NORMAL AND SEQUENTIAL CLIMATOLOGICAL WATER BALANCE FOR THE MUNICIPALITY OF PALMARES - PE BY ERA5-LAND REANALYSIS

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ABSTRACT: The climatological water balance is a recognized tool for estimating the water availability. The use of data from global atmospheric models, as ERA5-Land, has been widely used to estimate climatic variables in sites without nearby weather stations, as well as to obtain historical series without failures. Thus, this study aimed to estimate the climatological normal water balance (NWB) and sequential water balance (SWB) at the Palmares - PE, using monthly air temperature and rainfall data estimated by ERA5-Land to provide information for agricultural planning in the region. The historical series of rainfall and average air temperature data estimated by ERA5-Land was used from 2011 to 2020. Monthly means were calculated to obtain the NWB, while for SWB the annual means were used. The NWB provided detailed information of the following variables: Precipitation, Potential Evapotranspiration, Real Evapotranspiration, Water Deficiency, and Water Surplus. The SWB provided a more careful analysis of extreme values compared to NWB. Potential evapotranspiration was higher than precipitation from August to April resulting in soil water deficit. These results recommend the use of irrigation to avoid the reduction in growth and, consequently, in crop productivity.
KEYWORDS: Evapotranspiration, water deficiency, agricultural planning, irrigation

BALANÇO HÍDRICO CLIMATOLÓGICO NORMAL E SEQUENCIAL PARA O MUNICÍPIO DE PALMARES – PE VIA REANÁLISE ERA5-LAND

RESUMO: O balanço hídrico climatológico é uma ferramenta reconhecida para estimativa da disponibilidade hídrica. A utilização de dados provenientes de modelos atmosféricos globais,

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entre eles o ERA5-Land, vem sendo utilizada para estimar variáveis climáticas e obter séries históricas em localidades que não possuem estações meteorológicas próximas. Nesse sentido, este trabalho teve como objetivo estimar o balanço hídrico climatológico normal (NWB) e sequencial (SWB) em Palmares - PE, utilizando dados mensais de temperatura do ar e precipitação pluviométrica estimados pelo ERA5-Land de 2011 a 2020. As médias mensais dos dados foram calculadas para compor o NWB, enquanto, para o SWB utilizou-se as médias dos dados sequenciais anuais. O NWB forneceu informações detalhadas das seguintes variáveis: Precipitação, Evapotranspiração Potencial, Evapotranspiração Real, Deficiência Hídrica e Excesso Hídrico. O SWB proporcionou uma análise mais criteriosa dos valores extremos em comparação ao NWB. A evapotranspiração potencial foi superior a precipitação nos meses de agosto a abril, causando déficit de água no solo. Estes resultados recomendam o uso da irrigação suplementar a fim de evitar a redução no crescimento e, consequentemente, na produtividade das culturas.

PALAVRAS-CHAVES: Evapotranspiração, deficiência hídrica, planejamento agrícola, irrigação

INTRODUCTION

The Climatological Normal Water Balance (NWB) elaborated by Thornthwaite and Mather (1955) has become a very effective tool over the years to estimate the water availability of a given region to delimit and classify areas vulnerable to desertification (PASSOS et al., 2018). Thus, the NWB also influences the decision-making related to planting and harvesting times (ASCOLI et al., 2017; BISPO et al., 2017). On the other hand, sequential water balance (SWB) is a climatological identifier that has greater credibility when compared to NWB, because it has a greater capacity to determine severe periods of water deficiency (SOUZA et al., 2017). Marques & Teixeira (2019) highlight the importance of carrying out the integrated planning of water resources, implementing suitable irrigation systems, to mitigate the effects of soil water deficit.

The elaboration of the climatological water balance for a region is of fundamental importance, as it takes into account the aspects related to soil, depth effective plant root system and soil water dynamics during the period evaluated (MATOS et al., 2014). Carvalho et al. (2011) comment that through the estimation of the water balance is possible to determine the period of occurrence of water deficiency and of surplus, removal and replacement of water from the soil and the amount of water stored in it, through the monthly climatic elements, taken as input to the model, temperature of the air and rainfall.

