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Methodology for the spatialisation of a reference evapotranspiration from SRTM data[1]

Metodologia para espacialização da evapotranspiração de referência a partir de dados SRTM

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ABSTRACT - The aim of this work was to develop a methodology for the spatialisation of mean monthly reference evapotranspiration for the State of Ceará, using the Hargreaves and Samani equation, from estimated air-temperature data based on digital elevation models. The study area is located in northeastern Brazil, between the latitudes 2.5º and 8º South and longitudes 37º and 42º West. The data used in the study are from the network of meteorological stations of the National Institute of Meteorology. The equation proposed by Hargreaves and Samani was used to estimate ET, being spatialised in the form of maps using the Idrisi Andes© software for the manipulation of digital data of latitude, longitude and altitude in order to obtain the variables of the equation. The study used the SRTM data as an altitude map. To compare the results obtained by the Hargreaves and Samani equation to temperatures maps calculated from the digital terrain model, the value of ET was determined for each location from weather data with the help of the REF-ET program. The coefficients of determination of the temperature models generated varied between 0.88 and 0.98, which showed a good correlation between the air temperature and the geographic data. The proposed methodology for the spatialisation of ET from temperature maps obtained by SRTM, proved to be a viable alternative, given the results of statistical analysis when compared to the standard method.

Key words: Digital elevation model. Hargreaves and Samani. Air temperature. GIS.

RESUMO - O objetivo do presente trabalho foi desenvolver uma metodologia para espacialização da evapotranspiração de referência média mensal pela equação de Hargreaves e Samani para o Estado do Ceará, a partir de dados de temperatura do ar estimados em função de modelos digitais de elevação. A área do estudo se encontra localizada na região Nordeste do Brasil, entre os paralelos 2,5º e 8º de latitude Sul e os meridianos 37º e 42º de longitude Oeste. Os dados utilizados no estudo são oriundos da rede de estações meteorológicas pertencentes ao Instituto Nacional de Meteorologia. A equação proposta por Hargreaves e Samani foi utilizada para a estimativa da ET_o sendo espacializada na forma de mapas através do software Idrisi Andes© pela manipulação dos dados digitais de latitude, longitude e altitude para obtenção das variáveis da equação. Foram utilizados os dados do SRTM, como mapa de altitude. Para a comparação dos resultados obtidos pela equação de Hargreaves e Samani pelos mapas de temperaturas calculadas a partir do modelo numérico do terreno, foi determinado o valor de ET_o para cada localidade a partir dos dados climáticos com auxílio do programa REF-ET. Os coeficientes de determinação dos modelos de temperatura gerados variaram entre 0,88 a 0,98, o que demonstrou boa correlação entre a temperatura do ar e os dados geográficos. A metodologia proposta para espacialização de ET_o a partir de mapas de temperaturas obtidos pelo SRTM, mostrou-se uma alternativa viável tendo em vista os resultados da análise estatística em comparação ao método padrão.

Palavras-chave: Modelo digital elevação. Hargreaves e Samani. Temperatura do ar. SIG.

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INTRODUCTION

The reference evapotranspiration (ET_o) is a nonlinear complex, which depends on various climatic elements, and refers to that water removed from an area of land completely covered with a reference crop, and which is healthy, not under any kind of stress and has an ample supply of water (ALLEN *et al.* 1998; WALTER *et al.*, 2000). The estimation of ET_o is needed to give support to irrigation sizing and management, in hydrological studies of watersheds, in models for estimating crop yield, and in other models to simulate land water balance.

There are a multitude of methods for estimating ET_o. Techniques for estimation are based on one or more atmospheric variables such as air temperature, solar radiation, net radiation, air humidity, wind speed or any measurement related to these variables, such as evaporation. However, only some of these models are accurate and reliable, others giving only a rough approximation. Most of them were developed for use in specific studies, and are more suitable for use in climates similar to that for which they were developed.

Many studies have confirmed the superiority of the Penman-Monteith equation (ALLEN, 1986; GAVILÁN; BERENGENA; ALLEN, 2007; LOPEZ-URREA *et al.*, 2006; PEREIRA; PRUITT, 2004; VENTURA *et al.*, 1999). This method has two advantages over many other equations: first, because of its physical basis it can be used globally without any calibrations due to location, second, it is a well-documented equation and has been tested using a variety of lysimeters under various climatic conditions (DROOGERS; ALLEN, 2002).

