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GAP FILLING PROCEDURES OF CLIMATOLOGICAL SERIES IN THE STATE OF PERNAMBUCO

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1 ABSTRACT

This study aimed to compare the applicability of three methods of filling gaps in rainfall and temperature data from thirteen automatic weather stations (AWS) in the state of Pernambuco, from January to December 2019. The methods used were arithmetic mean, regional weighting, and simple linear regression. The data estimated by filling techniques have been subjected to comparison using R^2 and descriptive statistical analysis. The estimated data of air temperature presented R^2 equal or very close to 1 for the three methods. On the other hand, the estimated data of rainfall showed values similar or closer to the real data only to regional weighting (R^2 = 1) and linear regression (R^2 = 0.99) methods. The smallest values of standard deviation (1.70) for temperature were obtained with linear regression. The regional weighting method and unfilled data showed greater uniformity for precipitation. The analyzed methods to estimate the climatic variables, air temperature, and precipitation, on a monthly scale, were efficient to fill in missing data in the evaluated AWS. The simple linear regression method is more efficient and adequate, followed by regional weighting, to fill in missing data in climate databases.

Keywords: meteorology, automatic weather stations, rainfall, air temperature.

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PROCEDIMENTOS PARA PREENCHIMENTO DE FALHAS EM SÉRIES CLIMÁTICAS NO ESTADO DE PERNAMBUCO

2 RESUMO

Objetivou-se com este estudo comparar a aplicabilidade de três métodos de preenchimento de falhas de dados pluviométricos e de temperatura oriundos de treze estações meteorológicas automáticas (AWS) no estado de Pernambuco, no período de janeiro a dezembro de 2019. Os métodos utilizados foram média aritmética, ponderação regional e regressão linear simples. Os dados estimados pelas três metodologias foram submetidos à comparação por meio de R^2 e

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análise estatística descritiva. Para temperatura do ar, os dados estimados apresentaram R^2 igual ou muito próximo de 1 para os três métodos. Por outro lado, os dados estimados de precipitação pluviométrica foram semelhantes ou mais próximos dos dados reais somente para os métodos de ponderação regional ($R^2 = 1$) e regressão linear ($R^2 = 0,99$). Os menores valores de desvio padrão (1,70) para a temperatura foi obtido com regressão linear. O método ponderação regional e os dados não preenchidos apresentaram maior uniformidade para precipitação. Os métodos analisados para estimar as variáveis climáticas, temperatura do ar e precipitação, em escala mensal, foram eficientes para preenchimento de dados faltantes nas AWS avaliadas. O método regressão linear simples mostra-se mais eficiente e adequado, seguido de ponderação regional, para preenchimento de dados faltantes em bancos de dados climáticos.

Palavras-chave: meteorologia, estações meteorológicas automáticas, precipitação pluviométrica; temperatura do ar.

3 INTRODUCTION

The northeast region of Brazil is characterized by having great variability in the rainfall distribution (SILVA et al., 2011) and air temperature (SANTOS et al., 2010). The interpretation of rainfall together with temperature is essential for decision-making in the planning and management of environmental resources, with direct applications in the irrigation systems design, infrastructure works, and electricity generation, resulting in positive socioeconomic impacts (DIAS; SOARES, 2021).

The occurrence of problems in weather stations, including reading errors, caused by equipment failures in automatic stations and human observation errors in conventional stations (BIER; FERRAZ, 2017), generates inconsistencies in meteorological data. According to Wanderley, Amorim e Carvalho (2014), the inexistence of a continuous series of climatological data can limit the understanding of the spatial and temporal variability in different meteorological and hydrological processes, as well as affect the climate characterization of a region. Thus, the availability of a consistent series, without failures, is essential for climatological data application in different areas (COUTINHO et al., 2018).

To correct these data gaps, there are several methodologies for missing data filling. This procedure is done by replacing the lost data with estimated values through statistical and mathematical methods, such as simple arithmetic mean, linear regression (MELLO; SILVA, 2013), and regional weighting (BERTONI; TUCCI, 2007).