In general, the database used to calculate the water balance comes from surface weather stations. However, the lack of a continuous series of climatological data compromises the quality of the resulting studies. As a result, alternatives have been assessed, among them, the global atmospheric reanalysis. This database is based on the observed data set of weather stations and mathematical forecasting models (PARKER, 2016; ESSOU et al., 2017). The ERA5-Land reanalysis has a spatial resolution of 10 km and a one-hour time. Thus, this study aimed to estimate the normal and sequential climatological water balance for the municipality of Palmares - PE, using monthly air temperature and precipitation data estimated by ERA5-Land reanalysis to provide information for the agricultural planning of the region

MATERIAL AND METHODS

The municipality of Palmares is in the south forest region of the state of Pernambuco (Figure 1), at 128 km from the capital Recife, at a latitude 8°41'00” S, longitude -35° 35' 30” W and altitude of 164 m. The climate is characterized as humid tropical with autumn-winter rainy, topography predominantly undulating, characterized by a set of hills that do not exceed 120 m in altitude (REIS NETO, 2016).

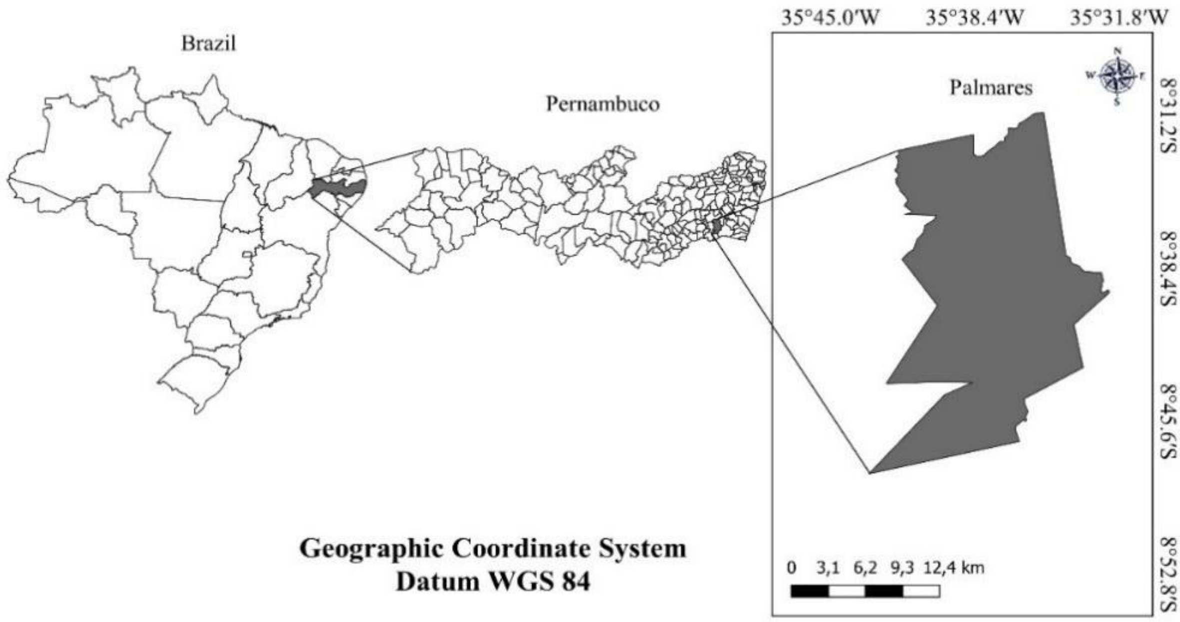

Figure 1. Location of the municipality of Palmares in the South Forest region of the state of Pernambuco.

The database used in this research was composed of the variables air temperature (T) and rainfall (P) recorded in the period from 2011 to 2020 in the municipality of Palmares, state of Pernambuco (PE). Air temperature and precipitation data were estimated by ERA5-Land atmospheric reanalysis produced by the European Center for Medium-Range Weather Forecast (ECMWF) through virtual stations. The air temperature reanalysis monthly data were converted from Kelvin to Celsius and rainfall data were converted from meters to millimeters. This climatic database needs to be validated based on surface data and, for this, data on air temperature (°C) and rainfall (mm) from the automatic meteorological station (AWS) belonging to the National Institute of Meteorology (INMET), located in the municipality of Palmares – PE, were used. The reanalysis data validation was performed by statistical indices of accuracy and precision, taking as standard the AWS data, which showed satisfactory results (Table 1).

