SPATIALIZATION OF THE RELATIVE AIR HUMIDITY TO A REGION OF THE SUB-MIDDLE OF SÃO FRANCISCO

Iug LOPES[1]
Brauliro Gonçalves LEAL[2]

- *ABSTRACT:* Among the meteorological variables that make up the calculation of the water balance, we have a highlight for the relative humidity, and with measurements of point form can be transformed into continuous fields using spatial interpolation methods. The objective of this work was to evaluate the power of the Inverse Distance Power (IDP) in the spatial daily values of relative humidity in the Petrolina-Juazeiro Development Pole, Brazil, for the seasons: winter, spring, summer, and autumn. The power parameters of the Inverse Distance Power interpolator of the minimum, mean and maximum relative humidity were obtained from the data measured in 14 INMET automatic meteorological stations in operation at the Petrolina-Juazeiro Development Pole. Interpolations were performed for annual, winter, spring, summer and fall seasons. The daily variation of the mean relative error was calculated using the data of minimum, mean and maximum relative humidity. The value of the power of the interpolator obtained for the year time were equal to 2.9; 3.0 and 2.9, respectively. The mean error values were relatively small compared to the instrumental error.

- *KEYWORDS:* Interpolation; validation cross; meteorological station.

1 Introduction

The knowledge of the values of climatic variables in a given region is fundamental to obtain the quantitative evapotranspiration. Among those composing this calculation, we have that the relative humidity of the air is one that allows a greater influence in natural physical processes and thus has great prominence in the various types of studies, mainly, directed to plant physiology, bioclimatology and agrometeorology (SILVA *et al.*, 2007).

In order to remain environmentally sustainable, irrigated agriculture needs to use water resources more efficiently (ALLEN *et al.*, 1998; LOPES *et al.*, 2016). In Brazil and in the world, the largest user of water is irrigation for food production, with 69% of the use destined for this purpose (BRAGA, 2008), and one of the ways to become more effective is to implement management irrigation.

It should be emphasized that among the meteorological variables required for the calculation of the water balance, the relative humidity, which has a continuity in the distance

[1] Universidade Federal Rural de Pernambuco - UFRPE, Departamento de Engenharia Agrícola, Recife, PE, Brasil. E-mail: *iuglopes@hotmail.com*
[2] Universidade Federal do Vale do São Francisco - UNIVASF, Colegiado de Engenharia da Computação, Juazeiro, BA, Brasil. E-mail: *brauliro.leal@univasf.edu.br*

quantitative, is more important, allowing the creation of continuous fields using spatial interpolation methods (CARDOSO and AMORIM, 2014). By performing the relative humidity spatialization, you can have data for locations where you do not have a weather station.

Perin *et al*. (2015) in a methodology of spatialization of meteorological data, observed that the most used in the publications was the Inverse Distance Power (IDP) with 63.6%, followed by Kriging. In addition, the IDP was more efficient because it does not require spatial continuity, and it has a better smoothing of the generated isolines (MARTINS and ROSA, 2012; MARCUZZO *et al.*, 2011).

In the verification of the performance of methods the cross-validation process is used, which allows to see the discrepancies between the calculated values and the measured values. From the difference between these values and the observed estimation error, it allows to select the model ranking (CASTRIGNANÒ, 2011).

The Mean Absolute Error (MAE) and the Mean Bias (MB) are the adequate measures to evaluate the errors of spatial interpolators and were proposed by Willmott e Matsuura (2006), through the study of the meteorological data errors interpolated by the Inverse of the Square of Distance. In addition, to the meteorological area, there are several researches that consolidate the verification by these two methods (DELGADO *et al.*, 2012; BORGES JÚNIOR *et al.*, 2012; MARCUZZO *et al.*, 2011).

All the knowledge of the importance of these statistical studies for agriculture, is necessary the study of the application in the area of agricultural development. The Petrolina-Juazeiro Pole of Development is an example of a region to be studied, which was constituted as a successful Brazilian public policy for the development of irrigation. This area is located in the extreme west of Pernambuco and North of Bahia and currently has an area of about 260,000 irrigated hectares (CODEVASF, 2016).

Considering the importance of the meteorological variables for the calculation of the water balance and due to the lack of bibliography related to the spatialization of meteorological variables for the Petrolina-Juazeiro Development Pole, the objective of this work was to obtain the power parameters for the interpolation method of the IDP in the spatialization of daily values of the minimum, medium and maximum relative humidity of this region, for the one-year periods, winter season, spring, summer and autumn.

2 Material and methods

2.1 Characterization of the study area

The region of study in which the Petrolina-Juazeiro Development Pole can be represented by a circle of approximately 250 km radius around the city of Petrolina-PE, Brazil (Latitude: -8.3647; Longitude: -42.2508) (Figure 1), in the North-eastern Semiarid.

