METHODOLOGY FOR SPATIALIZATION OF INTENSE RAINFALL EQUATION PARAMETERS

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ABSTRACT: The aim of this study was to generate maps of intense rainfall equation parameters using interpolated maximum intense rainfall data. The study area comprised Espírito Santo State, Brazil. A total of 59 intense rainfall equations were used to interpolate maximum intense rainfall, with a 1 x 1 km spatial resolution. Maximum intense rainfall was interpolated considering recurrence of 2; 5; 10; 20; 50 and 100 years, and duration of 10; 20; 30; 40; 50; 60; 120; 240; 360; 420; 660; 720; 900; 1,140; 1,380 and 1,440 minutes, resulting in 96 maps of maximum intense rainfall. The used interpolators were inverse distance weighting and ordinary kriging, for which significance level (p-value) and coefficient of determination (R^2) were evaluated for the cross-validation data, choosing the method that presented better R^2 to generate maps. Finally, maps of maximum intense precipitation were used to estimate, cell by cell, the intense rainfall equation parameters. In comparison with literature data, the mean percentage error of estimated intense rainfall equations was 13.8%. Maps of spatialized parameters, obtained in this study, are of simple use; once they are georeferenced, they may be imported into any geographic information system to be used for a specific area of interest.

KEYWORDS: intensity-duration-frequency equation, geostatistics, hydrology.

METODOLOGIA PARA A ESPACIALIZAÇÃO DOS PARÂMETROS DA EQUAÇÃO DE CHUVAS INTENSAS

RESUMO: Este trabalho tem como objetivo apresentar uma metodologia para espacializar os parâmetros da equação de chuvas intensas. A área de estudo abrange o território do Espírito Santo. Foram utilizadas um total de 59 equações de chuvas intensas. A partir destas equações foram calculadas e interpoladas as chuvas intensas máximas, com uma resolução espacial de 1 km por 1 km, para os períodos de retorno de 2; 5; 10; 20; 50 e 100 anos e durações de 10; 20; 30; 40; 50; 60; 120; 240; 360; 420; 660; 720; 900, 1140; 1380 e 1440 min, totalizando 96 mapas de intensidades máximas de precipitação. Os interpoladores utilizados foram o inverso da distância elevada a uma potência e a krigagem ordinária, para os quais se avaliaram, nos dados da tabulação cruzada, nível de significância (valor-p<0,05) e coeficiente de determinação (R^2), sendo escolhido como método de interpolação aquele significativo e de maior R^2. Por meio dos dados espacializados, foram estimados os parâmetros da equação de chuvas intensas. Quando comparadas as equações de chuvas intensas da literatura com as estimadas deste trabalho, o erro médio percentual foi de 13,8%. Os mapas dos parâmetros especializados deste trabalho são de simples utilização, uma vez que podem ser importados em ambiente de sistemas de informação geográfica e fazer a consulta dos parâmetros para a área de interesse.

PALAVRAS-CHAVE: equação intensidade-duração-frequência, geoestatística, hidrologia.

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INTRODUCTION

An intense rainfall is defined as a large volume of water precipitated in a short time, with both spatial and temporal irregular distribution (ARAÚJO et al., 2008). Its quantification is of great interest, as it may cause several adverse effects, such as destruction of dams and bridges, soil erosion, increase of river and lake siltation, flood of urban and rural areas, and fall of barriers (PRUSKI et al., 2006; OLIVEIRA et al., 2008).

For hydraulic dimensioning of engineering works for protection against these adverse effects, such as rainwater galleries, draining channels, dams, spillways, and agricultural terrace systems, hydrologic models are used to estimate runoff volume and/or flow, for which the specific work will have to operate without damage. Such models usually consider, for the rainfall variable, intensity, duration, and frequency. These rainfall characteristics may be related to each other via intense rainfall equations; the most used one is as follows:

$$i_m = KT^a/(t+b)^c \quad (1)$$

where,

i_m - rainfall mean maximum intensity, in mm/h;
T - recurrence period, in years;
t - rainfall duration, in minutes, and
K, a, b, c - parameters related to the area of interest.

An intense rainfall equation is only valid for the area where it was established, and for those *t* and *T* value ranges used for its determination. If there is no available equation for a specific area, the established one for the closest location may be used provided it has similar climatic conditions (DAMÉ et al., 2008). Also, parameters determined for locations close to the area of interest may be interpolated (MELLO et al., 2003; PRUSKI et al., 2006; CECÍLIO et al., 2009). For such interpolations, MELLO et al. (2003), who used the ordinary kriging and inverse distance squared methods, verified that ordinary kriging leaded to the best results; however, errors found for some locations were superior to 30% for some rainfall duration and recurrence periods. On the other hand, CECÍLIO & PRUSKI (2003) interpolated i_m equation parameters by the inverse distance weighting method, with different powers, in Minas Gerais State, Brazil, and obtained a minimum mean error of 18.7% for rainfall duration of 60 minutes and recurrence period of 10 years; for other conditions of *T* and *t*, the mean error was not established.

Nevertheless, results obtained using spatial interpolation procedures have not been, in general, consistent; that is, they have not provided good rainfall intensity estimates. CECÍLIO et al. (2009) and SENNA et al. (2010), when evaluating i_m estimate quality in Espírito Santo State, Brazil, for several conditions of *t* and *T*, from parameters interpolated by the inverse distance method, verified that errors may be unacceptable for certain *t* and *T* values, suggesting that other methods should be evaluated. MELLO et al. (2008), when analyzing the spatial continuity of intense rainfall in Minas Gerais, propose other approach to the problem and, instead of interpolating equation parameters, interpolated rainfall intensity for different duration and recurrence periods. The same result was found by SANTOS et al. (2009).