Table 1. Statistical indices of the validation of ERA5-Land reanalysis data based on the automatic weather station in Palmares – PE.

Statistical indices	Temperature (°C)	Precipitation (mm)
$R^2_{adjusted}$	0.95	0.51
r	0.97	0.72
d	0.999	0.994
c	0.97	0.71
RMSE	0.69	88.26
MBE	-0.61	-25.01
MAE	0.61	56.37
[1]Index Ranking r	Very strong	Strong
[2]Index Ranking c	Very good	Good

$R^2_{adjusted}$: Adjusted coefficient of determination; r: Pearson correlation; d: Agreement Index (Willmott, 1981); c: Camargo & Sentelhas Performance Index (1997); RMSE: Root mean square error; MBE: Mean Bias Error; MAE: Mean absolute error; [1]Callegari-Jacques classification (2009); [2]Camargo & Sentelhas classification (1997).

The method proposed by Thornthwaite & Mather (1955) was used to obtain the normal and sequential water balance, using the spreadsheet in the Microsoft Excel® (ROLIM et al., 1998), to determine the following components: water deficit (DEF); water surplus (EXC); soil water storage (SWS), in addition to estimating potential evapotranspiration (ETP) and actual evapotranspiration (ETR). This methodology adopts the value of available water capacity (AWC) equal to 100 mm, since is a value that meets the water requirement of several perennial cycle crops, and because it is standard for climatic purposes and for characterization of regional water availability (MATOS et al., 2018; ABREU & TONELLO, 2016; DUARTE & SENTELHAS, 2019). In the normal water balance (NWB) the air temperature and rainfall of the reanalysis monthly averages were used. However, for sequential water balance (SWB) the annual means of the reanalysis were used.

RESULTS AND DISCUSSION

Figure 2 shows the normal climatological water balance for the municipality of Palmares - PE. The monthly average rainfall was 79 mm month^{-1}, and May, June and July were the rainier, with values ranging from 114 to 139 mm month^{-1}. As can be noticed, the precipitation meets the demand for potential evapotranspiration (ETP) only from May to July, since in August to April the precipitation volume is not enough to supply the ETP demand, resulting in a water deficit in the soil during this period.

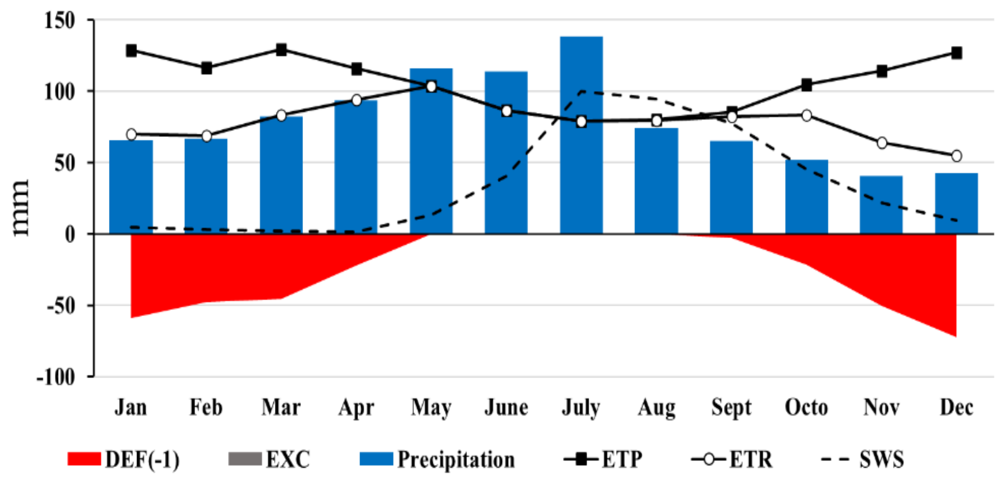

Figure 2. Normal climatological water balance for the municipality of Palmares - PE, between 2011 and 2020. DEF: Water deficiency; EXC: Water surplus; ETP: Potential evapotranspiration; ETR: Real evapotranspiration; SWS: Soil water storage.

