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PROBABLE PRECIPITATION AND REFERENCE EVAPOTRANSPIRATION IN THE STATE OF PARANÁ, SOUTHEST BRAZIL

BRUNO CESAR GURSKI[1]; JORGE LUIZ MORETTI DE SOUZA[1]; ALEXANDRE CANDIDO XAVIER[2]; STEFANIE LAIS KREUTZ ROSA[1]

[1] Departament of Soil and Agricultural Engineering, Federal University of Paraná, Rua dos Funcionários, 1540, Cabral, CEP 80035-050, Curitiba, Paraná, Brazil. E-mails: brunocep@gmail.com; jmoretti@ufpr.br; skreutzrosa@gmail.com.
[2] Departament of Rural Engineering, Federal University of Espírito Santo, Rua Alto Universitário, s/n, CEP 29500-000, Alegre, Espírito Santo, Brazil. E-mail: candido-xavier@ufes.br.

1 ABSTRACT

We aimed to determine the reference evapotranspiration (ETo) and precipitation (P) for different probabilities of occurrence in Paraná State and to determine the probability density functions (pdf's) of better adjustment to these variables and their parameters. The climatic data (1980 to 2013; 34 years) were spatialized with the best interpolator, obtained by cross-validation, in a regular grid of 0.25º x 0.25º. The ETo was calculated daily by the Penman-Monteith method. The daily ETo and P data were summed and grouped in ten days. Frequency distributions and Kolmogorov-Smirnov adhesion tests at 5% probability were applied to ETo and P, to perform the adjustment to pdf's (Exponential, Gamma, Normal, Triangular and Uniform) for the grid. Probable values of P at 50, 75 and 90% and ETo at 50, 25 and 10% were determined. The probable values were interpolated by ordinary kriging. The pdf's Gamma and Exponential were the ones that best fit the probable P, while Gamma and Normal were better for ETo. Probable P was higher in the littoral and southeast, and there was a growth in the ETo, independent of the probability level and season of the year, from the southeast region to the northwest of the Paraná State.

Keywords: probability density function, water components, spatialization, ten days.

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PRECIPITAÇÃO PLUVIOMÉTRICA E EVAPOTRANSPIRAÇÃO DE REFERÊNCIA PROVÁVEIS NO ESTADO DO PARANÁ, SUL DO BRASIL

2 RESUMO

Teve-se por objetivo no presente trabalho determinar evapotranspiração de referência (ETo) e precipitação (P) para diferentes probabilidades de ocorrência no estado do Paraná e determinar funções densidade de probabilidade (fdp's) de melhor ajuste a estas variáveis e seus parâmetros. Os dados climáticos (1980 a 2013; 34 anos) foram espacializados com o melhor interpolador, obtido por validação cruzada, em grid regular de 0,25º x 0, 25º. A ETo foi calculada diariamente pelo método de Penman-Monteith. Os dados diários de ETo e P foram somados e agrupados em decêndios. Foram realizadas distribuições de frequência e testes de aderência de Kolmogorov-Smirnov a 5% de probabilidade para ETo e P para realizar o ajustamento às fdp's

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(Exponencial, Gama, Normal, Triangular e Uniforme) para o grid. Determinou-se os valores decendiais prováveis de P a 50, 75 e 90% e ETo a 50, 25 e 10%. Os valores decendiais prováveis foram interpolados por krigagem ordinária. As fdp's Gama e Exponencial foram as que melhor se ajustaram à P, enquanto Gama e Normal à ETo. A P provável foi maior no litoral e sudeste, e houve crescimento na ETo, independentemente do nível de probabilidade e estação do ano, da região sudeste para a noroeste do estado Paraná.

Palavras-chave: função densidade de probabilidade, componentes hídricas, espacialização, decêndios.

3 INTRODUCTION

The probable reference evapotranspiration (ETo) or precipitation (P) refers to the minimum evapotranspiration or expected rainfall in a given period of the year, for a given level of probability. The study of the trend and distribution of ETo and P is important for the understanding and determination of critical periods, being relevant in the planning and rational management of agricultural production (RIBEIRO; FERREIRA JUNIOR; SILVA, 2013; DIAS et al., 2015; VICENTE-SERRANO et al., 2015). In addition, several authors recommend the use of probable ETo and P in the sizing of agricultural projects, since the use of mean values may result in errors (SILVA et al., 2015; ANAPALLI et al., 2019; FERNANDES et al., 2019).
Probabilistic studies of the distribution of ETo and P show that their occurrences consist of random phenomena influenced by geographical location. For this reason, many manuscripts are limited to studying small regions, such as cities, which does not contribute to macroplanning. This situation has been occurring in the State of Paraná. Another difficulty in studying the water components in macroregions refers to obtaining consistent and long series of climatic data, without failures or oscillation in the number of years, and having the same instrumental measurement standard (SOUZA; JERSZURKI; DAMAZIO, 2013; JERSZURKI; SOUZA; EVANGELISTA, 2015a; JERSZURKI; SOUZA; EVANGELISTA, 2015b; PAULO; MARTINS; PEREIRA, 2016). In this way, studies in large regions that minimize these problems should be prioritized and valued (STAGGE et al., 2015; VICENTE-SERRANO et al., 2015).