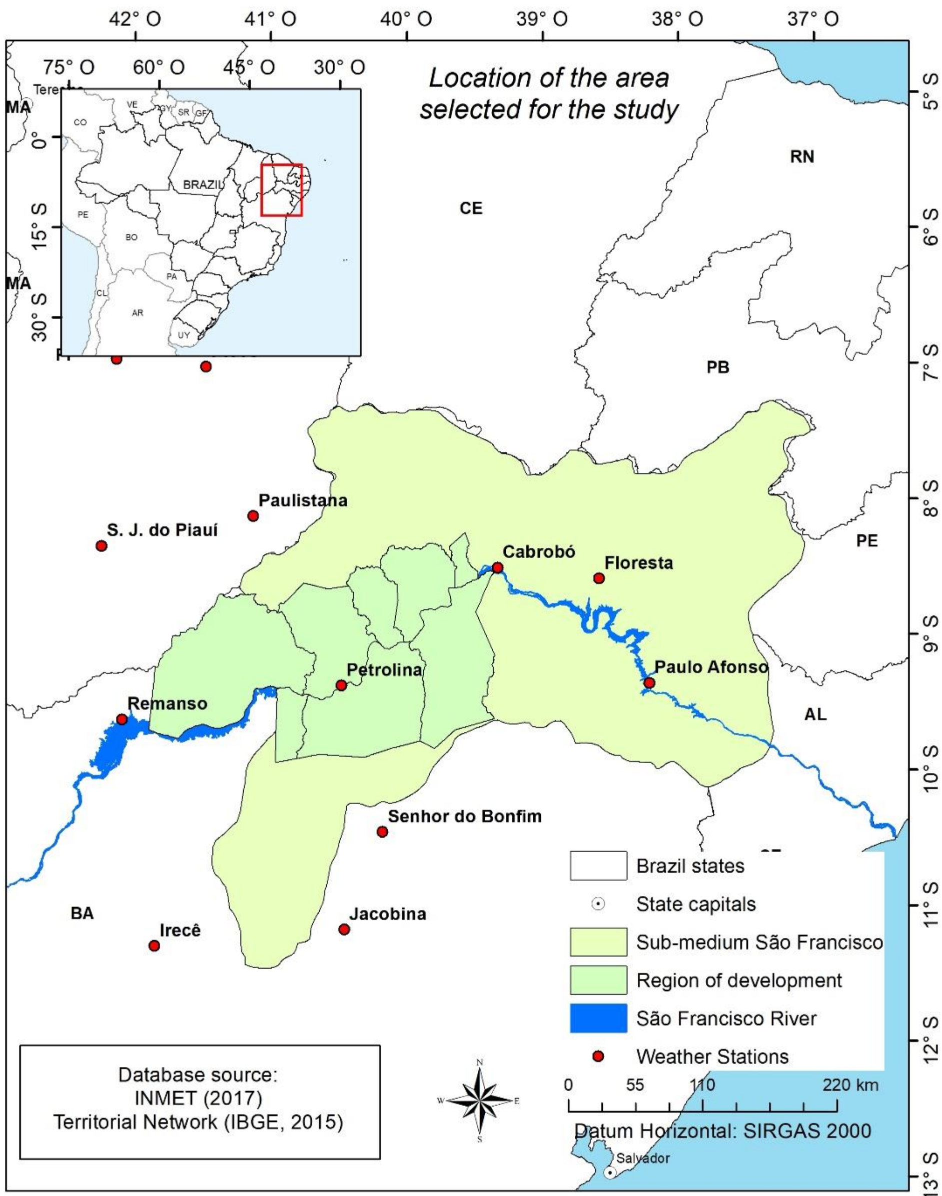

Figure 1 - INMET's area of spatialization study of the automatic stations used. With reference of Petrolina's station in the state of Pernambuco.

Time data from 14 automatic meteorological stations of the National Institute of Meteorology (INMET) were used in the study area (Table 1).

Table 1 - INMET automatic weather stations used in work with code, location, Federative Unit (FU), Latitude and Longitude

Code	Location	FU	Latitude (°)	Longitude (°)
A329	Cabrobó	PE	-9.3833	-40.8012
A443	Delfino	BA	-10.4553	-41.2072
A442	Euclides da Cunha	BA	-10.4442	-40.1469
A351	Floresta	PE	-8.1325	-41.1428
A424	Irecê	BA	-9.6189	-42.0831
A440	Jacobina	BA	-9.8336	-39.4956
A330	Paulistana	PI	-8.5036	-39.3144
A307	Petrolina	PE	-8.3647	-42.2508
A436	Queimadas	BA	-11.205	-40.4653
A423	Remanso	BA	-9.0331	-42.7006
A331	São João do Piauí	PI	-10.9847	-39.6171
A345	São Raimundo Nonato	PI	-10.5367	-38.9978
A428	Senhor do Bonfim	BA	-11.3289	-41.8647
A435	Uauá	BA	-8.6103	-38.5922

Figure 2 shows the altitude of these stations and their distances in relation to Petrolina station.

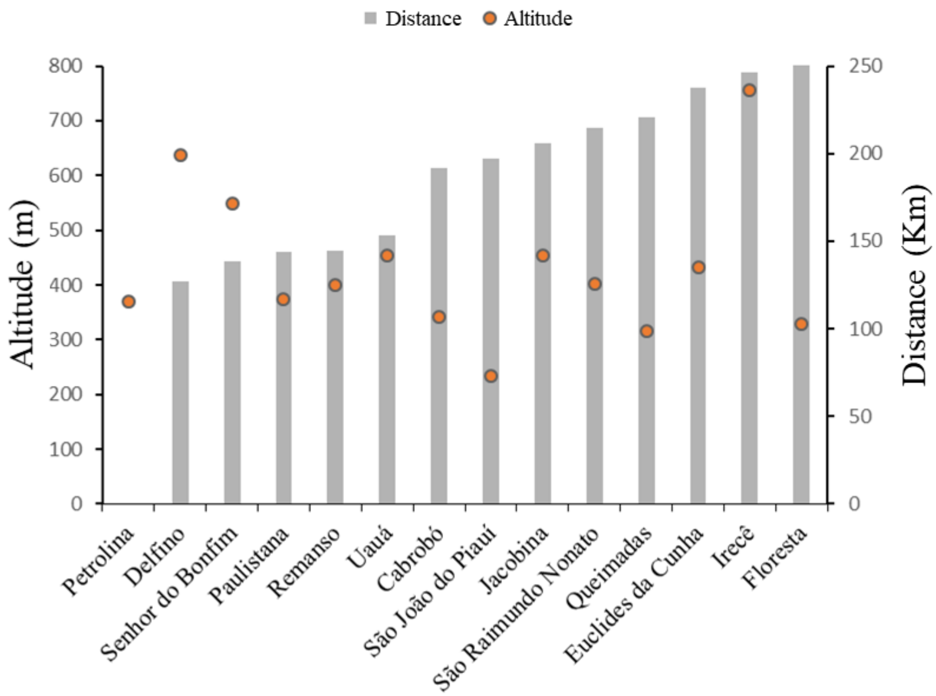

Figure 2 - Altitude of the stations and their distances in relation to the station of Petrolina-PE.