The average sequential rainfall from 2011 to 2020 is 951 mm year^{-1}, with the largest volume of precipitation occurring in 2011 with 1314 mm year^{-1} (Figure 3A) and the smallest in 2012 (692 mm year^{-1}) (Figure 3B). According to Silva & Listo (2019), there were floods in 2010 and 2017 due to the Eastern Wave Disturbance (EWD) which is more common between May and August causing severe rains. In this research, this disturbance confirms the accumulated values (one year after the flood) of the average sequential rainfall in the year 2011 (1,314 mm year^{-1}) and 2017 (1,164 mm year^{-1}) (Figures 3A and 3G) respectively. Similarly, the average monthly rainfall from May to August 2011 (168 mm month^{-1}) and 2017 (165 mm month^{-1}) (Figure 2) which were the years and months rainy.

The ETP average monthly was 106 mm month^{-1}, with the lowest value of 79 mm month^{-1} observed in the coldest month (July, 22.1°C) and the highest ETP of 129 mm month^{-1} seen in the hottest month (March, 25.6°C). From 2011 to 2020, the sequential average ETP was 1,274 mm year^{-1}, with the lowest ETP (1,225 mm year^{-1}) in 2012 (Figure 3B) and in 2020 (Figure 3J) the largest ETP recorded (1,336 mm year^{-1}). The ETP monthly historical average is higher than the average precipitation, providing water deficiency in the soil because the output of water from the soil (ETP) is higher than the input (Precipitation) (Figure 2). The mean monthly of real evapotranspiration (ETR) was 79 mm month^{-1} with a minimum of 55 mm recorded in December and a maximum of 104 mm in May. The sequential average ETR is 884.33 mm month^{-1}, with the minimum of 691.59 mm month^{-1} at the 2012 (Figure 3B) and the maximum of 996.04 mm month^{-1} in 2011 (Figure 3A).