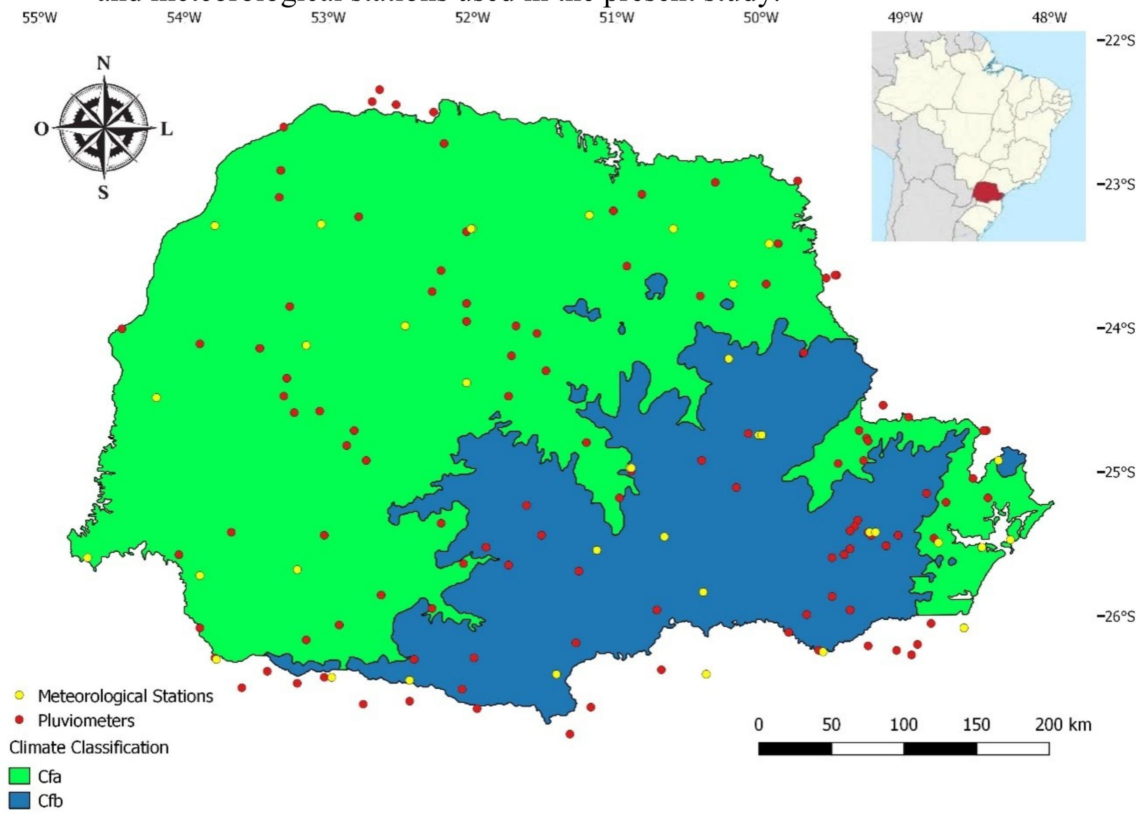
Another difficulty of the studies is to establish the levels of probability to be used. Based on the ETo, for risk minimization and adequate elaboration of agricultural projects, values with a 25% probability of being matched or exceeded are recommended, which corresponds to a return period of 1.33 years (DOORENBOS; PRUITT, 1977; VICENTE-SERRANO et al., 2015). For P, the recommendation is that should not work with probabilities lower than 75% or 80%, because the level of 75% represents the minimum amount of P that is expected to occur in three of four years (RIBEIRO; FERREIRA JUNIOR; SILVA, 2013; SOUZA; JERSZURKI; DAMAZIO, 2013). Jensen (1974) comments that the highest levels of probability (80% to 90%) are selected for crops of great economic value and low available water conditions in the soil. Doorenbos and Pruitt (1977) consider that probability levels should be between 75% and 80% in most irrigated regions. According to Wang et al. (2012), under the conditions of supplementary irrigation, it is hardly economically justified to adopt levels higher than 90%, usually using levels ranging from 50% to 75%.
Due the considerations previously set forth, we aimed to determine P and ETo for different probabilities of occurrence in the

State of Paraná, as well as to determine the probability density functions of better adjustment to these variables and their parameters in order to subsidize future planning and studies in the region.

4 MATERIAL AND METHODS

The State of Paraná is located in the Southern Brazil and its area is 199,307,922 km². There are two predominant climatic types (Figure 1), according to Köppen's classification: Cfa and Cfb (MAACK, 2012). The subtropical climate Cfa has a good distribution of rainfall, average annual temperature of 19 °C and rainfall of 1500 mm per year. The subtropical climate Cfb has good distribution of rainfall during the year and mild summers. The average annual temperature is 17 °C and rainfall is over 1200 mm per year (ALVARES et al., 2013).

Figure 1. Köppen climatic classification for the State of Paraná, and location of rain gauges and meteorological stations used in the present study.