2.2 Periods of time of the study

The daily values of the minimum relative humidity (URmin), mean (URmed) and maximum (URmax) were obtained from the hourly data of relative humidity measured in automatic meteorological stations, a methodology similar to that used by Lopes *et al.* (2016) for the study of precipitation in the region. Only days that had at least 18 valid hourly data been used. These data were organized in two periods and five times each:

• First period - from 06/21/2008 to 06/20/2009, with the seasons, year (21/06/2008 to 20/06/2009), winter (21/06/2008 to 22/09/2008), spring (23/09/2008 to 20/12/2008), summer (21/12/2008 to 20/03/2009) and autumn (21/03/2009 to 06/20/2009), these data were used to estimate the values of p of these epochs considered;

• Second period - from 03/21/2009 to 03/21/2010, these data were used to evaluate the power value error, when estimating data using p values in the first period.

2.3 Estimation of IDP power parameters

For the spatialization of the minimum relative, average and maximum relative humidity, the powers were evaluated for the Inverse Distance Power (IDP) interpolation method. The power parameter was varied from 0.1 to 25.0, with an increase of 0.1. Methodology also used by Castro *et al*. (2010) and Silva *et al*. (2011).

The IDP methodology takes into account that the quantitative variable to be estimated in any position. It is calculated by its neighbours and thus weighted by the inverse of its elevated distance to a power "p", according to Equation 1.

The performance of the IDP was determined using the Mean Absolute Error (*MAE*) (Equation 2) and Mean Bias (*VM*) values (Equation 3), calculated using the Cross-Validation (*CV*) technique applied to the data of the first period.

$$f_e(r) = \frac{\sum_{i=1}^{n} d(r, r_i)^{-p} \, f_m(r_i)}{\sum_{i=1}^{n} d(r, r_i)^{-p}} \tag{1}$$

$$MAE = \frac{1}{n} \sum_{i=1}^{n} \left| f_m(r_i) - f_e(r_i) \right| \tag{2}$$

$$VM = \frac{1}{n} \sum_{i=1}^{n} \left[f_m(r_i) - f_e(r_i) \right] \tag{3}$$

In equations from (1) to (3), $f_e(r)$ - estimated value of f in the position vector r; $f_m(r_i)$ - measured value of the position vector r_i; n - total number of points known and used in interpolation; $d(r, r_i)$ - Euclidean distance between vectors r and r_i, and p - power parameter.

In the elaboration of CV, the calculated values with data of less than 10 automatic meteorological stations were disregarded. In this stage the power values of the seasons of the year, winter, spring, summer and autumn were obtained.

Data were cross-validated according to the methodology of Robinson and Metternicht (2006) and Amorim *et al*. (2008). This methodology consists in which a measurement point is discarded successively in the interpolation, being possible to obtain the estimated value (E) relative to the withdrawn and in this way, we can compare it with the real value of the variable (O).

2.4 Assessment of the p-value

The p-value of the year period, obtained with the data of the first period, was evaluated using the data of the second period by means of the values of the average daily error, as defined below:

• Relative error of the relative minimum, average and maximum relative daily humidity (er_{day}), the relative error calculated from the estimated minimum daily, average and maximum relative humidity values (X_e) and measured minimum daily, average and maximum relative humidity values (X_m) in a weather station (equation 4).

• Average relative error of the minimum, average and maximum relative daily humidity (re_{mean}), the average arithmetic means of a set of meteorological stations (equation 5).

$$re_{day} = \frac{X_m - X_e}{X_m} \tag{4}$$

$$re_{mean} = média\{er_{dia}\} \tag{5}$$

3 Results and discussion

3.1 Characterization of air humidity data

From the first period, 4494, 4913 and 4537 minimums, means and maximums relative humidity values, respectively, were calculated using hourly data measured in the meteorological stations of Table 1. The minimum, median, median, maximum, first quartile values (Q1/4) and third quartile (Q3/4) of the data used by season of the first period are presented in Figure 3.

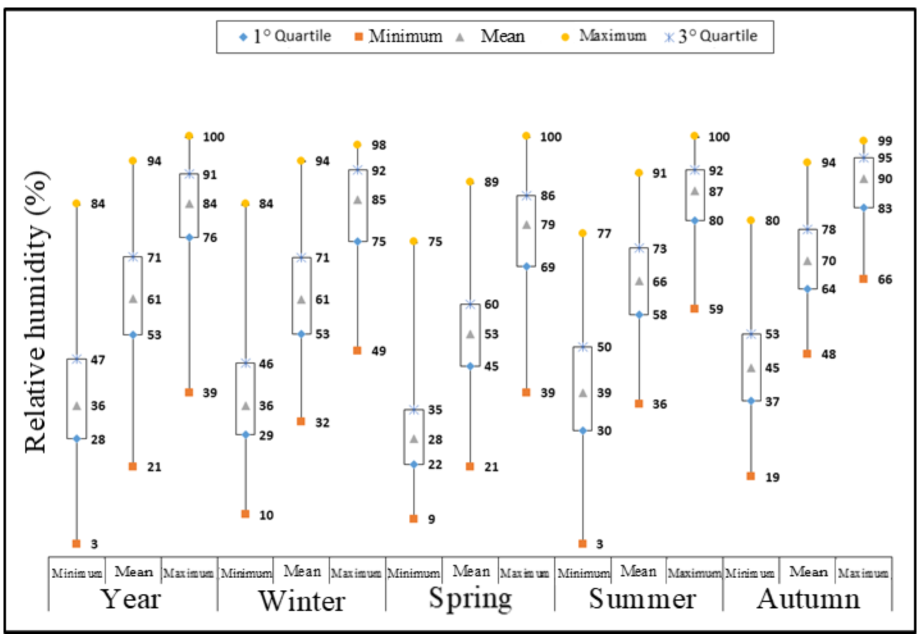

Figure 3 - Boxplot of the data of minimum, mean and maximum relative humidity used in the seasons, year, winter, spring, summer and autumn of the first period.

The maximum humidity in absolute mean value occurs in the autumn season with fluctuations of quartiles ranging from 83 to 95%. The variability of the minimum absolute mean value of air humidity ranged from 30 to 50% in the summer season, and this observation is related to the summer rainy season, which allows a very large variation between rainy and temperature days very high.

For the average relative humidity oscillated between 21 and 89% for the spring season, which comprises the period of lower humidity and allows for greater evapotranspiration in conjunction with sharp radiation, strong winds and elevated temperature.