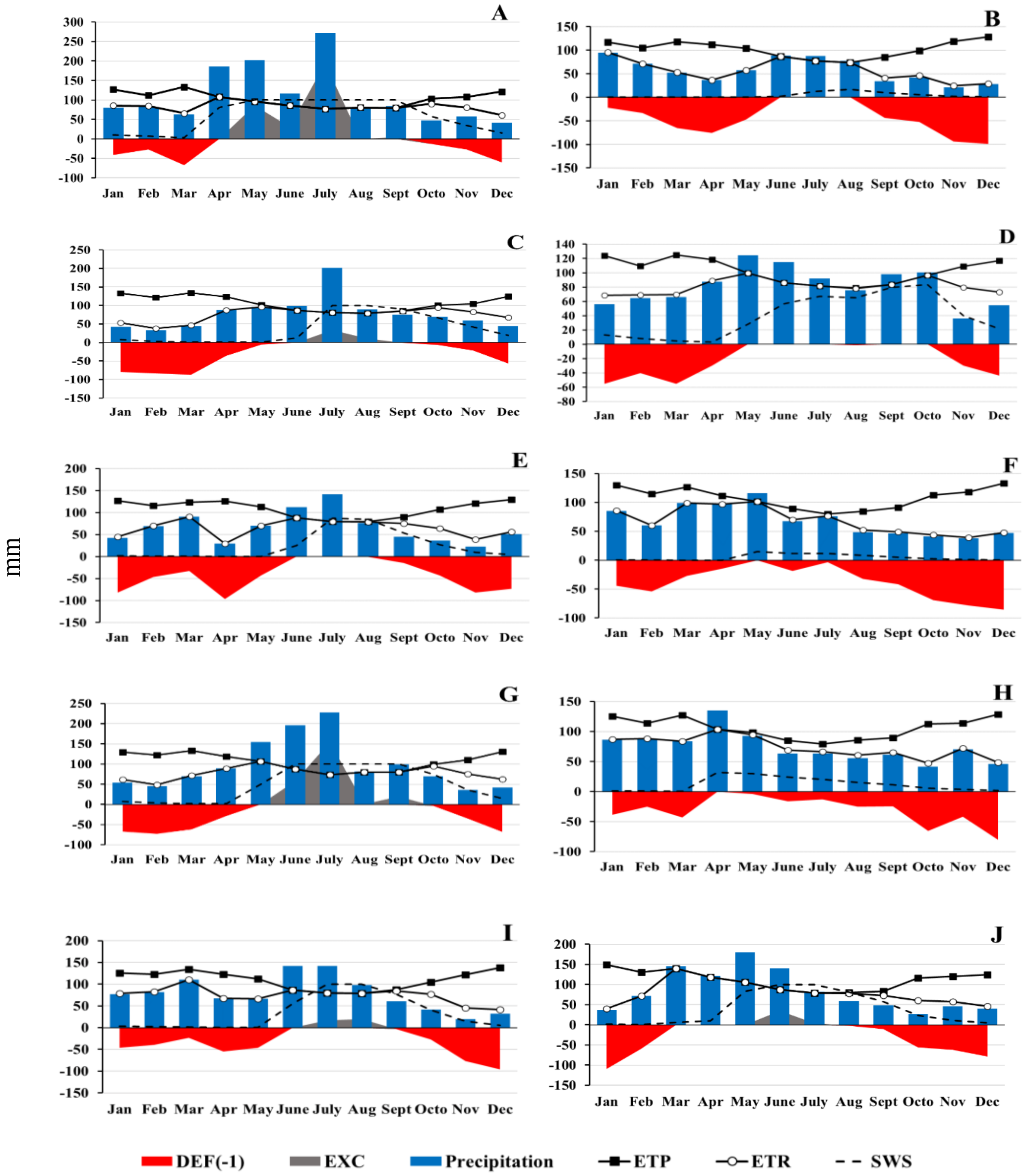

Figure 3. Sequential water balance for the municipality of Palmares - PE, between 2011 and 2020 (A to J, respectively). DEF: Water deficiency; EXC: Water surplus; ETP: Potential evapotranspiration; ETR: Real evapotranspiration; SWS: Soil water storage.

These results are similar to those reported by Feitosa (2013) analyzed the extreme precipitation climatic events in the period from 1980 to 2010 (30 years) in the same municipality, Palmares - PE, and concluded that the months from May to July were the rainier with averages ranging from 177 to 240 mm month^{-1}, and November and December those with the lowest averages of rainfall, 35 and 33 mm month^{-1}, respectively. The average rainfall for January, August to December (Figure 2) are lower than the values of real evapotranspiration, therefore, cultivate crops under rainfed conditions is not feasibly, requiring the use of irrigation systems with suitable management, to meet the water amount needed for the full crop development (PAULA et al., 2017).

The normal water balance shows that the average monthly water deficiency (DEF) was 27 mm month^{-1}, and the highest values were observed in January, February, March, November, and December (Figure 2). This DEF is the result of low water availability and high evaporative demand. Whereas, from May to July, no soil water deficit was detected, due to the higher water availability in these months, comprising the rainy season of this region. Medeiros (2018) elaborated the climatological balance for the municipality of Caruaru, state of Pernambuco, between 1913 and 2016, and found results similar to this work about water deficiency in August to May, with increased precipitation in June and July.

The sequential water balance for Palmares - PE, showed a mean annual water deficit (DEF) of -389 mm year^{-1}, with the largest soil water deficit (534 mm year^{-1}) observed in 2012 (Figure 3B) and the smallest (236 mm year^{-1}) in 2011 (Figure 3A). In 2016, in addition to having the greatest water deficit, no period of water surplus was observed either. Passos et al. (2017) and Silva & Silva (2016), state that the use of supplementary irrigation in cultivated areas is notorious, mainly in regions with eight to nine months under water deficit in the soil throughout the year. However, this region, even with a volume of rainfall necessary for the development of some crops, these rains are poorly distributed spatially, resulting in a soil with a negative water balance in most months of the year. However, this region, even with a volume of rainfall necessary for the development of some crops, these rains are poorly distributed spatially, resulting in a soil with a negative water balance in most months of the year. However, this region, even with a volume of rainfall necessary for the development of some crops, these rains are poorly distributed spatially, resulting in a soil with a negative water balance in most months of the year. According to the normal water balance (Figure 2), only in July, the water surplus (EXC) occurred, since it was the rainier month, while in August to December and January to June no excess of soil water was identified. By the sequential water balance, there was an average annual water surplus of 67 mm year^{-1}, and in 2012, 2014, 2015, 2016 and 2018 (Figures 3B, 3D, 3E, 3F, 3H, respectively), no excess soil water occurred. On the other hand, in 2011 the largest excess soil water (318 mm year^{-1}) occurred (Figure 3A). It can be noticed that in 2011 (post-flood) and 2017 (2nd flood) there were the highest average volumes of precipitation and consequently the largest excess water in the soil, while, in 2012, 2014, 2015, 2016 and 2018