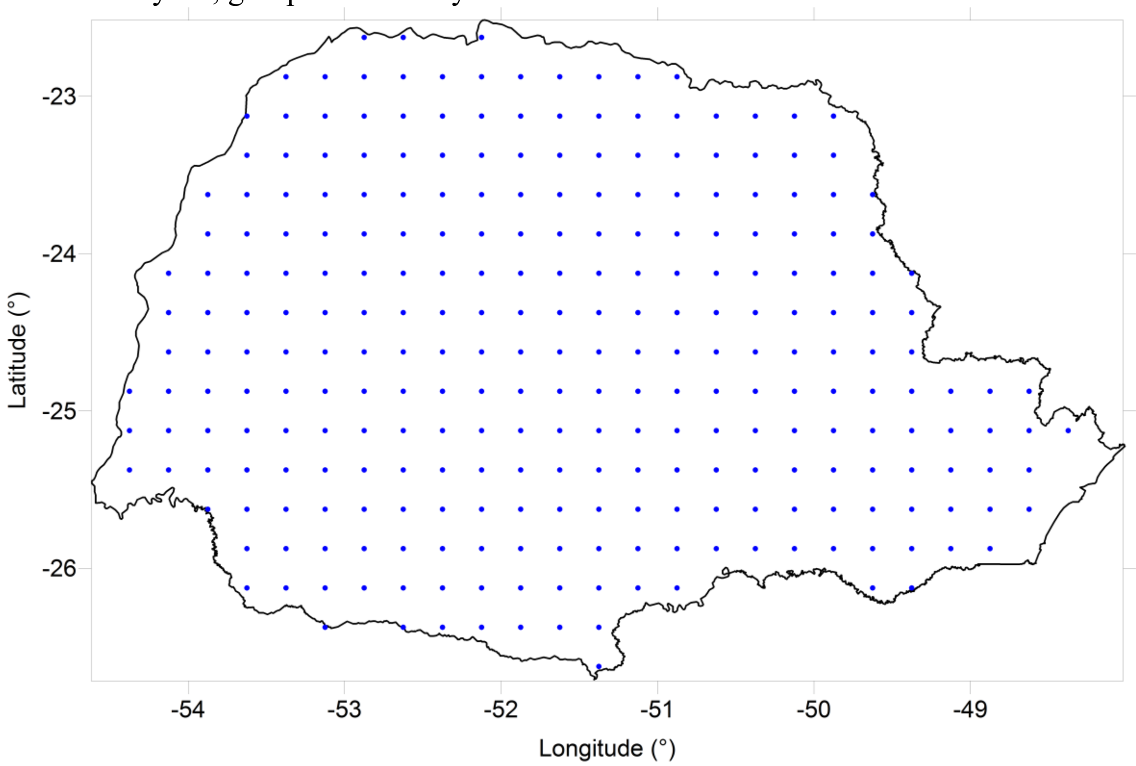


Source: Adapted from Instituto de Terras Cartografias e Geociências (2006)

The daily meteorological data used came from pluviometers (151 units), as well as conventional and automatic meteorological stations (38 units) (Figure 1), from January 1, 1980 to December 31, 2013 (34 years). The data sources were the "National Institute of Meteorology" (INMET) and the "National Water Agency" (ANA). ANA data were limited to precipitation (P). The INMET data were composed of: maximum (Tmax, °C), minimum (Tmin; ° C) and average (Tav; °C) air temperatures; relative humidity (RH; %); wind speed at 2 m height (U_2; m s^{-1}); precipitation (P; mm); daily solar brightness (n; hours) of conventional meteorological stations; and daily incident solar radiation (Rs; MJ m^{-2}) of automatic stations.

Several interpolators were tested to spatialize the meteorological data: inverse distance weighting; ordinary kriging; spline; natural interpolation; arithmetic mean. The best interpolator was obtained through cross-validation, and the meteorological data were spaced in a regular grid of 0.25º x 0.25º, covering the entire state of Paraná (XAVIER; KING; SCANLON, 2015). As a result, daily meteorological data (34 years) (P, Tmax, Tmin, Tav, RH, U_2, n, Rs) were obtained for the regular grid (Figure 2). The ETo was calculated on a daily basis using the Penman-Monteith method (ALLEN et al., 1998).

Figure 2. Regular grid of 0.25º x 0.25º, containing the 279 points in the State of Paraná, where daily values of reference evapotranspiration (ETo) and precipitation (P) were analyzed, grouped in ten days.



Source: The Autor

Considering the methodological procedures of Souza, Jerszurki and Damazio (2013), the following steps were performed to calculate the probability of occurrence of precipitation (P) and reference evapotranspiration (ETo):

a) Grouping of the daily values of P and ETo in periods of ten days;

b) Establishment of frequency distributions with observed series data;

c) Calculation of the statistical parameters of the probability density functions (pdf's) – Exponential, Gamma, Normal, Triangular and Uniform – with series of ten days values;

d) Verification of the adherence of the ten days periods values to the five pdf's with the Kolmogorov-Smirnov test at 5% probability;

e) Choice of the pdf that best fit every observed ten days period;

f) Determination of the probable values with different levels of probability of occurrence.

The daily values of P and ETo were organized in 37 ten days periods per year. The thirty-seventh ten days period of each year was composed of five or six (leap year) last days of the year. In the case of P, the daily data were tabulated and grouped, separating the ten days periods with value equal to zero from nonzero. To avoid inconsistencies in the estimation of the parameters of the pdf's used, the values less than 1 mm were considered zero.

The pdf's (Gamma, Normal, Exponential, Triangular and Uniform) were chosen based on the adhesion already obtained in similar regions (SAMPAIO et al., 2006; SOUZA; JERSZURKI; DAMAZIO, 2013) and on authors' propositions for analysis of phenomena in areas using long time series (FARAHMAND; AGHAKOUCHAK, 2015). The statistical parameters determined: alpha and beta for the Gamma distribution; mean and standard deviation for Normal; higher value, lower value and mode for Triangular; mean for Exponential; and higher and lower value for Uniform (ASSIS; ARRUDA; PEREIRA, 1996; BUSSAB; MORETTIN, 2010).

Since some of the pdf's analyzed do not admit null values, was adopted the concept of mixed distribution (ASSIS; ARRUDA; PEREIRA, 1996):

$$F(P) = P_o + (1 - P_o) \times D(P) \qquad (1)$$

where: F(P) is the cumulative probability function of the mixed distribution (%); P_o is the probability of occurrences of ten days periods with value equal to zero (%) or values less than 1 mm; and D(P) is the estimated probability with the best cumulative theoretical cumulative distribution, whose parameters were determined in the absence of ten days periods with value equal to zero (%).

The adherence of the decennial values to the pdf's was obtained by the Kolmogorov-Smirnov test at 5% probability. The test evaluates from Dmax value, the adjustment between the theoretical accumulated frequency distribution *F'(x)* and another, *F(x)*, from the sampled data.

$$D_{max} = Max|F(x) - F'(x)| \qquad (2)$$

where: Dmax is the critical value for the Kolmogorov-Smirnov statistic; F(x) is the theoretical probability distribution function; and F'(x) is the observed probability distribution function.