All these observations of moisture correspond to the wetter season, which is autumn, and the more arid that spring is. These values of relative air humidity can be influenced by the convergence zone of the inter-tropical region, which influences the climate characteristics in this region.

It can also be seen in Figure 3 that the minimum, mean and maximum relative humidity values of the first period ranged from 3 to 84; from 21 to 94; and 39 to 100%, respectively, with medians and standard deviations equal to 36, 61 and 84; and 1.40, 1.11 and 0.43, in the same sequence.

The standard deviation and the number of data used are shown in Table 2. It can be seen that the variation of the standard deviation (s) was minimal between the periods and the relative humidity, the data numbers used varied according to the availability of data collected.

Table 2. Statistics of the minimum, mean and maximum daily relative humidity of the first period and its epochs: standard deviation (s) and number of data used (n)

	Relative humidity (%)					
	Minimum		Mean		Maximum	
	s	n	s	n	s	n
Year	1.40	4494	1.11	4913	0.43	4537
Winter	2.04	1118	1.61	1188	0.37	1147
Spring	1.56	1114	0.92	1209	0.12	1106
Summer	0.43	1116	0.16	1235	0.18	1119
Autumn	1.73	1146	2.45	1281	1.70	1165

3.2 Power estimation

In Figures 4A, 4B and 4C you can observe the variation of the Mean Absolute Error (MAE) as a function of power in the times and period studied. MAE variation was similar at times, with a higher initial value trend, accompanied by a subtle reduction to a minimum value, followed by moderate growth.

The minimum WEM values for minimum relative humidity were 4.89; 6.65; 3.56; 4.37 and 4.95 for the annual, winter, spring, summer and fall seasons, respectively, with corresponding p values equal to 2.9; 2.3; 3.2; 2.7 and 3.2. For the same sequence of epochs, WEM values for mean relative humidity were 4.95; 5.08; 5.21; 4.75 and 4.75 with corresponding values of p, 3.0; 3.0; 2.9; 2.9 and 3.1. Following the WEM values for maximum relative humidity, 5.36, 5.21, 6.55, 5.11 and 4.48 with the corresponding values of p, 2.6, 2.9, 2, 6, 2.1 and 2.1. In general, the results obtained were independent of the influence of seasonality on the time scales considered.

The values of p obtained using MAE, since they are greater than 1.0, indicate a greater influence of the values closer to the interpolated point (BOOTH, 2001).

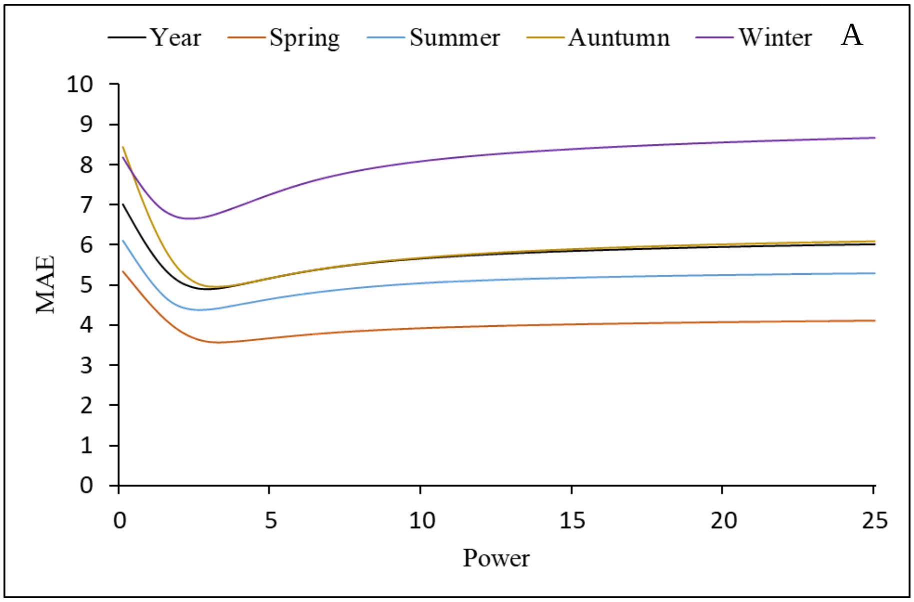

Figure 4 - Mean absolute error of powers used in the seasons winter, spring, summer and autumn of the first period for the minimum relative humidity (A).

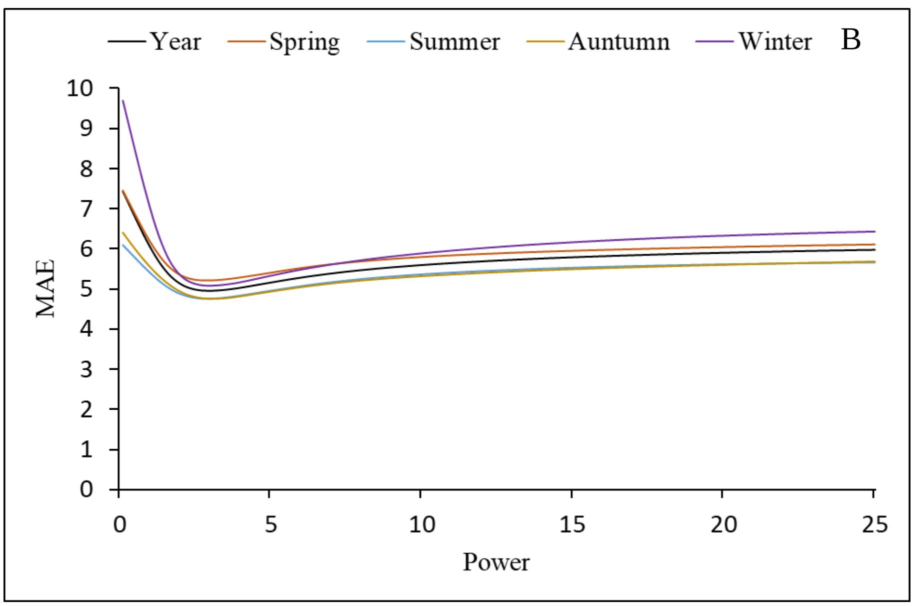

Figure 4 (Continuation) - Mean absolute error of powers used in the season winter, spring, summer and autumn of the first period for mean relative humidity (B).