Thus, a new spatialization methodology for *K*, *a*, *b*, and *c* parameters of intense rainfall equations is necessary. Since the spatial interpolation of rainfall intensity values seems to be more indicated (MELLO et al., 2008; SANTOS et al., 2009), this study considers that i_m maps with different *t* and *T* may be used for constructing spatial representation maps of intense rainfall equation parameters.

The main objective of this study was to propose a spatialization methodology for intense rainfall equation parameters. The specific objectives are: to evaluate the spatial distribution and density of stations with existing intense rainfall equations; to evaluate inverse distance interpolators and ordinary kriging for spatialization of intense rainfall maximum intensities, with different duration and recurrence periods; and to generate a product of simple use.

MATERIAL AND METHODS

The study area comprised Espírito Santo State, located approximately between 17º53’ and 21º19’ S, and 39º38’ and 41º54’ W. A total of 59 locations, with intense rainfall equations, were considered and, from those, 20 are in the state (Figure 1). Equations related to locations outside the state were used as estimate edges in the state west, north, and south regions, as well as to increase sample number. These were collected in the literature (SILVA et al., 1999; FREITAS et al., 2001), which references, names, locations, and parameters are indicated in Table 1 for Espírito Santo State.

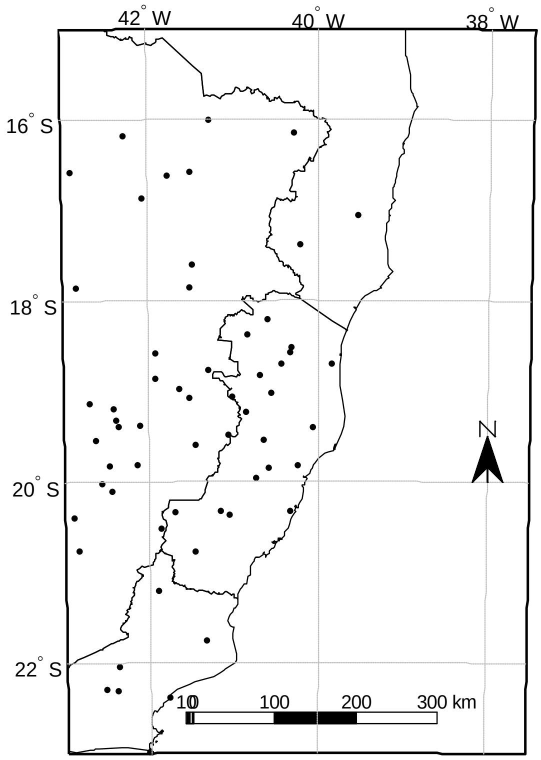

FIGURE 1. Location of the used intense rainfall equations.

TABLE 1. Station names in Espírito Santo State, Brazil, and respective references, locations, and intense rainfall equation parameters.

Reference	Station name	Latitude (S)	Longitude (W)	*K*	*a*	*B*	*c*
SILVA et al. (1999)	Alegre	20°46'	41°28'	1,497.7	0.258	19.294	0.855
FREITAS et al. (2001)	Alto Rio Novo	19°03'	41°01'	1,908.1	0.208	18.432	0.926
FREITAS et al. (2001)	Aracê	20°22'	41°03'	880.4	0.175	9.722	0.729
SILVA et al. (1999)	Aracruz	19°49'	40°15'	1,298.3	0.200	20.981	0.786
SILVA et al. (1999)	Boa Esperança	18°31'	40°19'	596.3	0.230	8.534	0.670
FREITAS et al. (2001)	Caldeirão	19°57'	40°44'	3,777.0	0.196	46.751	0.947
FREITAS et al. (2001)	Cedrolândia	18°48'	40°41'	4,000.0	0.178	51.492	0.920
FREITAS et al. (2001)	Colatina	19°32'	40°38'	709.9	0.201	7.331	0.687
FREITAS et al. (2001)	Córrego B. Espe.	18°42'	40°26'	4,350.7	0.202	40.254	1.003
FREITAS et al. (2001)	Ecoporanga	18°21'	40°50'	5,666.1	0.197	43.631	1.055
SILVA et al. (1999)	Linhares	19°24'	40°04'	3,647.2	0.223	20.665	1.000
FREITAS et al. (2001)	Pancas	19°13'	40°51'	1,227.8	0.185	20.628	0.758
FREITAS et al. (2001)	Patrimônio S. N.	18°12'	40°36'	2,407.0	0.187	34.383	0.877
FREITAS et al. (2001)	Santa C. Caparaó	20°19'	41°42'	3,873.6	0.180	35.418	0.986
SILVA et al. (1999)	Santa Teresa	19°51'	40°36'	632.2	0.247	13.543	0.714
SILVA et al. (1999)	São G. da Palha	19°01'	40°34'	1,309.2	0.230	15.375	0.821
FREITAS et al. (2001)	São J. da C. G.	18°33'	40°20'	5,829.1	0.192	33.421	1.089
SILVA et al. (1999)	São Mateus	18°42'	39°51'	4,999.3	0.191	49.999	0.983
SILVA et al. (1999)	Venda Nova	20°19'	41°10'	4,147.0	0.205	33.842	1.000
SILVA et al. (1999)	Vitória	20°19'	40°20'	4,003.6	0.203	49.997	0.931

Aiming at a brief evaluation of station distribution in the study area, an estimate of station density was generated by the Kernel method (MARTINEZ & MARTINEZ, 2008):

$$\hat{\lambda}_h(s) = \sum_{d_i \le h} \frac{3}{\pi h^2}\left(1 - \frac{d_i^2}{h^2}\right)^2 \quad (2)$$

where,

$\hat{\lambda}_h(s)$ - density estimate in the geographic position s;

h - estimate band size, and

d_i - distance between s and the location of the observed events (s_i).