Diaz, Pereira, and Nobrega (2018) evaluating the Regional Weighting method for estimating monthly rainfall data in the Pajeú River basin, Pernambuco, Brazil from 1998 to 2013, concluded that the method had a positive performance using data from three nearby rainfall stations. Bier and Ferraz (2017) comparing gap filling methodologies in meteorological data for stations in southern Brazil, observed that the regional weighting and multiple linear regression methods showed better results for temperature with mean absolute errors of 0.2 ºC and values of root mean square error between 0.25 ºC to 0.35 ºC, while for the variable precipitation there were no major differences between the regional and arithmetic weighting methods.

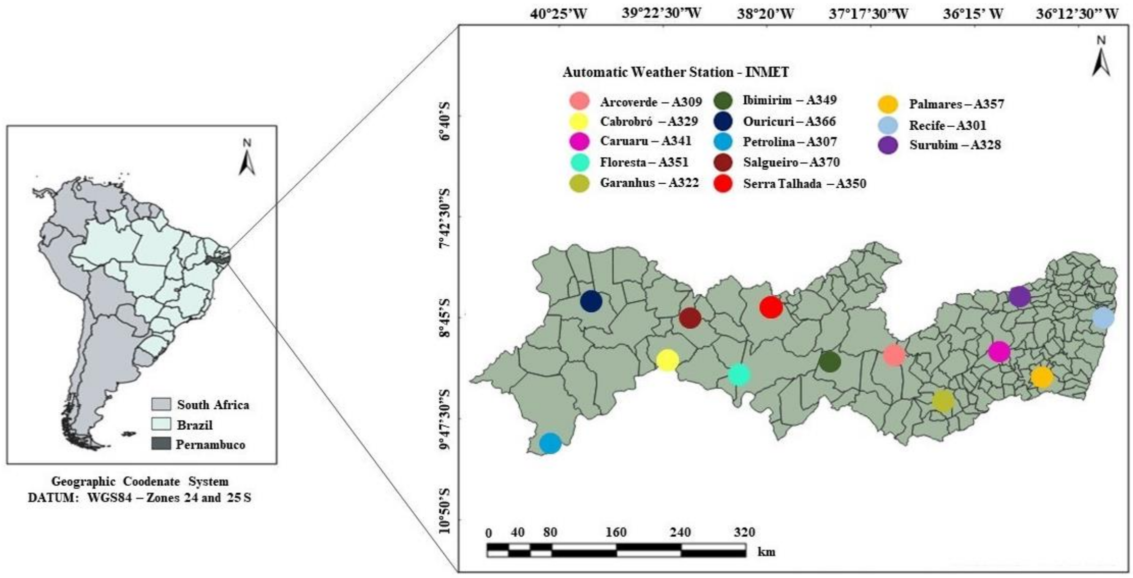
Thus, the objective of this study was to compare three methods of filling gaps in rainfall and temperature data from thirteen automatic weather stations (AWS) distributed in different regions of the state of Pernambuco, from January to December 2019, to optimize the use of historical series.

4 MATERIAL AND METHODS

The database used in this study consisted of monthly values of mean air temperature (°C) and accumulated rainfall (mm), from January to December 2019, registered by thirteen automatic weather stations (AWS) belonging to the network of the National Institute of Meteorology (INMET) of the state of Pernambuco. The station's coverage area is 98,146 km² and includes regions with humid tropical and semiarid climates with six climatic classes: Am, Aw, BWh, BSh, Csa, and Csb (ALVARES et al., 2013).

The map in figure 1 shows the spatial distribution of AWS in the municipalities of Arcoverde, Cabrobó, Caruaru, Floresta, Garanhuns, Ibimirim, Ouricuri, Petrolina, Salgueiro, Serra Telhada, Palmares, Recife and Surubim.

Figure 1. State of the Pernambuco location in northeastern Brazil and spatial distribution of automatic weather stations in the state of Pernambuco, identified by the city and the respective World Meteorological Organization - WMO code.



Source: INMET (2019); The authors.

Table 1 shows the AWS used in this study with the respective WMO code, geographical data, and climatic regions identified.

Table 1. Geographical data from automatic weather stations (AWS) in the state of Pernambuco.