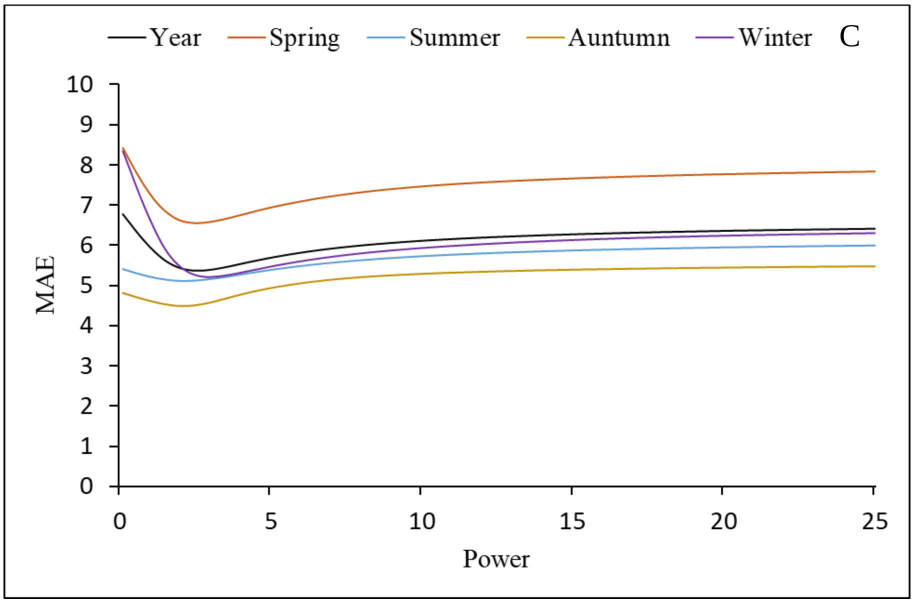

Figure 4 (Continuation) - Mean absolute error of powers used in the seasons winter, spring, summer and autumn of the first period for maximum relative humidity (C).

The application of the best quantitative of the power value is of fundamental importance in the quality of the relative humidity specialization, therefore they are essential for the irrigation management, since the area does not have a larger quantitative of public stations. In addition to that, the spatialization of relative humidity can contribute to verifications the perception of climate changes over time, in places that do not have meteorological data, as studied by Silva and Azevedo (2008) and Medeiros *et al*. (2014) variations in relative humidity and other climatic factors.

Figure 5A, 5B and 5C show the variation of VM as a function of p at the times and period studied, for the minimum, medium and maximum relative humidity, respectively. For the minimum, the general variation of the MB was not similar at the time, with initial values close, accompanied by a sharp increase up to a maximum value for autumn and spring, and this situation different from the other curves may be related to the stations of minors and higher values of minimum moisture in the region.

For the average relative humidity, the curves of the MB values were similar, except for the spring, which once again behaves as the lowest mean moisture value.

For the maximum relative humidity, where it is almost always observed with precipitation, it was observed that only in the spring season did a curve differentiation occurs, which is related to the low precipitation in this season.

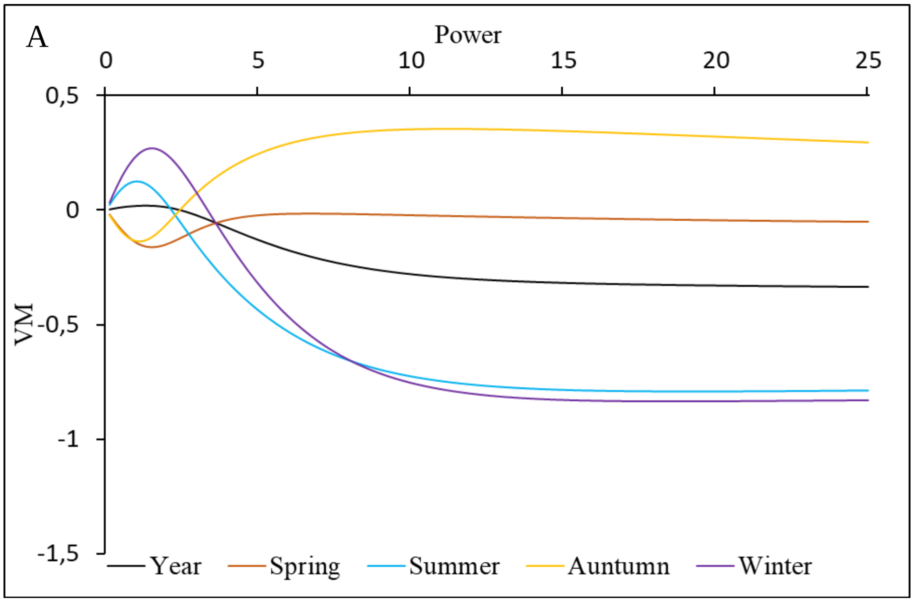

Figure 5 - Average bias of the potencies used in the seasons winter spring, summer and autumn of the first period for minimum relative humidity (A).

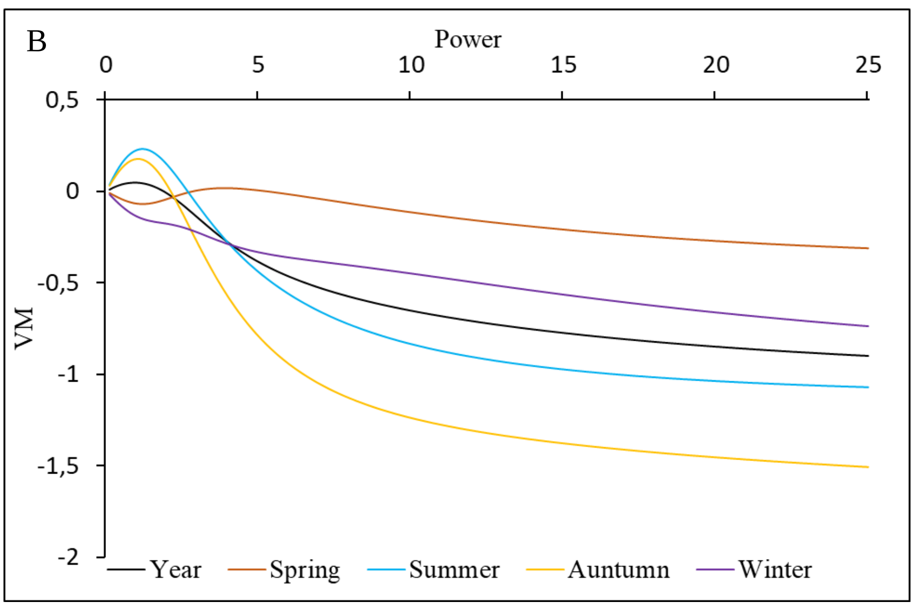

Figure 5 (Continuation) - Average bias of the potencies used in the seasons winter spring, summer and autumn of the first period for mean relative humidity (B).