Interpolation of intense rainfall maximum intensities (i_m), calculated by Equation 1 for each location, was performed for rainfall recurrence periods (*T*) of 2; 5; 10; 20; 50 and 100 years, and durations (*t*) of 10; 20; 30; 40; 50; 60; 120; 240; 360; 420; 660; 720; 900; 1,140; 1,380 and 1,440 minutes. Numbers of *T* and *t* resulted in 96 possible combinations of intense rainfall (six recurrence periods x 16 durations). The interpolated values of intense rainfall maximum intensities are called i_{m_int}.

For each of the 96 combinations, spatialization was evaluated testing the methods of ordinary kriging, and inverse distance weighting with different powers (SMITH et al., 2007). For kriging, the following theoretical models were used for semivariance: spherical, Gaussian, exponential, and linear. Since this is an initial study, anisotropy in the data spatial variation was not considered (WEBSTER & OLIVER, 2007). For the inverse distance weighting methodology, power values of 1; 2; 3; 4 and 5 were evaluated, and the number of nearest neighbors to be used in the interpolation ranged from 1 to 30. Interpolation and statistical evaluation were performed by a set of modules written in MATLAB R2010 (MATHWORKS, 2010; XAVIER et al., 2010).

For each *T* and *t* combination, rainfall intensity was calculated and respective data, interpolated, generating the cross-validation statistics (estimated value versus calculated value) and considering the methods of kriging and inverse distance weighting with different powers. The best method was chosen by evaluating the significance level ($p<0.05$) and determination coefficient (R^2) of the cross-validation data (i_m versus i_{m_int}) from the used stations. When there was no spatial correlation, the rainfall intensity mean was adopted as the best cell estimate.

After selection of the best interpolators for 96 i_m value sets, these were interpolated in a matrix grid with 1 x 1 km cells. Interpolated data were then adjusted to the intense rainfall equation (Equation 1), and new parameters *K*, *a*, *b*, and *c*, corresponding to each matrix grid pixel, were estimated. There is now a new intense rainfall equation generated from i_{m_int} data, which was compared with the original one (i_{m_orig}) by calculating the relative error for pairs of the considered *T* and *t* values ($E_{[T,t]}$), as follows:

$$E_{[T,t]} = 100\frac{i_{m\_int[T,t]} - i_{m\_orig[T,t]}}{i_{m\_orig[T,t]}} \quad (3)$$

From these data, it was possible to create an isoline map for a more appropriate error evaluation regarding its magnitude and possible dependences related to *T* and *t*.

RESULTS AND DISCUSSION

The station density, used in this study, is presented in Figure 2. The used band size (*h*) of Kernel estimator was 0.9º, what results in a determined station number for each 10^4 km^2. Thus, station density in the area is low, with higher concentration in the northeastern region that varies from six to eight stations each 10^4 km^2; the southwest presents an inferior number, from two to four stations each 10^4 km^2; finally, the lowest number, below two stations each 10^4 km^2, was found in the coastal region due to high data amount under the ocean and, also, in mainland. Since the number of stations with intense rainfall equations is low, the need for other methods of equation estimate is highlighted, as performed in this study.

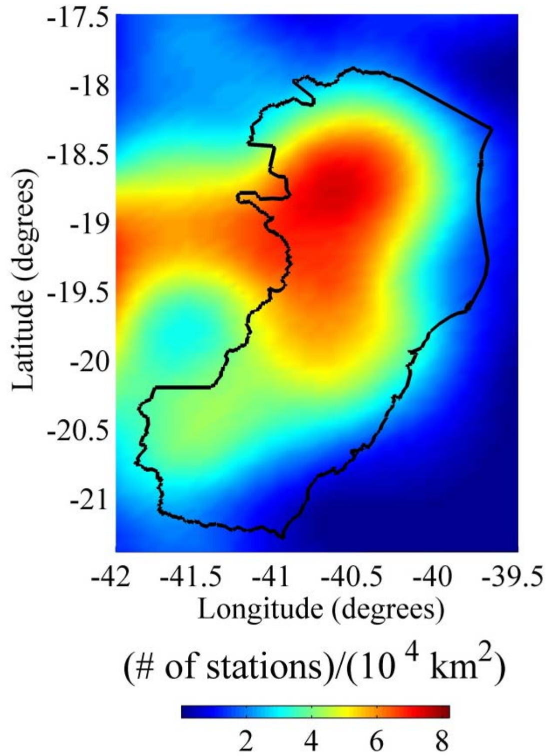

FIGURE 2. Density of locations with intense rainfall equations.

Combinations of *T* and *t*, that presented significant relationships in the evaluation of cross-validation data, are shown in Table 2. From 96 analyzed combinations of intense rainfall maximum intensity, 59 were significant ($p<0.05$), i.e., presented spatial correlation according to the methods used in this study. The highest R^2 value among the interpolated and calculated data for maximum rainfall intensity was 0.22 (T = 2 years with t = 420; 660 and 720 min); these interpolations were performed by the inverse distance method, with power value of 2 and number of nearest neighbors of 8 and 9. On the other hand, the lowest R^2 was 0.07 (T = 100 years, and t = 60 min), which interpolation was carried out by ordinary kriging with the Gaussian semivariance model. From those 59 significant relationships, the inverse distance method was better in 49 of them: 34 with power value of 1; 14 with power value of 2; and only one with power value of 3.