City - WMO code	Coordinates		Altitude	Climate Classification
	Latitude	Longitude	M	
Recife - A301	-8.06	-34.96	11.30	Am
Palmares - A357	-8.67	-35.57	164.01	Aw
Surubim - A328	-7.84	-35.80	421.44	Aw
Caruaru - A341	-8.24	-35.99	568.00	Aw
Garanhuns - A322	-8.91	-36.49	827.78	Aw
Arcoverde - A309	-8.42	-37.06	683.91	Aw
Ibimirim - A349	-8.51	-37.71	434.23	BSh
Floresta - A351	-8.60	-38.58	327,42	BSh
Serra Talhada - A350	-7.95	-38.30	499.02	BSh
Salgueiro - A370	-8.06	-39.10	447.00	BSh
Cabrobó - A329	-8.50	-39.32	342.78	BSh
Petrolina - A307	-9.39	-40.52	372.54	BSh
Ouricuri - A366	-7.88	-40.09	462.01	BSh

WMO code -World Meteorological Organization; Am: tropical humid or sub-humid climate; Aw: tropical climate with dry winter; BSh: hot semi-arid climate.
Source: INMET (2019); Alvares et al. (2013).

To verify the homogeneity of the historical series for each climatic variable, before and after gaps filling, the respective data were submitted to consistency analysis for each station separately, using the double mass methodology described by Bertoni and Tucci (2007). In this method, the station of interest and the three closest stations are selected, and the accumulated annual totals are plotted on the ordinates and, on the abscissa, the average accumulated annual totals of the other stations (BIER; FERRAZ, 2017; OLIVEIRA et al., 2010; TABONY, 1983). In the presence of a linear trend between the analyzed weather station with those close, the consistency of the annual totals is considered. Thus, based on the adjustment of the equation of the straight line and the coefficient of determination, the verification of the linearity between the observed and estimated values is evaluated. To assess the accuracy of filling gaps methods, descriptive statistical analysis (dispersion measures: standard deviation and coefficient of variation) was used. The methods used to fill in the gaps in the variables were arithmetic mean, regional weighting, and simple linear regression.

In the arithmetic mean method, used by Soares and Silva (2017), data from three nearby regions that have similar climatic characteristics can be used to estimate the value in meteorological stations with missing data, and the filling was based on the following equation:

$$Dx = \frac{1}{n}\sum_{i=1}^{n} D_i \quad (01)$$

Where: D_x is the missing data, Di is the dataset from nearby AWS, and n is the number of observations.

In the regional weighting method, used by Oliveira et al. (2010) and described by Paulhus and Kohler (1952) and Bertoni and Tucci (2007), the failure of the dataset at the meteorological station of interest is determined by using the following equation:

$$Dx = \frac{1}{n}\sum_{i=1}^{n} \frac{M_x}{M_i} D_i \quad (02)$$

Where: Dx is the missing monthly value to be estimated for the test station; Di is the value from the neighbor station of order “i” in the month of occurrence of the missing data; Mx is the monthly average value of the test station; Mi is the monthly average value of the neighboring station of order “i” and n is the number of neighboring stations.

According to Hoffmann (2016), the regression technique consists of establishing a mathematical relationship that defines the dependence of a certain variable y with a set of values of other variables x (independent variables). The term “linear” refers to the fact that the answer, y', is a linear function of the independent explanatory variables, x1, x2,..., xk. Generally, y = f(x1,x2,..., xk), being known as simple regression for having only one independent variable.

The gap-filling method by linear regression is more improved compared to regional weighting (BERTONI; TUCCI, 2007; OLIVEIRA et al., 2010; TUCCI, 2002). In simple regression, data from a station with missing data and a neighboring station are related. Thus, the linear regression graphs that generated the regression equations and the correlation coefficients (r) were carried out by Microsoft Excel®. According to recommendations by Pruski et al. (2004), the linear regression method is applied under an R^2 greater than 0.7 as a minimum criterion.

5 RESULTS AND DISCUSSION

The state of Pernambuco, characterized by a tropical climate, has high variability in precipitation and temperature in different mesoregions. According to INMET data, in 2019 the temperature variation in the state was from 21.1 to 28 °C and the most accentuated precipitation was in May, June, July, and August. Table 2 shows the amount of missing data in the thirteen AWS in 2019. For temperature, the smallest number of missing data relating to the total number of data were Recife and Surubim with 0.07% and 0.1%, respectively. The stations in the municipalities of Petrolina, Arcoverde, Garanhuns, Caruaru and Serra Talhada no missing data were detected. On the other hand, Palmares and Ouricuri had higher percentages of missing data, 24.63 and 18.01%, respectively. The AWS in Petrolina, Garanhuns and Serra Talhada did not present absence of rainfall data. The highest percentages of failures were registered at the Surubim and Ibimirim stations (58.24, and 54.05%, respectively), while Recife had the lowest percentage of failures (0.06%).