(Figures 3B, 3D, 3E, 3F, 3H, respectively) had the lowest average rainfall volumes, as a result no excess was registered. The sequential water balance showed the highest soil water storage values (SWS) in 2011 (709 mm year^{-1}) and 2017 (587 mm year^{-1}) (Figures 3A and 3G, respectively), highlighting as the years with the highest water supply in the period studied. The annual average was 364 mm year^{-1}, with the lowest value found in 2016 (56 mm year^{-1}) due to high air temperature, and consequently higher potential evapotranspiration and lower precipitation. Similarly, Aparecido et al. (2020) used ten-year data from the ERA-Interim reanalysis to obtain spatial and seasonal water characterization in Mato Grosso do Sul between 1989 and 2015, and found annual soil water storage (SWS) values ranging from 130 to 1,200 mm.

CONCLUSIONS

The ERA5-Land reanalysis database was satisfactorily validated, accurately estimating the air temperature and precipitation for the municipality of Palmares, state of Pernambuco.

The normal water balance calculated based on the ERA5-Land database provided subsidies for the analysis of the Precipitation, Potential Evapotranspiration, Real Evapotranspiration, Water Deficiency, and Water Surplus. over the 10 years evaluated.

The sequential water balance provided annual detailed information of climate variables from 2011 to 2020, allowing the identification of extreme values and their variation over the years.

The potential evapotranspiration was higher than precipitation from August to April, causing soil water deficit during this period, requiring the implementation of supplementary irrigation to avoid the reduction in growth and, consequently, in crop productivity.

REFERENCES

ABREU, M. C.; TONELLO, K. C. Estimativa do balanço hídrico climatológico da bacia hidrográfica do rio Sorocaba - São Paulo. **Ambiência [online]**, v. 11, 2016.

ASCOLI, A. A.; HERNANDEZ, F. B. T.; SENTELHAS, P. C.; TEIXEIRA, A. H. C.; AMENDOLA, E. C.; ASCOLI, R. T. Necessidade de irrigação na cultura da cana-de-açúcar em função da época de colheita. In: INOVAGRI International Meeting, IV. 2017. **Anais**... Fortaleza, CE: ABID, 2017.

BISPO, R. C.; HERNANDEZ, F. B. T.; TEIXEIRA, A. H. C. Balanço hídrico e estimativa do consumo relativo de água da cultura da cana-de-açúcar na região noroeste paulista. **Irriga**, Edição Especial, IRRIGA & INOVAGRI, p. 94-101, 2017.

CALLEGARI-JACQUES, S. M. **Bioestatística: princípios e aplicações**. Tradução. [s.l.] Artmed Editora, 2009.

CAMARGO, A. P.; SENTELHAS, P. C. Avaliação do desempenho de diferentes métodos de estimativa da evapotranspiração potencial no estado de São Paulo, Brasil. **Revista Brasileira de Agrometeorologia**, v. 5, n. 1, p. 89-97, 1997.

CARVALHO, H. P.; DOURADO NETO, D.; TEODORO, R. E. F.; MELO, B. Balanço hídrico climatológico, armazenamento efetivo da água no solo e transpiração na cultura de café. **Biociência Jornal**, v. 27, n. 2, p. 221-229, 2011.

DUARTE, Y. C. N.; SENTELHAS, P. NASA/POWER and DailyGridded weather datasets-how good they are for estimating maize yields in Brazil? **International Journal of Biometeorology**. 2019.