After adjusting the adherence of the pdf that best fitted to P and ETo, for each ten days period, the probable ten days periods values of precipitation were determined at 50, 75 and 90% probability ($P_{50\%}$, $P_{75\%}$, $P_{90\%}$), respectively (Equations 3 to 5), as well as, from ETo at 50, 25 and 10% probability ($ETo_{50\%}$, $ETo_{25\%}$, $ETo_{10\%}$), respectively (Equations 6 to 8), for each locality (Figure 2) of the regular grid:

$$P_{50\%} = P(P_{50\%} \in P|P_i \geq P_{50\%}) = 50\%) \qquad (3)$$

$$P_{75\%} = P(P_{75\%} \in P|P_i \geq P_{75\%}) = 75\%) \qquad (4)$$

$$P_{90\%} = P(P_{90\%} \in P|P_i \geq P_{90\%}) = 90\%) \qquad (5)$$

$$ETo_{10\%} = P(ETo_{10\%} \in ETo|ETo_i \geq ETo_{10\%}) = 10\%) \qquad (6)$$

$$ETo_{25\%} = P(ETo_{25\%} \in ETo|ETo_i \geq ETo_{25\%}) = 25\%) \qquad (7)$$

$$ETo_{50\%} = P(ETo_{50\%} \in ETo|ETo_i \geq ETo_{50\%}) = 50\%) \qquad (8)$$

Therefore, for each ten days period, $P_{75\%}$ refers to the value of P_i that has a 75% probability of being equalized or exceeded, which corresponds to the probability that precipitation Pi occurs three times every four years or with a return period T = 1.33 years, on average. For each ten days period, $ETo_{25\%}$ refers to the evapotranspiration value ETo_i that has a 25% probability of being equalized or exceeded, which corresponds to the probability of evapotranspiration ETo_i occurring once every four years or with return period T = 4 years, on average.

With the probable ten days period values calculated were generated ETo and P maps for the entire State of Paraná. The maps were generated from the interpolation of the probable data obtained from ETo and P. The method used for data interpolation was ordinary kriging, using a grid of 1000 by 637 lines.

5 RESULTS AND DISCUSSION

Several pdf's have been used to study the ETo and P, presenting variability regarding the adequacy of the historical series. The pdf's Gamma and Exponential adjusted better (approximately 85%) to the historical series of P, while Gamma and Normal (approximately 92%) for ETo (Table 1). It should be noted that there was an adjustment of at least one pdf in all ten days periods of all years evaluated.

Table 1. Frequency of probability density functions (N - Normal; G - Gamma; T - Triangular; E - Exponential; U - Uniform) of best fit for precipitation (P) and reference evapotranspiration (ETo), in the State of Paraná.

Ten days periods	Best fit for *P*					Best fit to *ETo*				
	N	G	T	E	U	N	G	T	E	U
1	30	222	3	24	0	211	24	44	0	0
2	109	123	22	11	14	92	166	12	0	9
3	27	210	8	34	0	141	99	36	0	3
4	99	161	11	2	6	87	137	55	0	0
5	76	184	9	8	2	68	191	16	0	4
6	89	168	10	4	8	174	74	29	0	2
7	43	181	8	47	0	151	118	8	0	2
8	11	198	5	63	2	204	58	17	0	0
9	15	136	14	112	2	41	131	58	0	49
10	29	201	5	44	0	190	76	13	0	0
11	58	151	41	19	10	75	202	2	0	0
12	1	135	0	143	0	114	155	10	0	0
13	2	124	4	149	0	83	167	6	0	23
14	7	117	3	152	0	200	64	7	0	8
15	8	178	5	88	0	95	178	6	0	0
16	2	208	0	69	0	117	161	1	0	0
17	13	151	6	109	0	59	203	11	0	6
18	0	169	0	110	0	124	133	20	0	2
19	2	155	0	122	0	58	208	13	0	0
20	0	119	1	159	0	22	250	7	0	0
21	51	129	11	82	6	160	105	1	0	13
22	5	177	1	96	0	32	245	2	0	0
23	0	180	0	99	0	28	249	2	0	0
24	2	136	2	139	0	169	48	62	0	0
25	14	132	0	133	0	150	89	9	0	31
26	61	129	21	59	9	71	184	21	0	3
27	31	215	6	26	1	170	93	12	0	4
28	5	135	2	137	0	82	142	15	0	40
29	48	185	11	34	1	147	115	17	0	0
30	50	184	12	33	0	190	82	3	0	4
31	132	120	17	3	7	136	130	13	0	0
32	43	175	28	31	2	44	223	12	0	0
33	21	231	5	22	0	212	13	54	0	0
34	39	192	13	35	0	170	91	18	0	0
35	50	192	13	23	1	155	96	2	0	26
36	38	181	1	59	0	121	150	4	0	4
37	4	185	5	85	0	96	179	4	0	0
Sum	1215	6169	303	2565	71	4439	5029	622	0	233
Percentage (%)	11.8	59.8	2.9	24.8	0.7	43.0	48.7	6.0	0.0	2.3

Similar results for P were found by Sampaio et al. (2006), who analyzed the monthly $P_{75\%}$ for Paraná, and Souza, Jerszurki and Damazio, (2013), for ten days period values in several Brazilian regions, as well as by Paulo, Martins and Pereira (2016) and Stagge et al. (2015), who tested the functions Gamma, Gumbel, Logistics, Log-Logistics, Lognormal, Normal and Weibull for the whole Europe.

