ALTITUDE AND GEOGRAPHIC COORDINATES TO ESTIMATE MONTHLY RAINFALL IN THE STATE OF MATO GROSSO DO SUL

ALTITUDE E COORDENADAS GEOGRÁFICAS NA ESTIMATIVA DA CHUVA MENSAL NO ESTADO DE MATO GROSSO DO SUL

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ABSTRACT: Adjustment of multiple linear regression equations has allowed estimating the value of a certain climatological variable according to geographical coordinates with acceptable degree of accuracy. The aim of this study was to verify if the average monthly rainfall could be estimated according to the altitude, latitude and longitude in Mato Grosso do Sul State (MS). Rainfall data of 32 stations of MS were collected from 1954 to 2013. It were formed 384 time series (12 months × 32 sites), with different numbers of years of observations in each series. On each of the 384 monthly rainfall time series it was calculated the average (a), at least 30 years of observation, forming 12 matrices 32 x 4 (32 sites x 4 variables: altitude, latitude, longitude and monthly rainfall). It was estimated for each matrix the Pearson's linear correlation coefficient among the variables, performing the multicollinearity diagnosis for each matrix. Correlations were unfolded by path analysis in direct and indirect effects and in each month it was used the multiple linear regression model. The altitude and latitude have greater effect on the spatial distribution of rainfall in MS. The multiple linear regression equations generated in this study will subsidize researches of crop zoning, indication for sowing times, irrigation, determination of yield potential, climate risks zoning and credit and agricultural insurance.

KEYWORDS: Correlation. Multiple linear regression. Path analysis.

INTRODUCTION

Mato Grosso do Sul State (MS) covers an area of approximately 350,000 km^2, of which 13,000 km^2 are exploited by agriculture, especially for soybean, corn, cotton, sugarcane sugar and irrigated rice (CONAB, 2014). Among the main factors that influence crop production is rain, because its spatial distribution and temporal variability interfere with agricultural planning, namely, the better time of tillage, harvest, sowing, defensive application and supplementary irrigation (CORRÊA et al., 2014; LYRA et al., 2014; TEODORO et al., 2015a,b; TORRES et al., 2016).

Adjustment of multiple linear regression equations has allowed estimating the value of a certain climatological variable according to the longitude, latitude and altitude; this methodology is widely used in the literature and has presented an acceptable degree of accuracy (MEDEIROS et al., 2005). The estimate of the minimum, medium and maximum monthly and annual air temperatures from the geographic coordinates has been the subject of several studies in different states and regions of Brazil (FERREIRA et al., 1971; COELHO et al., 1973; FERREIRA et al., 1974; FEITOZA et al., 1980a; FEITOZA et al., 1980b; CAMARGO, GHIZZI, 1991; PEDRO JÚNIOR et al., 1991; CAVALCANTI, SILVA, 1994; LUIZ, SILVA, 1995; LIMA, RIBEIRO, 1998; SEDIYAMA, MELO JÚNIOR, 1998; SEDIYAMA et al., 2002; MARIN et al., 2003; MEDEIROS et al., 2005; CARGNELUTTI FILHO et al., 2006; CARGNELUTTI FILHO et al., 2008).

However, did not find any work in the literature that investigated the hypothesis of obtaining the average monthly rainfall by altitude and geographical variables in Midwest region, especially in MS, deficient climatological research. The aim of this study was to verify if the average monthly rainfall could be estimated according to the altitude, latitude and longitude in sites of Mato Grosso do Sul State.

MATERIAL AND METHODS

Study area

Mato Grosso do Sul State is located in the Midwest of Brasil. Has a total area of 357, 145.32 km², composed of 79 municipalities. The state has several features edaphoclimatic distributed among three biomes with peculiar climatic attributes: Savanna, Atlantic Forest and Pantanal. Altitudes ranged from 24 to 1000 m, in the center of the South American continent.