Ordinary kriging was the method that presented the best result of intense rainfall intensity estimate, with 10 *t* and *T* combinations. The better adjusted models to the experimental semivariance were the Gaussian and exponential ones, both with five events. Model range values were 0.5^o similar (~ 50 km), that is, intense rainfall in a specific location of the study area is only related to the intense rainfall that occurs in up to 50 km around it. For the other non-significant 35 combinations, i_m mean values were considered as the best estimate.

TABLE 2. Statistics and parameters of those models/methods that presented maximum R^2 in the cross-validation data for different combinations among rainfall recurrence (*T*) and duration (*t*).

T(years)	*t(min)*	Interpolator	R^2	p-value	RMSE	# of neighbors	Co	C_1	Range (h)
2	120	Inverse distance (r=3)	0.07	0.04	4.68	20	-	-	-
2	240	Inverse distance (r=2)	0.16	0.00	2.78	8	-	-	-
2	360	Inverse distance (r=2)	0.21	0.00	2.09	8	-	-	-
2	420	Inverse distance (r=2)	0.22	0.00	1.89	8	-	-	-
2	660	Inverse distance (r=2)	0.22	0.00	1.45	9	-	-	-
2	720	Inverse distance (r=2)	0.22	0.00	1.38	9	-	-	-
2	900	Inverse distance (r=2)	0.21	0.00	1.23	9	-	-	-
2	1,140	Inverse distance (r=2)	0.19	0.00	1.10	9	-	-	-
2	1,380	Inverse distance (r=2)	0.17	0.00	1.00	9	-	-	-
2	1,440	Inverse distance (r=2)	0.17	0.00	0.98	9	-	-	-
5	240	Inverse distance (r=1)	0.15	0.00	3.24	8	-	-	-
5	360	Inverse distance (r=1)	0.20	0.00	2.46	8	-	-	-
5	420	Inverse distance (r=1)	0.21	0.00	2.23	8	-	-	-
5	660	Inverse distance (r=1)	0.22	0.00	1.72	8	-	-	-
5	720	Inverse distance (r=1)	0.21	0.00	1.65	8	-	-	-
5	900	Inverse distance (r=2)	0.20	0.00	1.47	9	-	-	-
5	1,140	Inverse distance (r=2)	0.18	0.00	1.31	9	-	-	-
5	1,380	Inverse distance (r=2)	0.17	0.00	1.20	9	-	-	-
5	1,440	Inverse distance (r=2)	0.16	0.00	1.18	9	-	-	-
10	240	Gaussian Model	0.15	0.00	3.67	-	10.82	4.95	0.004
10	360	Inverse distance (r=1)	0.19	0.00	2.80	8	-	-	-
10	420	Inverse distance (r=1)	0.20	0.00	2.55	8	-	-	-
10	660	Inverse distance (r=1)	0.21	0.00	1.98	8	-	-	-
10	720	Inverse distance (r=1)	0.20	0.00	1.89	8	-	-	-
10	900	Inverse distance (r=1)	0.19	0.00	1.69	9	-	-	-
10	1,140	Inverse distance (r=1)	0.17	0.00	1.50	9	-	-	-
10	1,380	Inverse distance (r=1)	0.16	0.00	1.37	9	-	-	-
10	1,440	Inverse distance (r=2)	0.16	0.00	1.36	9	-	-	-
20	120	Gaussian Model	0.08	0.03	7.17	-	25.53	24.36	0.60
20	240	Exponential Model	0.14	0.00	4.28	-	5.16	17.23	0.61
20	360	Inverse distance (r=1)	0.18	0.00	3.24	8	-	-	-
20	420	Inverse distance (r=1)	0.19	0.00	2.94	8	-	-	-
20	660	Inverse distance (r=1)	0.19	0.00	2.29	8	-	-	-
20	720	Inverse distance (r=1)	0.19	0.00	2.19	8	-	-	-
20	900	Inverse distance (r=1)	0.18	0.00	1.96	8	-	-	-
20	1,140	Inverse distance (r=1)	0.16	0.00	1.74	9	-	-	-
20	1,380	Inverse distance (r=1)	0.15	0.00	1.59	9	-	-	-
20	1,440	Inverse distance (r=1)	0.15	0.00	1.56	9	-	-	-
50	120	Gaussian Model	0.11	0.01	8.64	-	34.29	38.19	0.63
50	240	Exponential Model	0.15	0.00	5.09	-	2.49	29.64	0.47
50	360	Exponential Model	0.15	0.00	4.07	-	4.48	15.64	0.60
50	420	Inverse distance (r=1)	0.16	0.00	3.61	8	-	-	-
50	660	Inverse distance (r=1)	0.17	0.00	2.81	8	-	-	-
50	720	Inverse distance (r=1)	0.17	0.00	2.69	8	-	-	-
50	900	Inverse distance (r=1)	0.16	0.00	2.41	8	-	-	-
50	1,140	Inverse distance (r=1)	0.14	0.00	2.14	9	-	-	-
50	1,380	Inverse distance (r=1)	0.13	0.00	1.95	9	-	-	-
50	1,440	Inverse distance (r=1)	0.13	0.01	1.91	9	-	-	-
100	60	Gaussian Model	0.07	0.05	16.43	-	123.03	90.36	0.79
100	120	Gaussian Model	0.11	0.01	10.51	-	43.34	61.44	0.66
100	240	Exponential Model	0.14	0.00	5.91	-	0	42.73	0.38
100	360	Exponential Model	0.14	0.00	4.74	-	3.97	23.09	0.52
100	420	Inverse distance (r=1)	0.13	0.00	4.26	8	-	-	-
100	660	Inverse distance (r=1)	0.15	0.00	3.31	8	-	-	-
100	720	Inverse distance (r=1)	0.14	0.00	3.17	8	-	-	-
100	900	Inverse distance (r=1)	0.14	0.00	2.83	8	-	-	-
100	1,140	Inverse distance (r=1)	0.13	0.01	2.52	9	-	-	-
100	1,380	Inverse distance (r=1)	0.12	0.01	2.29	9	-	-	-
100	1,440	Inverse distance (r=1)	0.11	0.01	2.24	9	-	-	-

