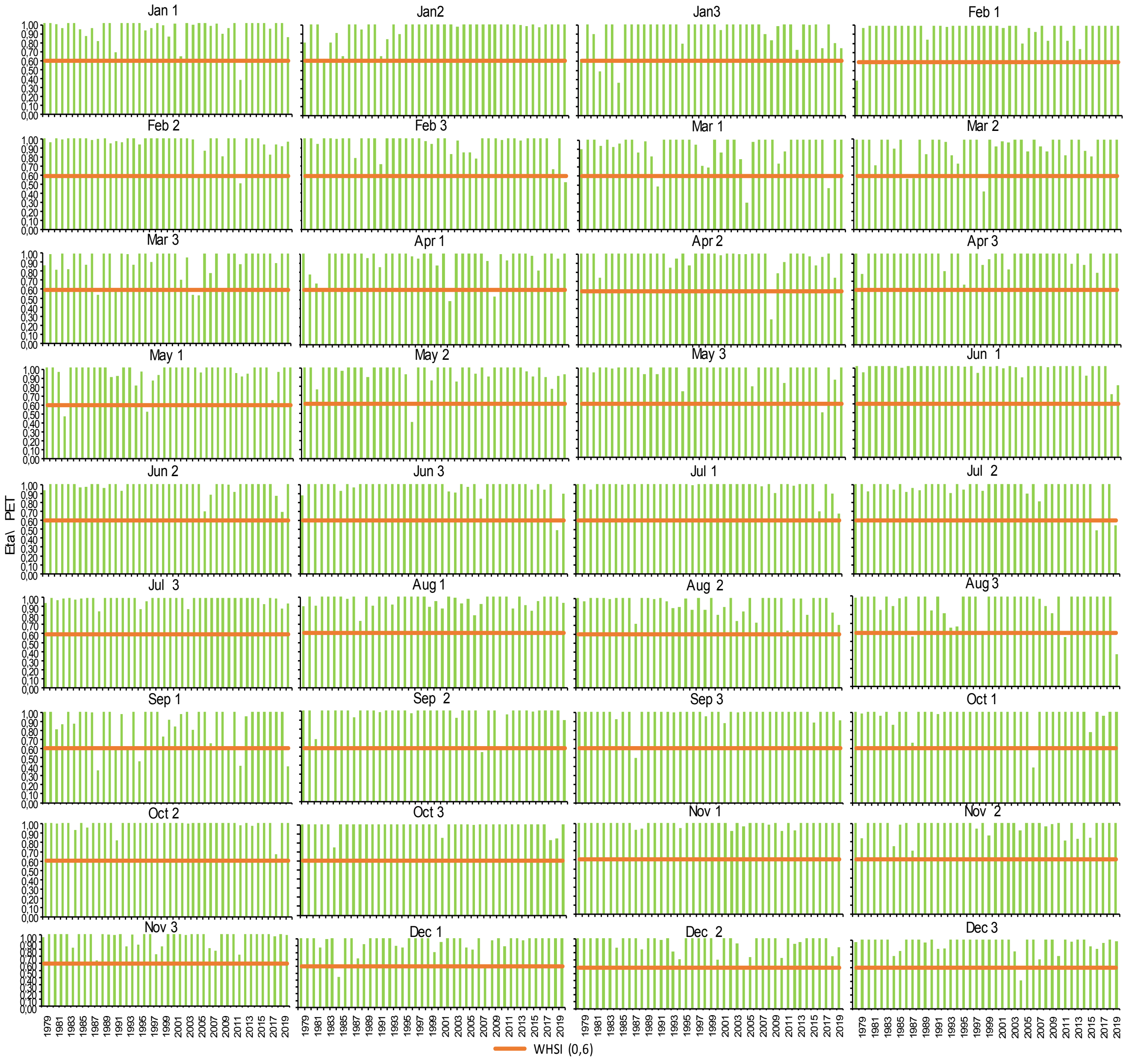

Figure 18. Decade ETa/PET ratio in the southwest region.