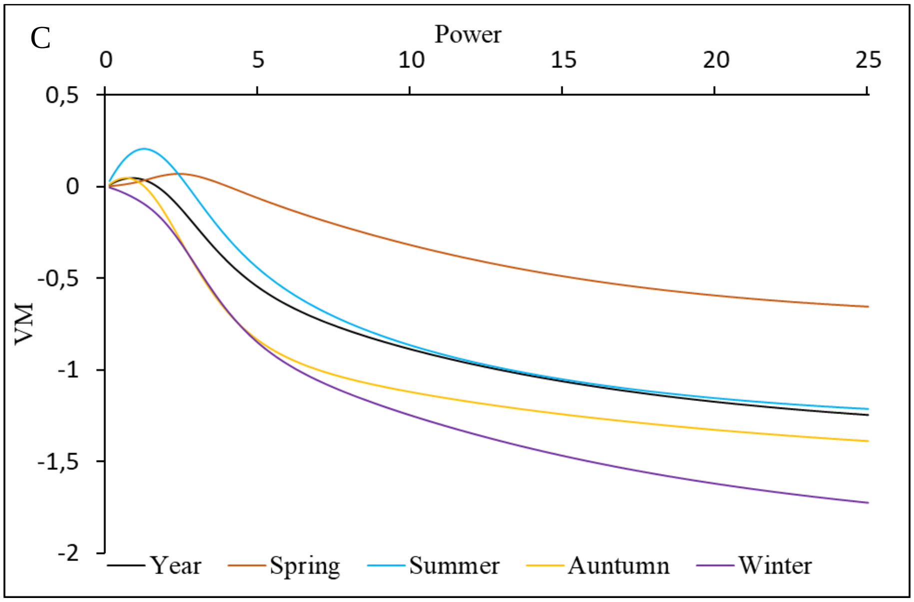

Figure 5 (Continuation) - Average bias of the potencies used in the seasons winter spring, summer and autumn of the first period for maximum relative humidity (C).

The best measure of performance to evaluate the average spatial interpolation errors of meteorological parameters in the region and in the period studied is the comparison of the behavior of MAE and MB. It allows to infer that MAE, for having a similar behavior for the times and also for presenting a single point of minimum, which is in agreement with the result obtained by Willmott and Matsuura (2006).

3.3 Performance of estimated power value

The efficiency of the interpolation method for application in the parameter relative humidity in the Petrolina-Juazeiro Development Region can be observed in Figures 5 and 6, where the minimum difference between the estimated values is visualized.

This precision in the methodology has also been verified by Perin *et al.* (2015), concluding that the interpolation method is efficient in estimating relative humidity, although the use of specialized relative humidity acquisition methodologies is widespread.

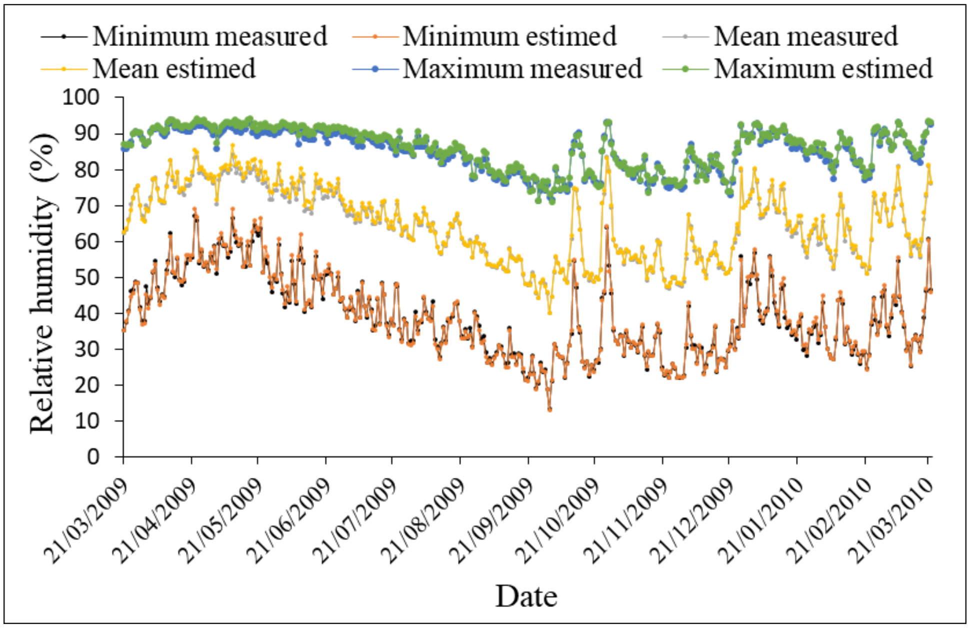

Figure 6 - Minimum, mean and maximum relative humidity measured and estimated for the second period.

Figure 6 shows the daily variation of the mean (re_{mean}) relative error calculated using the data of minimum, average and maximum relative humidity of the second period using the p value obtained for the year, p = 3.3; p = 3.0; p = 2.6, for the respective humidities. In Figure 6 it can be observed that the re_{mean} variation is of a random nature, with a slight downward tendency. In general, re_{mean} values were small, minimum relative humidity ranged from -4.0 to 3.2% and a mean of 0.5%, mean relative humidity ranged from -1.6 to 3.0% and mean of 0.6%, for maximum relative humidity ranged from -2.0 to 2.5% and a mean of 0.8%. These values, which are already small, may still be related to the sensor's accuracy range, ranging from -0.58 to 0.50% (VAISALA, 2011).