In the state there are three major topographical units: i) Pantanal, in the west portion, with a singular drainage network, spread over an immense plain of modest altitudes between 80 to 200 m; ii) in the center, shows the Divisor Plateau or Serra de Maracajú, elongated in the NE-SW direction, separating the waters

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of the Paraguay and Paraná river basins, with altitudes ranging from 300 m (Serra de Bodoquena) to over 650 m (Plateau of Amambaí); and iii) in the eastern portion, is located the Alto Paraná shaft, drained by major rivers of arenitic-basalt plateau, with altitudes ranging between 200 and 250 m along the trough (ZAVATTINI, 2009).

Data collection

Rainfall data of 32 stations (sites) of Mato Grosso do Sul (MS) were obtained of the National Water Agency Database (ANA, 2014), collected from 1954 to 2013 (Table 1). At each site and year, the rainfall daily data were added up to obtain the monthly rainfall (mm monthly^{-1}), of each month of the year. Thus, were formed 384 time series (12 months × 32 sites), with different numbers of years of observations in each series, defined according to the availability of meteorological data.

Table 1. Altitude (m), latitude and longitude (°) and observation period of monthly rainfall of 32 municipalities in Mato Grosso do Sul, Brazil.

Site	Altitude (m)	Latitude (S, °)	Longitude (W, °)	Period
Água Clara	376	20°6’7’’	52°55’33”	1975-2013
Amambai	395	22°55’59’’	55°13’0’’	1973-2013
Anastácio	106	19°34’0’’	56°12’0’’	1960-2000
Anaurilândia	284	22°11’11’’	52°42’48’’	1975-2013
Aparecida do Taboado	375	20°1’6’’	51°6’13’’	1983-2013
Aquidauana	155	20°27’24’’	55°40’17’’	1960-2000
Bataguassu	293	21°43’33’’	52°20’3’’	1975-2013
Bodoquena	133	19°52’15’’	56°59’1’’	1954-2013
Caarapó	454	22°37’28’’	54°49’29’’	1973-2013
Camapuã	404	19°29’48’’	53°59’48’’	1973-2013
Campo Grande	559	20°28’0’’	54°40’0’’	1975-2013
Chapadão do Sul	570	18°59’52’’	52°35’17’’	1983-2013
Corumbá	101	17°37’24’’	56°57’54’’	1983-2013
Costa Rica	635	18°32’50’’	53°8’7’’	1983-2013
Coxim	250	18°38’57’’	54°21’26’’	1973-2013
Dourados	293	22°23’53’’	54°47’30’’	1973-2013
Glória de Dourados	422	22°24’21’’	54°14’7’’	1973-2013
Iguatemi	333	23°40’55’’	54°33’42’’	1975-2013
Inocência	502	19°44’11’’	51°56’1’’	1983-2013
Maracaju	356	21°37’7’’	55°8’13’’	1973-2013
Miranda	140	20°6’7’’	56°47’43’’	1960-2000
Navirai	366	23°3’28’’	54°11’38’’	1975-2013
Nova Andradina	271	21°36’55’’	53°3’8’’	1975-2013
Paranaíba	458	19°23’27’’	51°36’32’’	1983-2013
Ponta Porã	650	22°32’0’’	55°43’0’’	1973-2013
Porto Murtinho	83	21°42’5’’	57°53’30’’	1983-2013
Ribas do Rio Pardo	373	20°26’41’’	53°45’29’’	1975-2013
Rio Brilhante	287	21°38’50’’	54°25’31’’	1973-2013
Rio Negro	233	19°26’23’’	54°59’0’’	1975-2013
Santa Rita do Pardo	393	21°17’43’’	52°48’38’’	1975-2013
Selviria	348	20°21’49’’	51°25’26’’	1983-2013
Três Lagoas	313	20°47’41’’	51°42’46’’	1975-2013

Statistical analysis

On each of the 384 monthly rainfall time series it was calculated the average (a), at least 30 years of observation, forming 12 matrices 32 x 4, being 32 the number of sites and 4 the number of variables (altitude, latitude, longitude and monthly rainfall). Initially, we estimated for each matrix the Pearson’s linear correlation coefficient (r) among the variables. The multicollinearity diagnosis was performed for each matrix to keep control about which variables (very correlated with others) could be excluded from the study in order to avoid estimates of biased direct and indirect effects in path analysis.