Conclusions

Our study findings revealed that the month of August, particularly its last decade, experiences the highest frequency of drought occurrences across the entire state. The northwest region stands as the most susceptible to drought, followed by the north, south, southwest, and coastal regions. In terms of seasonal impact, winter emerged as the season most severely affected by drought, with fall, spring, and summer following in decreasing order of vulnerability.

References

Barbosa, L. A. (2017). *Limite crítico do potencial hídrico da soja durante os estádios vegetativo e reprodutivo.* Dissertação de mestrado, Universidade Federal de Uberlândia, Uberlândia, SP, Brasil. https://repositorio.ufu.br/handle/123456789/19843

Becker, W. R., Prudente, V. H. R., Johann, J. A., Richetti, J., & Mercante, E. (2015). Obtenção de dados espaciais e temporais das culturas agrícolas no estado do Paraná. *Anais do Simpósio Brasileiro de Sensoriamento Remoto,* João Pessoa, PB, Brasil, 17.

Bonfim, O. E. T., Silva, D. F. D., Kayano, M. T., & Rocha, L. H. D. S. (2021). Análise dos eventos climáticos extremos e de suas causas climáticas para redução de riscos nas bacias hidrográficas Aguapeí e Peixe, São Paulo, Brasil. *Revista Brasileira de Meteorologia, 35*(Esp.), 755-768. doi: 10.1590/0102-7786355000004

Carmello, V. (2017). Análise do impacto da variabilidade das chuvas em municípios que produzem soja no Paraná, Brasil. *Os Desafios da Geografia Física na Fronteira do Conhecimento, 1*(1), 1719-1727. doi: 10.20396/sbgfa.v1i2017.2276

Cintra, P. H. N., Melo, O. F. P. de, & Menezes, J. O. S. de. (2020). Produção agrícola: uma revisão bibliográfica sobre as mudanças climáticas e produtividade de plantas graníferas no Brasil. *Revista Agrotecnologia Ipameri, 11*(1), 2179-5959.

Companhia Nacional de Abastecimento (2022). *Acompanhamento da safra brasileira de grãos* (v. 9, safra 2021/22, n. 10 levantamento). CONAB.

Silva Lima, M. J. da, Silva Cavalcante, I. B. da, Silva Mendonça, H. da, Souza, P. F. de, Neto, Silva, S. D. da, Amorim, D. D. O. C., & Silva, D. F. da. (2018). Classificação, quantificação e ocorrência de eventos climáticos extremos nas três mesorregiões do estado de Alagoas (BR). *Ciência e Sustentabilidade, 4*(2), 151-172. doi: 10.33809/2447-4606.422018151-172

Fança, M. V. de, Medeiros, R. M. de, Holanda, R. M. de, Saboya, L. M. F., Rolim, F. C., Neto, & Araújo, W. R. de. (2021). Análise da estimativa da evapotranspiração por diferentes modelos para Amparo de São Francisco–Sergipe. *Research, Society and Development, 10*(13), e514101321505-e514101321505. doi: 10.33448/rsd-v10i13.21505

Sales, R. A. de, Ambrozim, C. S., Posse, R. P., Oliveira, E. C. de, & Posse, S. P. (2017). Índice de satisfação das demandas de água e produtividade do feijão em diferentes lâminas de irrigação em Colatina-ES. *Energia na Agricultura, 32*(1), 81-87. doi: 10.17224/EnergAgric.2017v32n1p81-87

Dias, S. K. F. (2018). *Avaliação da aplicação do vazio sanitário na cultura da soja no manejo da ferrugem-asiática no Distrito Federal e entorno.* Trabalho de conclusão de curso, Universidade de Brasília, Faculdade de Agronomia e Medicina Veterinária, Brasília, DF, Brasil. https://bdm.unb.br/handle/1048 3/21226

Evangelista, B., Campos, L., Silva, F. A. M. da, Simon, J., Ribeiro, I., & Vale, T. M. do. (2022). *Possíveis impactos das mudanças climáticas sobre o zoneamento agrícola de risco climático da cultura da soja no estado do Tocantins.* http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1143011

Farias, J. R. B., Assad, E. D., Almeida, I. D., Evangelista, B. A., Lazzarotto, C., Neumaier, N., & Nepomuceno, A. L. (2001). Caracterização de risco de déficit hídrico nas regiões produtoras de soja no Brasil. *Revista Brasileira de Agrometeorologia, 9*(3), 415-421.