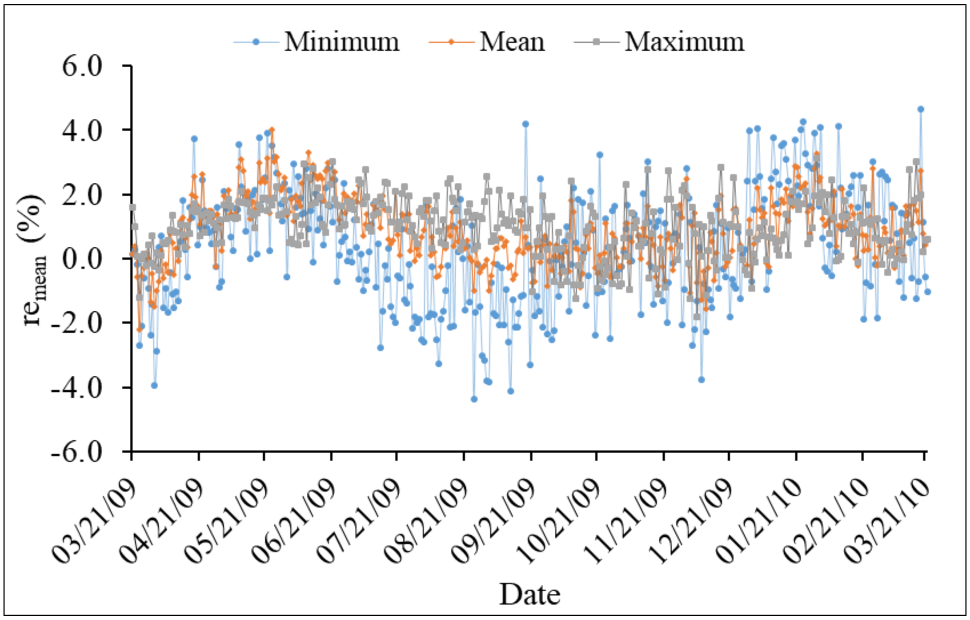

Figure 7 - Mean error between measured and estimated values for the second period, for minimum, mean and maximum relative humidity.

As for the correlation between the measured and estimated moisture data (Figure 7A, 7B, 7C), once again the efficiency of the interpolation application for the minimum, medium and maximum moisture data for the region is noticeable.

Although the meteorological stations are distant from each other, one can observe a great agreement between the measured and estimated values of the relative humidity using the data of the second period, in Figures 7A, 7B, and 7C, with $R^2 = 98.49\%$, $R^2 = 99.52\%$ and $R^2 = 99.52\%$.

The good results found in the correlation of the values of the measured and estimated humidity were not found in the studies with climatic data by Castro et al. (2010) and of Cecílio *et al.* (2012). This distinct result for the interpolation of climatic data that subsidizes the Climatological Water Balance by IQD may be related to the choice of the best power for the method, whose authors varied the power in unit value up to 4, while the current study varied from decimal form until the power 25.

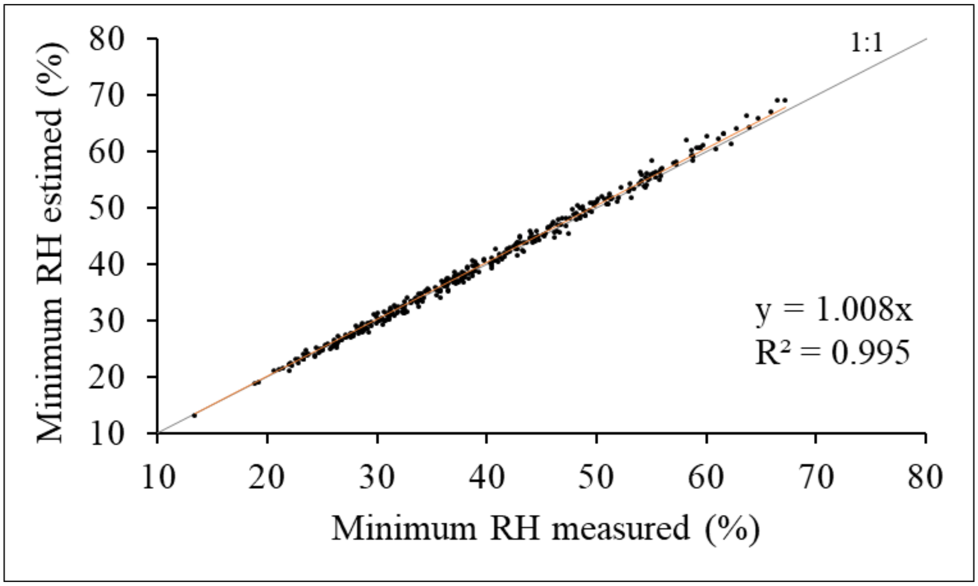

Figure 7 - Correlation of minimum relative humidity (RH) between measured and estimated data for the second period.