From the interpolated data, the intense rainfall equation was adjusted to the same locations where the state stations are situated. To illustrate the comparison between the generated equation from the interpolated i_m values and that created from pluviograph data (available in the literature), equations from Alegre Station were considered (Figure 3). The result of the intense rainfall interpolation for 96 combinations of T and t, for Alegre, is presented in Figure 3a, as well as the graph of the intense rainfall function equation adjusted to these data. It is noted that, in the Alegre data interpolation, the original intense rainfall equation is removed from the database. Once more, from 96 interpolated values shown in the figure, 59 were estimated by the methods presented in Table 2, and the others from the intense rainfall mean of the used 58 equations. Data adjustment to intense rainfall is very good, presenting a regression mean error of 4.2 mm h^{-1}. The graphic result from the Equation generated by SILVA et al. (1999) for that county, using pluviograph data, is presented in Figure 3b. Finally, Figure 3c shows the relative error (E) between the equation from this study and that obtained by SILVA et al. (1999). For Alegre, the mean percentage error (MPE) was 7.6%, with greater underestimate. The greatest underestimate, of around -15%, occurred for the highest T and t values, while overestimates of around 10% occurred for T and t lower than, respectively, 10 years and 200 min.

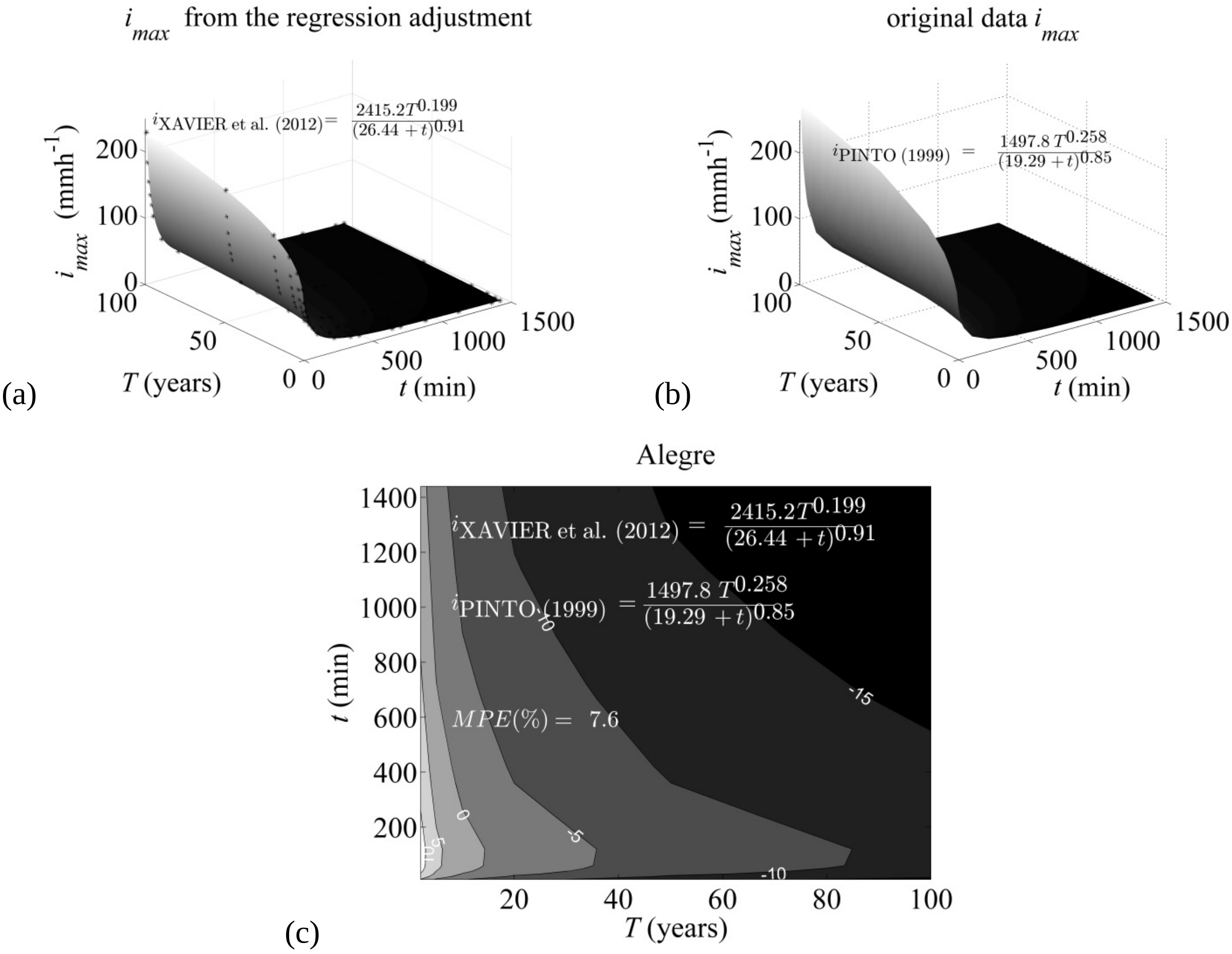

FIGURE 3. Interpolated intense rainfall for Alegre and adjustment to the intense rainfall equation (a); intense rainfall equation surface plot for Alegre, according to Pinto (1999) (b); and relative error between equations from this study and from Pinto (1999) (c).