Many studies have shown that pdf Gamma is the one that best applies to studies involving probable precipitation (RIBEIRO; FERREIRA JUNIOR; SILVA, 2013; STAGGE et al., 2015; PAULO; MARTINS; PEREIRA, 2016). According to Dale (1968), the pdf Gamma has a good fit for continuous variables that have a lower limit equal to zero and do not have an upper limit and therefore is widely used for the study of historical series of precipitation. However, Souza, Jerszurki and Damazio (2013), Jerszurki, Souza and Evangelista, (2015a) and Jerszurki, Souza and Evangelista (2015b) verified the adherence of other pdf's, especially when the historical series of daily rainfall data (extensive or short) shows few records with precipitation above 1 mm in the period, as in dry and summer periods. These peculiarities in the application of the adhesion tests occurred because although the Paraná had high average P (1799mm $year^{-1}$), there were not usual pdf's (Triangular, Uniform) that had a good fit, despite the low percentage expression in relation to the total (Table 1). The Normal and Exponential pdf's were also antagonistic, since in the periods of low rainfall (ten days periods 12 to 25, autumn and winter), many days had P = 0, and the adjustment to Normal was lower.

For Pruitt, Oettingen, Morgan (1972) and Fernandes et al. (2019) the most used pdf's for adjusting ETo are Normal, Gamma, Beta, Weibull and Gumbel. For Silva et al. (2015), Gamma and Normal are the only pdf's that deserves prominence, especially in the design of irrigation systems. Such information is in agreement with the results obtained this manuscript. In the analyzes performed, no adjustment to the Exponential distribution was observed due to the nature of the evapotranspiration phenomenon.

The parameters of the best fit pdf's for the 37 ten days periods of the year, in the regular grid of 0.25º x 0.25º containing the 279 points in the State of Paraná, as well as the probable values of P and ETo for any probability (1% to 99%), are available for consultation in Gurski (2018). These data have several applications such as support activities and decisions aimed at hydrographic basin planning, power generation, water supply, agricultural activities, irrigation management, agricultural crop forecasting, definition of agricultural zoning, among other applications (RIBEIRO; FERREIRA JUNIOR; SILVA, 2013; SOUZA; JERSZURKI; DAMAZIO, 2013; SILVA et al., 2015; FERNANDES et al., 2019).

The average value of P decreased substantially as more restrictive probability was adopted, while in ETo this aspect was not observed (Table 2). On average, the only condition tested in which it did not provide water deficit (P > ETo) was in the 50% probability. Even so, there were still decennials in which $P_{50\%}$ was lower than $ETo_{50\%}$. Many authors (RIBEIRO; FERREIRA JUNIOR; SILVA, 2013; SOUZA; JERSZURKI; DAMAZIO, 2013; SILVA et al., 2015; VICENTE-SERRANO et al., 2015) argue that $P_{50\%}$ should not be used in agricultural planning and irrigation system design because it can generate substantial economic losses in detriment of low yield due the water deficit.

Table 2. Ten days period averages of precipitation (P; mm ten days period^{-1}) and reference evapotranspiration (ETo; mm ten days period^{-1}), considering the 279 points in the State of Paraná.

Ten days period	$P_{average}$	$P_{50\%}$	$P_{75\%}$	$P_{90\%}$	$ETo_{average}$	$ETo_{50\%}$	$ETo_{25\%}$	$ETo_{10\%}$
1	57.20	48.9	28.4	15.3	42.34	42.4	46.7	50.5
2	69.69	62.5	33.7	13.5	41.39	41.2	45.4	49.3
3	64.16	52.6	28.4	13.9	40.05	40.0	43.7	46.9
4	61.46	54.2	29.9	11.7	40.14	39.8	43.9	47.7
5	65.47	58.5	34.9	18.3	37.85	37.7	41.3	44.7
6	55.72	51.0	31.3	17.0	37.28	37.2	40.4	43.2
7	40.86	32.9	16.8	6.9	38.02	37.9	41.4	44.5
8	45.40	36.2	19.2	9.4	34.71	34.7	37.9	40.7
9	44.32	30.6	12.2	2.9	33.08	32.8	36.3	39.2
10	34.38	26.1	12.2	4.1	31.21	31.2	33.5	35.6
11	46.55	36.7	17.1	3.9	28.07	27.9	30.9	33.8
12	52.95	29.7	8.2	0.5	24.84	24.7	27.5	30.0
13	39.22	21.1	5.0	0.2	22.37	22.3	24.6	26.8
14	57.50	33.7	9.6	0.7	19.46	19.4	21.4	23.2
15	52.79	34.4	12.6	1.9	18.10	18.0	19.9	21.7
16	37.90	24.2	8.8	1.9	16.86	16.8	18.8	20.7
17	45.78	27.1	7.7	1.0	16.84	16.7	18.8	20.7
18	54.65	31.0	8.9	1.1	16.27	16.2	18.0	19.8
19	38.52	22.9	7.1	0.8	17.82	17.6	20.0	22.2
20	41.68	21.5	4.8	0.2	18.40	18.2	20.6	23.0
21	33.35	19.6	5.2	0.5	20.13	20.0	22.6	24.8
22	33.77	13.9	2.3	0.1	22.06	21.9	24.5	27.0
23	33.55	11.3	1.4	0.1	24.79	24.5	27.9	31.2
24	38.71	12.0	1.0	0.1	27.13	27.2	30.5	33.4
25	39.05	19.7	3.9	0.2	29.40	29.3	33.1	36.5
26	47.47	31.8	8.7	0.6	30.45	30.1	34.7	39.0
27	56.42	43.8	21.1	7.1	30.60	30.5	33.9	36.9
28	58.33	41.4	18.0	6.3	32.13	31.9	36.1	39.7
29	59.43	49.6	26.9	12.3	34.59	34.5	37.4	40.1
30	57.16	48.8	27.2	13.3	36.44	36.4	39.8	42.8
31	49.79	45.4	26.1	11.3	39.39	39.3	42.6	45.6
32	51.16	42.0	21.6	8.8	40.87	40.6	44.7	48.5
33	43.27	34.3	17.4	7.2	43.03	43.2	46.7	49.8
34	50.34	40.6	20.9	8.9	43.42	43.4	47.2	50.8
35	58.17	50.0	28.8	14.4	41.55	41.5	45.0	48.1
36	50.40	40.4	20.8	9.2	43.42	43.3	47.1	50.6
37	33.35	21.9	8.5	1.6	21.86	21.7	24.5	27.2
Mean	48.65	35.2	16.1	6.1	30.71	30.6	33.8	36.7
Sum	1799.92	1302.5	596.4	226.8	1136.39	1131.9	1249.2	1356.3