Subsequently, the correlations were unfolded by path analysis in direct and indirect effects, considering the following model: $Y = p_1X_1 + p_2X_2 + ... + p_nX_n + p_\varepsilon u$, wherein Y is the principal dependent variable (monthly rainfall); $X_1, X_2, ..., X_n$: are the independent explanatory variables (altitude, latitude, longitude); $p_1, p_2, ..., p_n$: are the path analysis coefficients. The coefficient of determination was calculated by the expression $R^2 = p_{1y}^2 + p_{2y}^2 + ... 2p_{2y}p_{2n}r_{2n}$.

In each month, we used the multiple linear regression model with k independent variables: $Y_j = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \varepsilon_i$, wherein Y_j is the observed value of the average monthly rainfall; β_0 is the linear coefficient; β_i is the regression coefficient of the independent variables X_i; X_{ij} are the independent variable X_i in the observation j; and ε is the error associated to variable Y in the observation j. In this model, the variable Y is the linear function of the independent variables; the values of the independent variables are fixed; and errors has zero average, are homocedastic, independent and with normal distribution (HOFFMANN; VIEIRA, 1998; SOUZA, 1998).

The parameters of multiple linear regression equations model were estimated by step by step with test for variable output (stepwise backward), being the average monthly rainfall the dependent variable and the other (altitude, latitude and longitude) the independents, as performed by Cargnelutti Filho et al. (2006, 2008). Statistical analyzes were carried out with the applications GENES (CRUZ, 2013) and Microsoft Office Excel®.

RESULTS AND DISCUSSION

There was similar score and signal of r coefficient among the average monthly rainfall and altitude (0.29< r <0.57) and longitude (-0.58< r <-0.41) (Table 2). Cargnelutti Filho et al. (2006) and Cargnelutti Filho et al. (2008) when estimating the maximum and minimum decendial temperatures in Rio Grande do Sul State, respectively, through the altitude and geographic coordinates verified r in similar magnitudes to those observed in this study. In principle, these results indicate that rainfall in Mato Grosso do Sul State is directly related to the geographic distribution of its municipalities.

Table 2. Estimate of Pearson's correlation coefficient (r) among average monthly rainfall (mm month^{-1}) with the altitude (m), latitude and longitude (°) in Mato Grosso do Sul, Brazil.

Month	Altitude (m)	Latitude (S,°)	Longitude (W,°)
January	0.42*	-0.62**	-0.56**
February	0.56**	-0.40*	-0.58**
March	0.57**	-0.52**	-0.51**
April	0.44*	0.37*	0.13^{ns}
May	0.20^{ns}	0.78**	0.21^{ns}
June	0.05^{ns}	0.79**	0.27^{ns}
July	0.05^{ns}	0.84**	0.20^{ns}
August	0.21^{ns}	0.78**	0.10^{ns}
September	0.29*	0.81**	-0.02^{ns}
October	0.45*	0.54**	0.06^{ns}
November	0.53**	0.05^{ns}	0.10^{ns}
December	0.47**	-0.55**	-0.41*

^{ns}, * and ** not significant, sigificant at 5 and 1% probability, respectively, by t-test, with 29 degrees of freedom.

The monthly rainfall positively correlated with altitude in the months from September to April (dry season). The monthly rainfall correlated positively with latitude in the months from April to October and negatively in the months from December to March. The monthly rainfall was negatively correlated with the longitude in the months from December to January (wet season). The topographic aligning, arranged in the longitudinal direction (NE-SW), shows morphological features well defined: the plain and the plateau. This arrangement exerts strong influence in the rainfall behavior in Mato Grosso do Sul State (NIMER, 1989; CORRÊA et al., 2014; TEODORO et al., 2015a,b). Given these results, we can infer that a multiple linear regression model is adequate to estimate the average monthly rainfall according to altitude, latitude and longitude.