The same analysis was performed for the other stations, and general results are presented in Table 3. There was no relationship of a standard behavior and E with T and t, i.e., it is not possible to affirm that for higher T or t values, E either increases or decreases. Thus, the proposed methodology shows no bias. The E varied from 3.6% minimum to 33.9% maximum, for Santa Cruz do Caparaó and Alto Rio Novo stations, respectively. The MPE for 20 stations in Espírito Santo was 13.8%. In comparison with other studies, which presented *K*, *a*, *b*, and *c* interpolation for later i_m calculation, we observed that the *MPE* calculated for this study is systematically lower than those calculated by CECÍLIO et al. (2009) (ranging, approximately, from 15 to 45%), who used the inverse distance method, with five different power values, for the same region. It is clear, therefore, that there is an effective reduction in the estimate error of the intense rainfall intensities when the methodology proposed by this study is applied. For comparison, yet, the *MPE* found in this study was also lower than the 19% described by CECÍLIO & PRUSKI (2003), who evaluated only one value of rainfall recurrence and duration for intense rainfall in Minas Gerais State. It was also fairly close, although lower than the 14 and 16% found by MELLO et al. (2003), who used the kriging and inverse distance squared methods, respectively for each percentage, in São Paulo State, Brazil.

TABLE 3. Parameters of maximum rainfall intensity equations estimated in this study and mean percentage error (MPE) among these equations and original ones.

County	*K*	*a*	*b*	*c*	MPE (%)
Alegre	2,415.2	0.199	26.4	0.912	7.6
Alto Rio Novo	1,897.0	0.200	24.1	0.861	33.9
Aracê	1,780.3	0.203	24.1	0.846	7.4
Aracruz	1,529.0	0.198	20.8	0.820	4.6
Boa Esperança	2,501.7	0.198	26.5	0.920	17.9
Caldeirão	1,544.9	0.198	20.7	0.824	5.7
Cedrolândia	2,364.2	0.206	28.5	0.901	18.5
Colatina	1,720.6	0.199	22.6	0.843	10.2
Córrego da Boa Esp.	1,642.5	0.198	21.6	0.836	10.4
Ecoporanga	1,741.5	0.201	23.5	0.843	18.2
Linhares	1,512.6	0.204	22.4	0.813	27.1
Pancas	2,052.4	0.198	24.2	0.880	14.0
Patrimônio S. L. do N.	1,842.7	0.204	24.9	0.853	4.3
Santa Cruz do Caparaó	2,652.7	0.198	26.9	0.933	3.6
Santa Teresa	1,358.9	0.202	20.7	0.793	18.4
São Gabriel da Palha	1,923.4	0.209	27.0	0.856	7.0
São João da C. Grande	1,839.3	0.201	23.8	0.856	31.6
São Mateus	2,157.6	0.200	25.3	0.889	12.5
Venda Nova	2,431.5	0.198	26.0	0.915	5.5
Vitória	1,733.6	0.202	23.2	0.844	16.8

Parameter spatializations of the intense rainfall equations for Espírito Santo, which were estimated from interpolated data of maximum intensities, are presented in Figure 4. A total of 48,667 intense rainfall equations were adjusted, corresponding to the number of pixels that cover the state in the adopted resolution. We observed that parameter values present similar magnitudes to those found in the literature for the same region. The regression mean error map, shown in Figure 4e, indicates a minor adjustment error of the rainfall intensity models to the interpolated data, with lower values than 3 mm/h, what indicates a good adjustment.

Considering all the results, it is possible to infer that i_m estimates, via intense rainfall equations and map parameters shown in Figure 4, will be better than those obtained by the currently used procedure (spatial interpolation of *K*, *a*, *b*, and *c* for close locations). This is due to the previous adjustment of equation parameters to the rainfall intensities of each location.