Table 2. The number of available and missing data from AWS for temperature and rainfall.

City	Air Temperature			Rainfall		
	Available	**Missing**	**%**	**Available**	**Missing**	**%**
Recife	8.75	6	0.07	8.75	5	0.06
Palmares	6.60	2.15	24.63	5.70	3.05	34.89
Surubim	8.75	1	0.01	3.65	5.10	58.24
Caruaru	8.83	0	0	7.28	1.47	16.69
Garanhuns	8.76	0	0	8.76	0	0
Arcoverde	8.76	0	0	7.28	1.47	16.82
Ibimirim	7.55	1.20	13.76	4.02	4.73	54.05
Floresta	7.99	770	8.79	7.99	770	8.79
Serra Talhada	8.76	0	0	8.76	0	0
Salgueiro	7.44	1.31	15.01	7.44	1.31	15.01
Cabrobó	7.50	1.25	14.28	7.50	1.25	14.28
Petrolina	8.76	0	0	8.76	0	0
Ouricuri	7.18	1.57	18.01	7.18	1.57	18.01

Source: The authors.

Table 3 shows the coefficients of determination (R^2) between data observed and estimated by the three methods in different AWS for air temperature and precipitation. The highest correlations (R^2 = 1) were observed in the weather stations with smaller amounts of missing data in the two variables, being for temperature the municipalities of Recife and Surubim (0.01% and 0.07%, respectively) and precipitation Recife and Salgueiro (0.06% and 15.01%, respectively).

Table 3. Coefficient of determination between observed and estimated dataset by the methods arithmetic mean, regional weighting, and simple linear regression in the air temperature and rainfall in the state of Pernambuco.

City	Air temperature			Rainfall		
	Regional Weighting	**Arithmetic Average**	**Linear Regression**	**Regional Weighting**	**Arithmetic Average**	**Linear Regression**
Recife	0.99	1.00	1.00	1.00	0.59	1.00
Petrolina	1.00	1.00	1.00	0.99	0.91	1.00
Arcoverde	1.00	1.00	1.00	0.81	0.99	0.97
Garanhuns	1.00	1.00	1.00	1.00	0.99	0.99
Surubim	1.00	1.00	1.00	0.51	0.04	0.89
Cabrobó	0.98	0.80	0.98	0.69	0.77	0.30
Caruaru	1.00	1.00	1.00	0.67	0.98	0.98
Ibimirim	0.91	0.95	0.94	0.22	0.96	0.95
S. Talhada	1.00	1.00	1.00	1.00	1.00	1.00
Floresta	0.98	0.99	1.00	0.92	0.80	0.72
Salgueiro	0.31	0.36	0.11	0.96	0.99	0.98
Palmares	0.85	0.59	1.00	0.37	0.29	0.56
Ouricuri	0.94	0.97	1.00	0.78	0.67	0.57

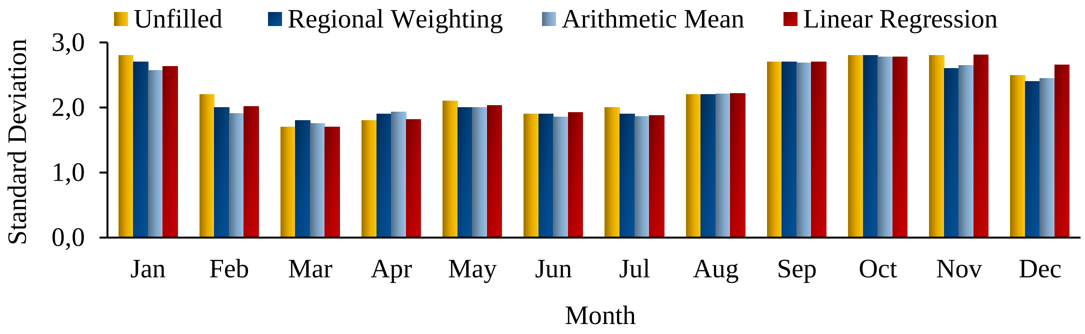
Source: The authors.