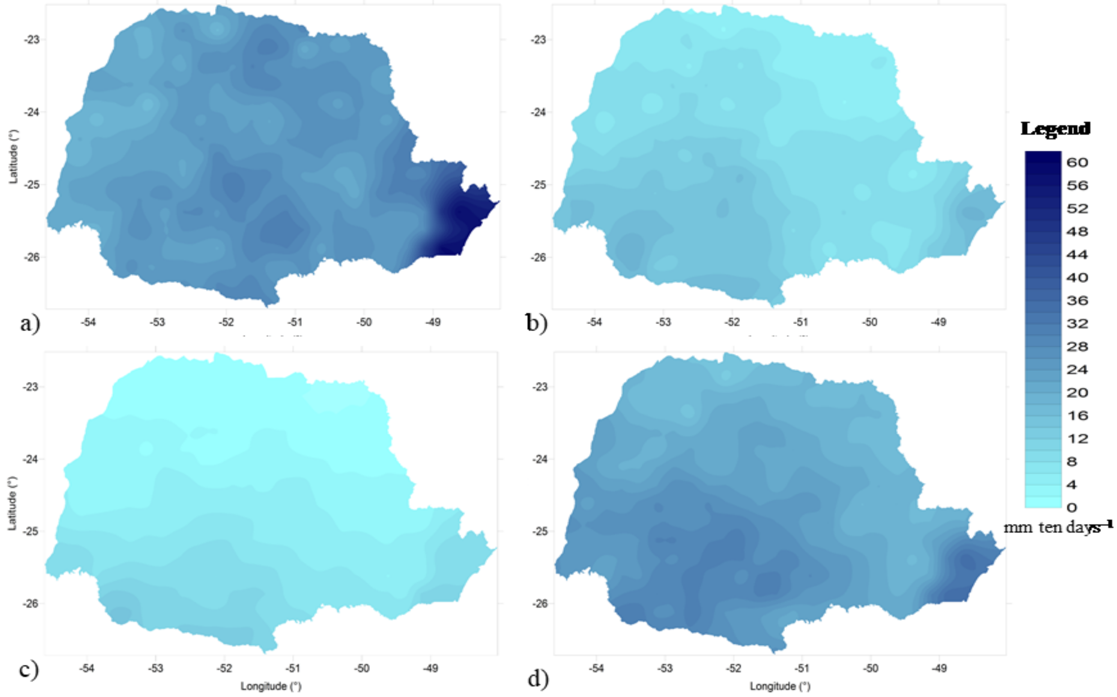
The average P and ETo were not always equal to the values of $P_{50\%}$ and $ETo_{50\%}$, respectively, especially when the two components adjusted better to some pdf other than Normal (Table 2). This aspect is important, since they are cases where the mean does not reflect the probable value at 50% probability. The adjustment to others pdf's, other than Normal, makes it possible to obtain more reliable probable values.

The $P_{90\%}$ condition proved to be extremely restrictive to agricultural cultivation. In the period between autumn and winter (ten days periods 12 to 26; 140 days) it was found P < 2 mm ten days period^{-1}. According to Wang et al. (2012), under the conditions of the irrigation system design it is hardly economically justified to adopt $P_{90\%}$. The intermediate combination ($P_{75\%}$ - $ETo_{25\%}$), on average, also showed a restrictive condition, and water use was more than twice higher than water replenishment in the system. The situation generates warnings to study more deeply the water components throughout the year and the place where they occur in the State of Paraná. Another important issue that deserves further studies is the evapotranspiration in agricultural crops, which is more variable than ETo throughout the plant cycle.

The mentioned probability levels ($P_{75\%}$ and $ETo_{25\%}$) are the most used and recommended by the literature (DOORENBOS; PRUITT, 1977; RIBEIRO; FERREIRA JUNIOR; SILVA, 2013; SOUZA; JERSZURKI; DAMAZIO, 2013; VICENTE-SERRANO et al., 2015) to design irrigation systems, considering reasonable levels of safety and cost. Each irrigation project will have its peculiarities, but a more restrictive levels should only be adopted for crops with high added value or low soil water availability (JENSEN, 1974; WANG et al., 2012). For example, the Northwest of Paraná has sandy soils, with low water storage, but with higher temperatures and consequently greater evapotranspiration. Perhaps in this region higher levels of probability ($P_{90\%}$ and $ETo_{10\%}$) should be considered. In contrast, in the southeastern region of the state, the scenario is reversed, and less restrictive probability levels can be adopted ($P_{50\%}$ and $ETo_{50\%}$).