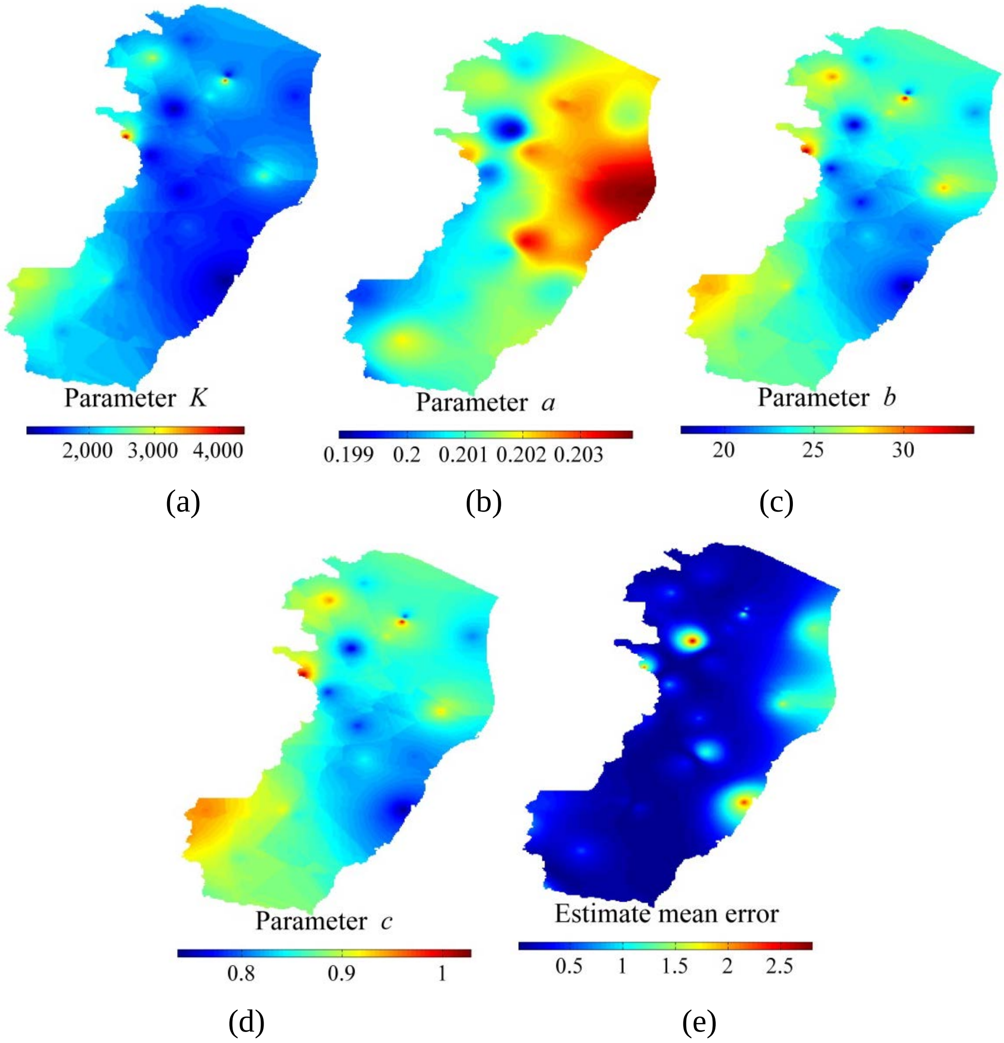

FIGURE 4. Spatialization of intense rainfall equation parameters *K* (a), *a* (b), *b* (c), and *c* (d), and regression mean error (%) (e).

Studies in the literature showed that, in several situations (*T* and *t* values), there is an i_m estimate deficiency when it is calculated by interpolation of intense rainfall equation parameters (MELLO et al., 2003; CECÍLIO et al., 2009). MELLO et al. (2008) described the interpolation importance for rainfall intensity spatialization, instead of intense rainfall equation parameters, for the achievement of better results of rainfall intensity spatial estimates. However, many applications of hydrologic modeling require knowledge of intense rainfall equation parameters, such as estimates of slope runoff (SOUZA, 2010) and water basins (ZANETTI et al., 2009), and hydrologic dimensioning of unpaved roads (GRIEBELER et al., 2005), soil conservation systems (PRUSKI, 2009), or structures for flood control (TRAVIS & MAYS, 2008). Therefore, results obtained in this study are of great importance for many applications in the field of Agricultural and Environmental Sciences. The spatialization of intense rainfall equation parameters for Espírito Santo, which are georeferenced, enables construction of rainfall intensity maps for certain recurrence and duration periods simply by the intense rainfall equation application; this is easily performed by GIS calculators, such as IDRISI (EASTMAN, 2009), or GIS own programming language, such as Spring (CÂMARA et al., 1996). Thus, the user that requires such information may import maps to a GIS software and then, researching by coordinate (SMITH et al., 2007), find the needed parameters and apply in intense rainfall equations. Also, from rainfall recurrence and duration data, it is possible to calculate and research the value for a specific region.

The use of spatialized parameters, as proposed in this study, is able to provide localized intense rainfall estimates using only the geographic location of the area of interest. This consists in a greater practical applicability than the intense rainfall equation regionalization methodology (MADSEN et al., 2009). In this methodology, equation parameters are adjusted by statistical procedures for homogeneous areas, and the localized estimate depends on the knowledge of other hydrologic or environmental variables related to the area of interest, such as total annual rainfall or altitude.

We consider that our results have potential to be expanded to other studies all over the country; furthermore, they may integrate updates, corrections, or new versions of softwares that provide intense rainfall equations for the whole country, such as Plúvio 2.1 (PRUSKI et al., 2006).

CONCLUSIONS

We used, in this study, a new spatialization methodology of maximum intense rainfall equation parameters. It consists of spatializing intense rainfall for different recurrence and duration periods and, later, adjusting intense rainfall equations to these data. The used spatialization interpolators were inverse distance and kriging. As a conclusion of this study on Espírito Santo State, we may cite:

Density of locations with available equations is low and poorly distributed;

From 96 combinations of rainfall recurrence and duration periods to interpolate maximum rainfall intensity, 59 showed significance for cross-validation data, that is, 49 presented spatial dependence by the inverse distance method, and 10 of them, by ordinary kriging;

The comparison among intense rainfall equations existing for the state, and those generated by this study, resulted in a mean percentage error of 13.8%;

Parameter maps were generated, which may be easily used to estimate intense rainfall intensity in GIS environment.

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REFERENCES

ARAÚJO, L.E.; SOUSA, F.A.S.; RIBEIRO, M.A.F.M.; SANTOS, A.S.; MEDEIROS, P.C. Análise estatística de chuvas intensas na bacia hidrográfica do rio Paraíba. *Revista Brasileira de Meteorologia*, São Paulo, v.23, n.2, p.162-169, 2008.

CÂMARA, G. SPRING integrating remote sensing and GIS with object oriented data modelling. *Computers & Graphics*, Elmsford, v.15, n.6, p.13-22, 1996.

CECÍLIO, R.A.; PRUSKI, F.F. Interpolação dos parâmetros da equação de chuvas intensas com uso do inverso de potências da distância. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v.7, n.3, p.501-504, 2003.