Félix, A. D. S., Nascimento, J. W. B., Melo, D. F. de, Furtado, D. A., & Santos, A. M. dos. (2020). Análise exploratória dos impactos das mudanças climáticas na produção vegetal no Brasil. *Revista em Agronegócio e Meio Ambiente, 13*(1), 397-409. doi: 10.17765/2176-9l68.2020v13n1p397-407

Ferreira, R. C. (2016). *Quantificação das perdas por seca na cultura da soja no Brasil.* Tese de doutorado, Universidade Estadual de Londrina, Londrina, PR, Brasil.

Franco, B. M., Ziani, F. A., Konrad, J., & Andres, C. M. (2019). Comparação entre métodos de estimativa de evapotranspiração potencial e de referência. *Revista Brasileira de Ciência, Tecnologia e Inovação, 4*(2), 180-189.

Lins, F. A. C., Santos Araújo, D. C. dos, Silva, J. L. B. da, Lopes, P. M. O., & Oliveira, J. D. A. (2017). Estimativa de parâmetros biofísicos e evapotranspiração real no semiárido pernambucano utilizando sensoriamento remoto. *Irriga, 1*(1), 64-75. doi: 10.15809/irriga.2017v1n1p64-75

Massignam, A. M., Pandolfo, C., Silva Ricce, W. da, Santi, A., & Machado, L. N. (2015). Impacto das mudanças climáticas para o período futuro 2071-2100 no zoneamento do milho no Sul do Brasil. *Agropecuária Catarinense, 28*(2), 55-60.

Nitsche, P. R., Caramori, P. H., Ricce, W. D. S., & Pinto, L. F. D. (2019). *Atlas climático do estado do Paraná.* Instituto Agronômico do Paraná.

Nóbrega, R. S., & Santiago, G. A. C. F. (2016). Tendências do controle climático oceânico sob a variabilidade temporal da precipitação no Nordeste do Brasil. *Revista de Geografía Norte Grande,* (63), 9-26. doi: 10.4067/S0718-34022016000100002.

Paula, A. C. P. (2018). *Estimativa da evapotranspiração real da cultura da soja e do feijoeiro pelo método da razão de Bowen e pelo modelo SSEBop.* Dissertação de mestrado, Universidade de Brasília, Faculdade de Agronomia e Medicina Veterinária, Brasília, DF, Brasil. https://repositorio.unb.br/handle/10482/32 379

Pereira, A. R., Angelocci, L. R., & Sentelhas, P. C. (2007). *LCE 306.*

Primo, D. F., Trevisan, D. P., & Duarte, R. T. (2018). Análise comparativa de métodos de estimativa de evapotranspiração para fins agrícolas na região de São Carlos-SP. *Revista Brasileira de Iniciação Científica, 6*(1), 13-32. https://www.researchgate.net/publication/330873870_1009-5143-1-PB#full TextFileContent

Rolim, G. S., Sentelhas, P. C., & Barbieri, V. (1998). Planilhas no ambiente EXCEL TM para os cálculos de balanços hídricos: normal, sequencial, de cultura e de produtividade real e potencial. *Revista Brasileira de Agrometeorologia, 6*(1), 133-137. http://www.leb.esalq.usp.br/agmfacil/artigos/artigos_sentelhas_1998/1998_RBAgro_6(1)_133-137_PlanilhasBH.pdf

Thornthwaite, C. W. (1948). An approach toward a rational classification of climate. *Geographical Review, 38*(1), 55-94. doi: 10.2307/210739

Thornthwaite, C. W., & Mather, J. R. (1955). The water balance. *Publications in Climatology, Drexel Institute of Technology, 8*(1), 5-6.

Willmott, C. J. (1981). On the validation of models. *Physical Geography, 2*(2), 184-194. doi: 10.1080/02723646.1981.10642213