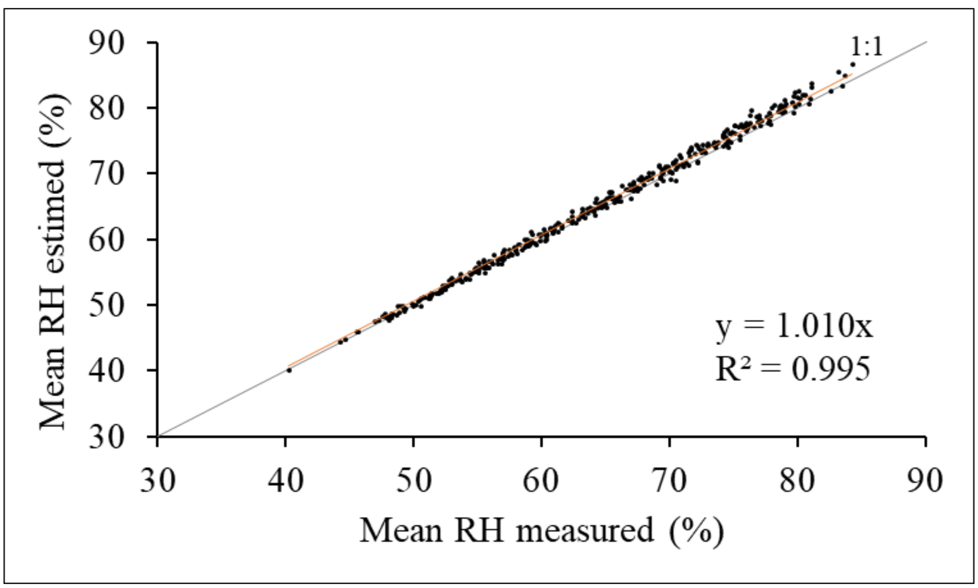

Figure 7 (Continuation) - Correlation of mean relative humidity between measured and estimated data for the second period.

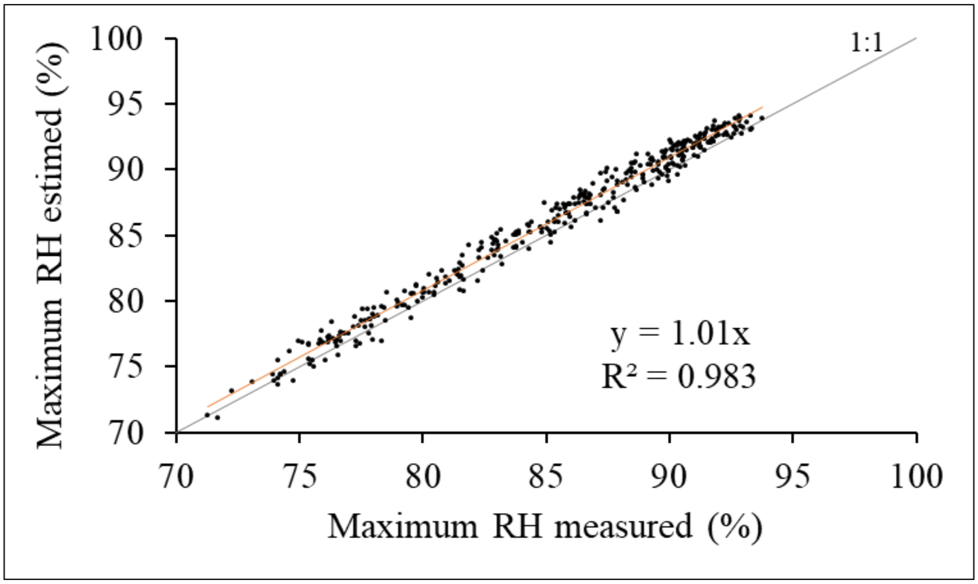

Figure 7 (Continuation) - Correlation of maximum relative humidity between measured and estimated data for the second period.

The results obtained with the interpolation of the 14 stations allow the creation of thematic maps for the Petrolina-Juazeiro Development Pole, that is, the relative humidity demonstration for a 250 km radius of the city of Petrolina. In this way, however, with less precision, it was performed by Medeiros *et al*. (2005), which adjusted regression equations to estimate monthly and annual climatic parameters. It is possible to elaborate thematic maps of the relative humidity of the Brazilian Northeast Region.

A possible application of these data can be the estimation of the maximum and minimum humidity in regions with agricultural production susceptible to abrupt meteorological changes. As in the study carried out by Bardin *et al*. (2012), who performed the estimation of maximum and minimum climatic parameters for a given agricultural region of the state of São Paulo and thus providing subsidies for better agricultural planning in agricultural regions.

Conclusions

The values of the power (p) of the inverse of the distance power for the interpolation of the humidities in the Petrolina-Juazeiro Development Pole, using cross-validation and mean absolute error, were estimated. The values of p obtained for minimum relative humidity corresponded to 2.9; 2,3; 3.2; 2.7 and 3.2 for the year, winter, spring, summer and autumn, respectively. In the same sequence of epochs, the mean relative humidity was 3.0; 3.0; 2.9; 2.9 and 3. And for maximum relative humidity, 2.6, 2.9, 2.6, 2.1 and 2.1.

The mean absolute error was the best performance measure of the inverse of the distance power for the spatialization of the humidities at the Petrolina-Juazeiro Pole. The mean error values were small compared to instrumental error.

Further studies should be carried out to maximize the knowledge of the spatialization of the climatological water balance in the Petrolina-Juazeiro Development Pole, in order to make a subsidy for irrigation decision making by farmers in the irrigated perimeters that are present in this area.

LOPES, I; LEAL, B. G. Spatialization of the relative air humidity to a region of the Sub-Middle of São Francisco. *Rev. Bras. Biom*., Lavras, v.36, n.1, p.89-107, 2018.

- *RESUMO: Entre as variáveis meteorológicas que compõe o cálculo do balanço hídrico, tem-se um destaque para a umidade relativa, sendo que com medições de forma pontual pode ser transformada em campos contínuos utilizando métodos de interpolação espacial. O objetivo deste trabalho foi avaliar potências para o método de interpolação do Inverso da Potência da Distância (IPD) na espacialização de valores diários da umidade relativa no Polo de Desenvolvimento Petrolina-Juazeiro, para os períodos de um ano, das estações do ano (inverno, primavera, verão e outono). Foi obtido os parâmetros de potência do interpolador Inverso da Potência da Distância das umidades relativas mínimas, médias e máximas a partir dos dados medidos em 14 estações meteorológicas automáticas do INMET em operação no Polo de Desenvolvimento Petrolina-Juazeiro. Foram realizadas interpolação para as épocas anual, inverno, primavera, verão e outono. A variação diária do erro relativo médio calculado utilizando os dados de umidade relativa mínima, média e máxima utilizando o valor da potência do interpolador obtida para a época ano foram iguais a 2,9; 3,0; e 2,9, respectivamente. Os valores de erro médio foram relativamente pequenos comparados com o erro instrumental.*

- *PALAVRAS-CHAVE: Interpolação; validação cruzada; estação meteorológica.*

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