CECÍLIO, R.A.; XAVIER, A.C.; PRUSKI, F.F.; HOLLANDA, M.P.; PEZZOPANE, J.E.M. Avaliação de interpoladores para os parâmetros das equações de chuvas intensas no Espírito Santo. *Revista Ambiente & Água*, Taubaté, v.4, n.3, p.82-92, 2009.

EASTMAN, J.R. *Taiga - Guide to GIS and image processing*. Worcester, Clark University, 2009. 193 p.

FREITAS, A.J.; SILVA, D.D.; PRUSKI, F.F.; PINTO, F.A.; PEREIRA, S.B.; GOMES FILHO, R.R.; TEIXEIRA, A.F.; BAENA, L.G.N.; MELLO, L.T.A.; NOVAES, L.F. *Equações de chuvas intensas no Estado de Minas Gerais*. Belo Horizonte: Companhia de Saneamento de Minas Gerais; Viçosa: Universidade Federal de Viçosa, 2001. 65 p.

GRIEBELER, N.P.; PRUSKI, F.F.; SILVA, J.M.A.; RAMOS, M.M.; SILVA, D.D. Modelo para a determinação do espaçamento entre desaguadouros em estradas não pavimentadas. *Revista Brasileira de Ciência do Solo*, Viçosa-MG, v.29, n.3, p.397-405, 2005.

MADSEN, H.; ARNBJERG-NIELSEN, K.; MIKKELSEN, P.S. Update of regional intensity -duration-frequency curves in Denmark: tendency towards increased storm intensities. *Atmospheric Research*, Amsterdam, v.92, n.3, p.343-349, 2009.

MARTINEZ, W.L.; MARTINEZ, A.R. *Computational statistics handbook with MATLAB*. 2nd ed. 2007. 792 p. (Computer Science and Data Analysis)

MATHWORKS. *MATLAB® & Simulink®*. Release Notes for R2010. The MathWorks, Inc. 2010.

MELLO, C.R.; LIMA, J.M.; SILVA, A.M.; MELLO, J.M.; OLIVEIRA, M.S. Krigagem e inverso do quadrado da distância para interpolação dos parâmetros da equação de chuvas intensas. *Revista Brasileira de Ciência do Solo*, Viçosa-MG, v.27, n.5, p.925-933, 2003.

MELLO, C. R.; VIOLA, M. R.; MELLO, J. M.; SILVA, A. M. Continuidade espacial de chuvas intensas no estado de Minas Gerais. *Ciência e Agrotecnologia*, Lavras, v.32, n.2, p.532-539, 2008.

OLIVEIRA, L. F. C.; ANTONINI, J. C. A.; GRIEBELER, N. P. Estimativas de chuvas intensas para o Estado de Goiás. *Engenharia Agrícola*, Jaboticabal, v.28, n.1, p. 22-33, 2008.

PRUSKI, F.F.; TEIXEIRA, A.F.; SILVA, D.D.; CECÍLIO, R.A.; SILVA, J.M.A. Plúvio 2.1: Chuvas intensas para o Brasil. In: PRUSKI, F.F.; SILVA, D.D.; TEIXEIRA, A.F.; CECÍLIO, R.A.; SILVA, J.M.A.; GRIEBELER, N.P. (Org.) *HIDROS:* dimensionamento de sistemas hidroagrícolas. Viçosa-MG: Editora UFV, 2006, p. 15-25.

SANTOS, G.G.; FIGUEIREDO, C.C.; OLIVEIRA, L.F.C.; GRIBELER, N.P. Intensidade-duração-frequência de chuvas para o Estado de Mato Grosso do Sul. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v.13, (Suplemento), p.899-905, 2009.

SENNA, R.S.; XAVIER, A.C.; LIMA, J.S.S.; CECÍLIO, R.A. Metodologias para estimativa dos parâmetros da equação de chuvas intensas no Estado do Espírito Santo. *Engenharia na Agricultura*, Viçosa, v.18, n.6, p.496-503, 2010.

SILVA, D.D.; PINTO, F.R.L.; PRUSKI, F.F.; PINTO, F.A. Estimativa e espacialização dos parâmetros da equação de intensidade-duração-frequência da precipitação para os estados do Rio de Janeiro e Espírito Santo. *Engenharia Agrícola*, Jaboticabal, v.18, n.3, p.11-21, 1999.

SMITH, M.J.; GOODCHILD, M.F.; LONGLEY, P.A. *Geospatial analysis: a* comprehensive guide to principles, techniques and software tools. 2nd Ed. Troubador Publishing Ltd., 2007. 516 p.

SOUZA, C.D.F. *Sistema computacional para estimativa do escoamento superficial*. 2010. 78 f. Dissertação (Mestrado em Engenharia Agrícola) - Universidade Federal de Viçosa, Viçosa, 2010.

TRAVIS, Q.B.; MAYS, L.W. Optimizing retention basin networks. *Journal of Water Resources Planning and Management*, New York, v.134, n.5, p.432-439, 2008.

XAVIER, A. C.; CECÍLIO, R. A.; LIMA; J. S. S. Módulos em Matlab para interpolação espacial pelo método de krigagem ordinária e do inverso da distância. *Revista Brasileira de Cartografia*, Rio de Janeiro, v.62, n.1, p.67-76, 2010.

WEBSTER, R.; OLIVER, M. A. *Geostatistics for environmental scientists* (*Statistics in Practice*). 2nd ed. John Wiley & Sons, 2007. 330 p.

ZANETTI, S.S.; SILVA, J.M.A.; SOUSA, E.F.; OLIVEIRA, V.P.S.; ALMEIDA, F.T. Modelagem hidrológica em microbacia hidrográfica Parte I: Aprimoramento do modelo HidroBacia. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v.13, p.429-434, 2009.