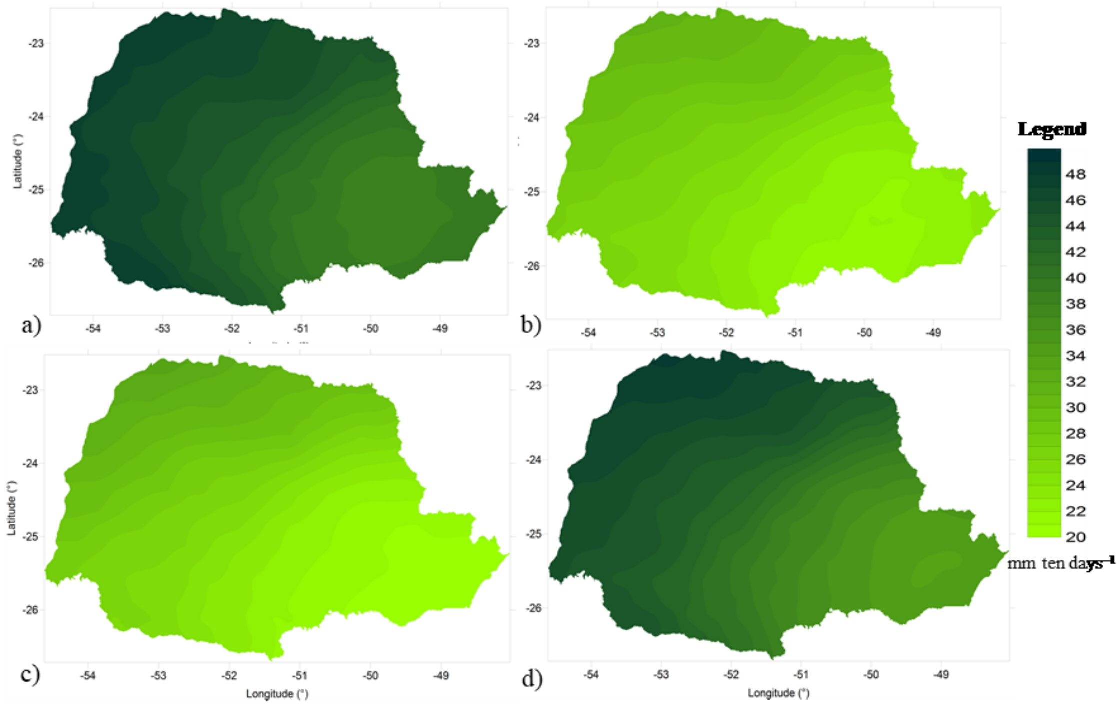
The probable average P was higher in the coast and southwest of the state of Paraná, regardless of probability (Figure 3), because they are regions that have lower elevations in state relief, and the Cfb climate type is more wet (ALVARES et al., 2013). There was a growth in values (mm ten days period^{-1}) of the probable average total ETo, regardless of the probability level, from the southeast region to the northwest of the state (Figure 4).

Figure 3. Probable average of ten days period of precipitation at 75% ($P_{75\%}$) in the state of Paraná, in the seasons: a) summer; b) autumn; c) winter; and d) spring.



Source: The Autor

Figure 4. Probable average of ten days period of reference evapotranspiration at 25% ($ETo_{25\%}$) in the State of Paraná, in the seasons: a) summer; b) autumn; c) winter; and d) spring.



Source: The Autor

The ETo trend in Paraná was highly correlated with its climatic classification (Figure 1). From the southeast to the northwest, the temperature tends to increase, but above all, the thermal amplitude increases, causing a great deficit of vapor pressure, increasing the ETo (ALLEN et al., 1998; JERSZURKI; SOUZA; SILVA, 2017). The lowest values of ETo occurred on the coast and in the region of Curitiba (southeast) due to lower wind velocity (U_2) and higher relative humidity (RH) throughout the year. The combination of U_2 and RH generates a low vapor pressure deficit in both regions, reducing the evapotranspiration demand at the plant-atmosphere interface. In addition, another factor that may have influenced is the solar radiation, which is lower in the southeast compared to the northeast of the state (DIAS et al., 2015).

6 CONCLUSIONS

The probability density functions (pdf's) Gamma and Exponential were the ones that best fit to the ten days period of precipitation, while the pdf's Gamma and Normal fit better to the reference evapotranspiration (ETo).

The probable precipitation (P) was higher on the coast and southeast. The increase in ETo, regardless of probability level and season, occurs from the southeast region to the northwest of the State of Paraná.

The pdf's parameters of best fit made it possible to provide much data and values of P and ETo for any probability (1% to 99%), being a fast and useful tool for agricultural planning in the State of Paraná.

The probability levels $P_{75\%}$ and $ETo_{25\%}$ are the most used and recommended by the literature to design irrigation systems, considering reasonable levels of safety and cost. However, considering the characteristics of the Northeast region of Paraná, a more restrictive levels of probability ($P_{90\%}$ and $ETo_{10\%}$) can be adopted and in the Southeast region less restrictive ($P_{50\%}$ and $ETo_{50\%}$).

7 REFERENCES

ALLEN, R. G.; PEREIRA, L. S.; RAES, D.; SMITH, M. **Crop evapotranspiration**: guidelines for computing crop water requirements. 1. ed. Rome: FAO, 1998.

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. J.; GONÇALVES, J. L. M.; SPAROVEK, G. Koppen's climate Classification map for Brazil. **Meteorologische Zeitschrift**, Stuttgart, v. 22, n. 6, p. 711-728, 2013.

ANAPALLI, S. S.; FISHER, D. K.; REDDY, K. N.; RAJAN, N.; PINNAMANENI, S. R. Modeling evapotranspiration for irrigation water management in a humid climate. **Agricultural Water Management**, Amsterdam, v. 225, p. 105731, nov. 2019. DOI: http://dx.doi.org/10.1016/j.agwat.2019.105731. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0378377419307036. Accessed on: 29 jun. 2021.

ASSIS, F. N.; ARRUDA, H. V.; PEREIRA, A. R. **Aplicações de estatística à climatologia**: teoria e prática. Pelotas: Editora UFPel, 1996.

BUSSAB, W.O.; MORETTIN, P. A. **Estatística básica**. 6. ed. São Paulo: Saraiva, 2010.