Estimative r is a measure of association that assesses the linear relationship degree among the variables. Only this parameter is not possible to conclude what effect direct and/or indirect of the altitude, latitude and longitude on the average monthly rainfall. Thus, the path analysis is appropriate for these inferences, since investigates these relationships and provides scores, called path coefficients, which measure the influence of a variable on the other, independently from the others, allowing unfold the simple correlation coefficients in effect direct and indirect (VENCOVSKY; BARRIGA, 1992; TEODORO et al., 2014).

The multicollinearity diagnosis among the variables showed weak collinearity in 12 matrices of correlation coefficients, with condition number ranging between 12 and 18, which allows the performance of analysis without discarding variables for its realization. The unfolding of the total correlation of each variable (altitude, latitude and longitude) on the variable average monthly rainfall in direct and indirect effects is showed in Table 3.

Table 3. Estimate of Pearson's correlation coefficients and estimate of the direct and indirect effects of the variables altitude (ALT), latitude (LAT) and longitude (LON) on the average monthly rainfall in Mato Grosso do Sul, Brazil.

Effect	ALT	LAT	LON	ALT	LAT	LON	ALT	LAT	LON
		January			February			March	
Direct on RAINF	0.27	0.62	-0.39	0.42	-0.42	-0.35	0,50	-0.55	-0.23
Indirect by ALT	---	0.02	-0.14	---	0.04	-0.21	---	0.04	-0.25
Indirect by LAT	-0.05	---	-0.03	-0.04	---	-0.02	-0,05	---	-0.03
Indirect by LON	0.20	-0.02	---	0.18	-0.02	---	0,12	-0.01	---
Total (r)	0.42*	0.62**	-0.56**	0.56**	0.40*	-0.58**	0,57**	-0.52**	-0.51**
		April			May			June	
Direct on RAINF	0.64	0.30	0.44	0.31	0.74	0.34	0,14	0.76	0.30
Indirect by ALT	---	0.05	-0.32	---	0.03	-0.16	---	0.02	-0.07
Indirect by LAT	0.03	---	0.01	0.06	---	0.03	0,07	---	0.04
Indirect by LON	-0.23	0.02	---	-0.17	0.01	---	-0,16	0.02	---
Total (r)	0.44*	0.37*	0.13^{ns}	0.20^{ns}	0.78**	0.21^{ns}	0,05^{ns}	0.79**	0.27^{ns}
		July			August			September	
Direct on RAINF	0.08	0.82	0.20	0.24	0.75	0.19	0,26	0.78	0.08
Indirect by ALT	---	0.01	-0.04	---	0.02	-0.12	---	0.02	-0.13
Indirect by LAT	0.07	---	0.04	0.06	---	0.03	0,07	---	0.03
Indirect by LON	-0.10	0.01	---	-0.09	0.01	---	-0,03	0.01	---
Total (r)	0.05 ^{ns}	0.84**	0.20^{ns}	0.21^{ns}	0.78**	0.10^{ns}	0,29^{ns}	0.81**	-0.02^{ns}
		October			November			December	
Direct on RAINF	0.58	0.48	0.34	0.79	-0.04	0.50	0,44	-0.58	-0.16
Indirect by ALT	---	0.05	-0.29	---	0.07	-0.40	---	0.04	-0.22
Indirect by LAT	0.04	---	0.01	0.00	---	0.00	-0,05	---	-0.03
Indirect by LON	-0.17	0.1	---	-0.26	0.02	---	0,08	-0.01	---
Total (r)	0.45*	0.54**	0.06^{ns}	0.53**	0.05^{ns}	0.10^{ns}	0,47**	-0.55**	-0.41*

^{ns}, * and ** not significant, sigificant at 5 and 1% probability, respectively, by t-test, with 29 degrees of freedom.