ESSOU, G. R. C.; BRISSETTE, F.; LUCAS-PICHER, P. The use of reanalyses and gridded observations as weather input data for a hydrological model: comparison of performances of simulated river flows based on the density of weather stations. **Journal of Hydrometeorology**, v. 18, p. 497-513, 2017.

FEITOSA, A. Classificação dos eventos climáticos extremos de precipitação no período outono-inverno: um estudo de caso sobre suas ocorrências no município de Palmares, Zona da Mata, Pernambuco. **Revista Ambientale-UNEAL**, v. 1, n. 4, p. 19-29, 2013.

MARQUES, P. E.; TEIXEIRA, E. C. Sistema de apoio à decisão para alocação de água na agricultura irrigada em nível de microbacia hidrográfica. **Revista Iberoamericana del Agua[online]**, v. 6, n. 1, p. 63-77, 2019.

MATOS, R. M.; SILVA, J. A. S.; MEDEIROS, R. M. Aptidão climática para a cultura do feijão caupi do município de Barbalha - CE. **Revista Brasileira de Agricultura Irrigada**, v. 8, n. 6, p. 422-431, 2014.

MATOS, R. M.; SILVA, P. F.; BORGES, V. E.; SOBRINHO, T. G.; DANTAS NETO, J.; SABOYA, L. M. F. Potencial agroclimático para a cultura da mangueira no município de Barbalha - CE. **Revista Brasileira de Agricultura Irrigada [online]**, v. 12, 2018.

MEDEIROS, R. M. O balanço e o aquecimento no município de Caruaru - PE. **Revista Equador**, v. 7, n. 2, p. 126-146, 2018.

PARKER, W. S. Reanalyses and observations: What's the difference? **Bulletin of the American Meteorological Society**, v. 97, n. 9, p. 1565-1572. 2016.

PASSOS, M. L. V.; SOUZA, J. B. C.; MENDES, T. J. Balanço hídrico e classificação climática para o município de Turiaçu - MA. **Revista Agropecuária Científica no Semiárido**, v. 14, 2018.

PASSOS, M. L.V.; ZAMBRZYCKI, G. C.; PEREIRA, R. S. Balanço hídrico climatológico e classificação climática para o município de Balsas - MA. **Scientia Agraria [online]**, v. 18, n. 1, p. 83-89, 2017.

REIS NETO, A. F. **Potencialidades e limitação para aplicação da Redução do Desmatamento e da Degradação Florestal (REDD) na mata atlântica pernambucana**. Dissertação (Mestrado pelo Programa de Pós-graduação em Desenvolvimento e Meio Ambiente) - Universidade Federal de Pernambuco, Recife, 2016, 103p.

ROLIM, G. S.; SENTELHAS, P. C.; BARBIERI, V. Planilha em ambiente EXCELTM para os cálculos de balanços hídricos: normal, sequencial, de cultura e de produtividade real e potencial. **Revista Brasileira de Agrometereologia**, v. 6, n. 1, p. 131-139, 1998.

SILVA, A. F.; SILVA, M. C. B. C. Agricultura no nordeste semiárido e os resíduos orgânicos aproveitáveis. **Revista equador**, v. 5, n. 2, p. 102-119, 2016.

SILVA, L. L.; LISTO, F. L. R. Inundações severas no município de Palmares - PE: uma análise comparativa preliminar dos eventos de 2010 e 2017. **Revista GeoUECE (Online)**, v. 8, n. 14, p. 329-350, 2019.

SOUZA, M. H. C.; SANTOS, R. D. S.; VENTURA, K. M.; BISPO, R. C.; BASSOI, L. H. Balanço hídrico normal e sequencial para o município de Petrolina. IV INOVAGRI International Meeting, **Anais...** Fortaleza - CE, Brasil. 2017.

THORNTHWAITE, C. W.; MATHER, J. R. **The water balance**. Publication in Climatology 8, Laboratory of Climatology, Centerton, N. J. 1955

WILLMOTT, C. J. On the validation models. **Physical Geography,** v. 2, n. 2, p. 184-194, 1981.