DALE, R. F. **Applied climatology**. Indiana: Purdue University, 1968.

DIAS, L. C. P.; MACEDO, M. N.; COSTA, M. H.; COE, M. T.; NEILL, C. Effects of land cover change on evapotranspiration and streamflow of small catchments in the Upper Xingu River Basin, Central Brazil. **Journal of Hydrology**, Amsterdam, v. 4, n. 4B, p. 108-122, 2015.

DOORENBOS, J.; PRUITT, W. O. **Crop water requirements**. Rome: FAO, 1977. (FAO Irrigation and Drainage Paper, 24).

FARAHMAND, A.; AGHAKOUCHAK, A. A generalized framework for deriving nonparametric standardized drought indicators. **Advances in Water Resources**, Southampton, v. 76, n. 1, p. 140-145, 2015.

FERNANDES, R. D. M.; JOSÉ, J. V.; WOLFF, W.; COSTA, J. O.; FOLEGATTI, M. V. Probability distribution functions applied in the water requirement estimates in irrigation projects. **Caatinga**, Mossoró, v. 32, n. 1, p. 189-199, 2019.

GURSKI, B. C. **Componentes hídricas prováveis e zoneamento de risco agroclimático para o estado do Paraná**. 2018. Tese (Doutorado em Ciências Agrárias) – Universidade Federal do Paraná, Curitiba, 2018. Available at: http://www.moretti.agrarias.ufpr.br/publicacoes/tese_2018_gurski_b_c_apendice_4.xlsm. Accessed on: 19 aug. 2020.

INSTITUTO DE TERRAS CARTOGRAFIAS E GEOCIÊNCIAS. **Mapa de clima do Estado do Paraná**. Curitiba: ITCG, 2006.

JENSEN, M. E. **Consumptive use of water and irrigation water requirements**. New York: ASCE, 1974.

JERSZURKI, D.; SOUZA, J. L. M.; EVANGELISTA, A. W. P. Probability and temporal variation of reference evapotranspiration in the region of Telêmaco Borba-PR. **Revista Brasileira de Biometria**, Lavras, v. 33, n. 2, p. 118-129, 2015a.

JERSZURKI, D.; SOUZA, J. L. M.; EVANGELISTA, A. W. P. Probability distribution and time movements of precipitation in Telêmaco Borba, Paraná, Brazil. **Revista Brasileira de Ciências Agrárias**, Recife, v. 10, n. 1, p. 110-116, 2015b.

JERSZURKI, D.; SOUZA, J. L. M.; SILVA, L. C. R. Expanding the geography of evapotranspiration: an improved method to quantify land-to-air water fluxes in tropical and subtropical regions. **PLoS ONE**, San Francisco, v. 12, n. 6, p. 1-19, 2017.

MAACK, R. **Geografia física do Estado do Paraná**. 4. ed. Curitiba: IBPT, 2012.

PAULO, A.; MARTINS, D.; PEREIRA, L. S. Influence of precipitation changes on the SPI and related drought severity: an analysis using long-term data series. **Water Resource Management**, Athens, v. 30, n. 1, p. 5737-5757, 2016.

PRUITT, W. O.; OETTINGEN, S. V.; MORGAN, D. L. Central California evapotranspiration frequencies. **Journal of the Irrigation and Drainage Division**, New York, v. 98, n. 2, p. 177-184, 1972.

RIBEIRO, B. T.; FERREIRA JUNIOR, D. C.; SILVA, C. R. Ten-day probable rainfall for Uberlândia, Minas Gerais State, Brazil. **Bioscience Journal**, Uberlândia, v. 29, n. 3, p. 536-542, 2013.

SAMPAIO, S. C.; LONGO, A. J.; QUEIROZ, M. M. F.; GOMES, B. M.; VILLAS BOAS, M. A.; SUSZEK, M. Estimate and probable monthly rain precipitation distribution in the state of Paraná. **Acta Scientiarum Human and Social Sciences**, Maringá, v. 28, n. 2, p. 267-272, 2006.

SILVA, A. O.; CORREIA, J. S.; BASSOI, L. H.; TEIXEIRA, A. H. C. Reference evapotranspiration for design of irrigation systems in Petrolina, Brazil. **Brazilian Journal of Biosystems Engineering**, Tupã, v. 9, n. 1, p. 30-38, 2015.

SOUZA, J. L. M.; JERSZURKI, D.; DAMAZIO, E. C. Relações funcionais entre precipitação provável e média em regiões e climas brasileiros. **Pesquisa Agropecuária Brasileira**, Rio de Janeiro, v. 48, n. 7, p. 693-702, 2013.

STAGGE, J. H.; TALLAKSEN, L. M.; GUDMUNDSSON, L.; LOONC, A. F. V.; STAHL, K. Candidate distributions for climatological drought indices. **International Journal of Climatology**, Chichester, v. 35, n. 13, p. 4027-4040, 2015.

VICENTE-SERRANO, S. M.; SCHRIER, G. V.; BEGUERÍA, S.; AZORIN-MOLINA, C.; LOPEZ-MORENO, J. I. Contribution of precipitation and reference evapotranspiration to drought indices under different climates. **Journal of Hydrology**, Amsterdam, v. 526, n. 1, p. 42-54, 2015.

WANG, P.; SONG, X.; HAN, D.; ZHANG, Y.; ZHANG, B. Determination of evaporation, transpiration and deep percolation of summer corn and winter wheat after irrigation. **Agricultural Water Management**, Amsterdam, v. 105, n. 1, p. 32-37, 2012.

XAVIER, A. C.; KING, C. W.; SCANLON, B. R. Daily gridded meteorological variables in Brazil (1980–2013). **International Journal of Climatology**, Chichester, v. 36, n. 6, p. 2644-2659, 2015.