In Salgueiro, the air temperature presented the lowest R^2, indicating high dispersion for all evaluated gap-filling methods. On the other hand, the estimated data for the other twelve weather stations presented linear performance with R^2 equal or very close to one, indicating that the three methods showed efficiency in estimating the real data measured in the AWS. This definition is similar to that found in Buriol et al. (2006) in which values of coefficients of determination close to 1 result from database considered homogeneous. The lowest values of R^2 for air temperature in the municipality of Salgueiro are probably related to the semiarid climate, a region characterized by a large variation in annual temperature averages. According to Miao et al. (2015; 2016), due to climatic variations, several regions reflect the changes in the climate average.

The highest and lowest values of R^2 for the rainfall dataset were obtained in Salgueiro and Cabrobó, respectively. The results showed that the regional weighting (R^2 = 1) and simple linear regression (R^2 = 0,99) methods presented values similar or closer to the real data, showing that both methods are suitable for filling gaps in historical series of rainfall data in the AWS of the state of Pernambuco.

The standard deviation of air temperature estimated and observed data was calculated on a monthly scale (Figure 2). March and April presented the lowest values for standard deviation (1.70) based on the simple linear regression statistical method, however, there was no statistical difference for the database not filled out. Consequently, these months were more homogeneous and uniform when compared to the other months of the year analyzed in this study.

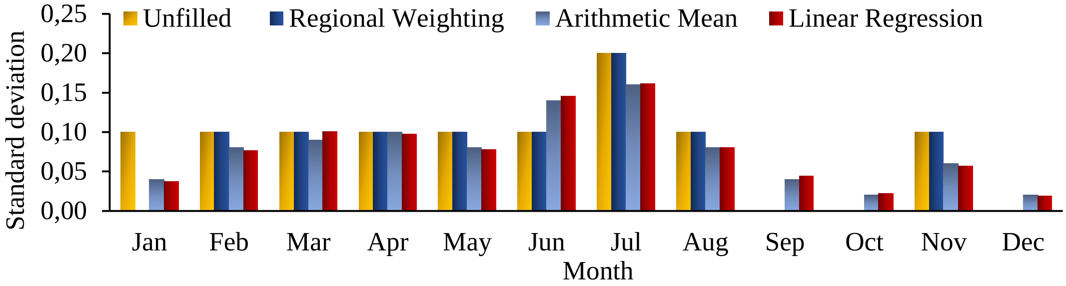
Figure 2. The standard deviation of air temperature estimated and observed data.



Source: The authors.

Figure 3 shows the standard deviation on a monthly scale of rainfall estimates made by each technique used. September, October, December, and January did not show deviation for the regional weighting method, and the data was not filled out. Thus, can be noticed that in these months, the estimate had been more homogeneous compared to the other months. In general, the deviations did not differ between the evaluated methods. Future studies with a broader dataset and greater temporal coverage could reinforce the results found in this study.

Figure 3. The standard deviation of precipitation estimated and observed data.



Source: The authors.

6 CONCLUSIONS

The regional weighting, arithmetic mean, and linear regression methods used to fill gaps showed accuracy in estimating air temperature and precipitation in thirteen municipalities in the state of Pernambuco. The linear regression method presented higher values of coefficient of determination compared to the arithmetic mean and regional weighting methods. The municipalities that performed better in the three methods, in terms of estimating the climatic variables, were those that presented little amount of missing data, highlighting the smallest R^2 observed in Salgueiro, indicating high dispersion for all evaluated missing data filling methods.

For air temperature, the highest and lowest values of R^2 were obtained in Ouricuri and Salgueiro, respectively. While, for precipitation, the highest and lowest values of R^2 were obtained in Salgueiro and Cabrobó, respectively. The lowest values of standard deviation (1.7) for the temperature were in March and April, using the simple linear regression statistical method. As for precipitation, September, October, December, and January did not show any deviation for the regional weighting method and unfilled data, indicating greater uniformity when compared to the other months.

The simple linear regression method is more efficient and suitable, followed by the regional weighting method, to fill in missing data in climate databases.

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