In the 12 months of the year, the causal variable altitude showed direct effect on average monthly rainfall, which allows us to infer that largest average monthly rainfall will proceed in the highest places of Mato Grosso do Sul. This behavior demonstrates that despite tropical features present in the State, altitude is among the physiographic factors, followed by the latitude, which most influences the monthly rainfall behavior in dry, transition and rainy periods, resembling to results obtained by researches carried out in other Brazilian states (BAÚ et al. 2006; ANDRÉ et al. 2008; ÁVILA et al. 2009; TEODORO et al., 2015b).

It was observed in Table 4 a high coefficient of determination (R²) for multiple linear regression equations for Mato Grosso do Sul, independent of the month. Cargnelutti Filho et al. (2006) and Cargnelutti Filho et al. (2008), when estimating the maximum and minimum decendial temperatures, respectively, through the altitude and geographic coordinates, verified R² in lower magnitudes to those observed in this study. This indicates good credibility of the equations generated to estimate monthly rainfall of Mato Grosso do Sul municipalities through geographic coordinates.

Table 4. Estimate of the parameters (β_0, β_1, β_2 and β_3) of the multiple linear regression and coefficient of determination (R^2), of average monthly rainfall according to altitude (m), latitude (°) and longitude (°), in Mato Grosso do Sul, Brazil.

Month	Constant (β_0)	Altitude (β_1)	Latitude (β_2)	Longitude (β_3)	R²
January	1056.92	-0.08	-18.06	-9.15	0,85
February	659.11	0.09	-9.03	-6.02	0,78
March	589.88	0.10	-11.83	-4.16	0,83
April	-315.24	4.69	5.25	0.09	0,65
May	-468.63	0.05	13.01	4.89	0,85
June	-468.31	0.03	13.10	4.40	0,84
July	-214.77	0.01	7.66	1.53	0,86
August	-219.44	0.02	7.54	1.65	0,81
September	-231.13	0.04	12.08	0.91	0,85
October	-378.64	0.11	9.08	5.23	0,73
November	-234.06	0.12	-0.56	6.62	0,69
December	530.04	0.08	-11.04	-2.54	0,77

CONCLUSION

The altitude and latitude have greater effect on the spatial distribution of rainfall in Mato Grosso do Sul State. The multiple linear regression equations generated in this study will subsidize researches of crop zoning, indication for sowing times, irrigation, determination of yield potential, climate risks zoning and credit and agricultural insurance.

RESUMO: O ajuste de equações de regressão linear múltipla tem possibilitado que se estime o valor de uma determinada variável climatológica em função das coordenadas geográficas com grau aceitável de acurácia. O objetivo do trabalho foi verificar se a chuva mensal média pode ser estimada em função da altitude, latitude e longitude no Estado do Mato Grosso do Sul (MS). Os dados pluviométricos de 32 estações do MS foram coletados do período de 1954 a 2013. Formaram-se 384 séries temporais (12 meses × 32 locais), com número diferenciado de anos de observações em cada série. Em cada série temporal de chuva mensal calculou-se a média, formando-se 12 matrizes de 32 x 4 (32 locais e 4 variáveis: altitude, latitude, longitude e chuva mensal). Estimou-se para cada matriz o coeficiente de correlação linear de Pearson entre as variáveis, realizando-se o diagnóstico multicolinearidade para cada matriz. As correlações foram desdobradas, por meio da análise de trilha, em efeitos diretos e indiretos e em cada mês foi usado o modelo de regressão linear múltipla. A altitude e latitude exercem maior efeito na distribuição espacial da chuva no MS. As equações de regressão linear múltipla geradas neste estudo subsidiarão trabalhos de zoneamento de culturas, indicação de épocas de semeadura, irrigação, determinação de potencial de rendimento, zoneamento de riscos climáticos, crédito e seguro agrícola.

PALAVRAS-CHAVE: Correlação. Regressão linear múltipla. Análise de trilha.

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