Recently a version of the Penman-Monteith equation, parameterized by the FAO in its manual 56, was established as a standard for the calculation of reference evapotranspiration (ALLEN *et al*., 1998). The calculation procedure requires accurate measurements of air temperature and relative humidity, solar radiation and wind speed. Unfortunately there is a limited number of meteorological stations where these climatic variables are measured with precision and satisfactory geographic distribution, even in developed countries (GAVILAN *et al*., 2006; XU *et al*., 2006).

The lack of meteorological data was solved by Hargreaves and Samani (1985) who developed a simple method to estimate ET_0. The Hargreaves and Samani equation (1985) is based on the average air temperature, and the maximum and minimum air temperatures, usually available in most weather stations around the world, and on extraterrestrial solar radiation (DROOGERS; 2002; HARGREAVES; 1985).

The application of hydrological models requires the spatial and temporal quantification of the variables of the hydrological system, among them ET_o (XU *et al*., 2006). Several studies have used the GIS (Geographic Information System) to specify weather data (BARBOSA, TEIXEIRA; GONDIM, 2005; BARDIN; PEDRO JÚNIOR; MORAES, 2010; CARGNELUTTI FILHO; MALUF; MATZENAUER, 2008; PEZZOPANE *et al*., 2004; ROCHA *et al*., 2011). Therefore the aim of this work was to develop a methodology for the spatialisation of the average monthly reference evapotranspiration by the Hargreaves and Samani equation (1985) for the state of Ceará, using air-temperature data estimated according to digital models of elevation, and compare values obtained from the traditional method based on data from meteorological stations.

MATERIAL E METHODS

The study was carried out in the state of Ceará, which is located in northeastern Brazil, between the latitudes 2.5º and 8º South, and longitudes 37º and 42º West. According to the Köppen climate classification the study area has three types of climate: BSw'h', Aw' and Cw', with the predominance in approximately 80% of the area of BSw'h' (hot semiarid). The data used in the study are from the network of meteorological stations in the state (Table 1 and Figure 1), belonging to the National Institute of Meteorology (INMET). The stations from the surrounding states were used to provide boundary conditions.

To estimate the reference evapotranspiration the model proposed by Hargreaves and Samani (1985) was used:

$$ET_o = 0{,}0023(Tx - Tn)^{0{,}5}(Tm + 17{,}8)Ra \quad (1)$$

where: ET_o (mm day^{-1}) is the reference evapotranspiration; Tx, Tn and Tm represent the maximum, minimum and average air temperatures respectively (°C); and Ra, the solar radiation at the top of the atmosphere (mm day^{-1}).

For estimates of the spatialised maximum, minimum and average temperatures a multiple linear regression model was tested, with altitude, latitude and longitude as independent variables and the measured temperature as the dependent variable, based on the general quadratic model:

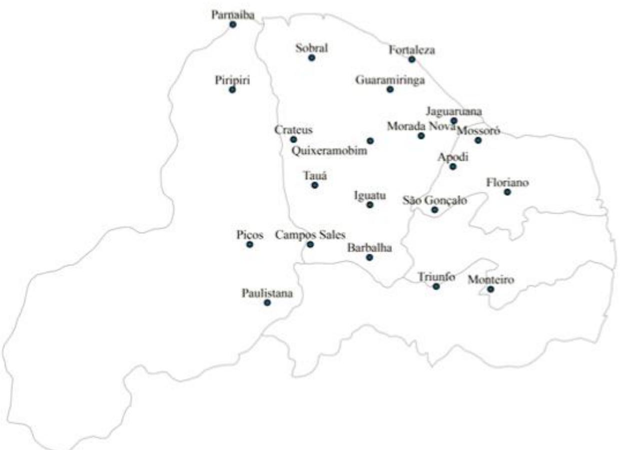
$$T_i = A_0 + A_1.h + A_2.h^2 + A_3.\lambda + A_4.\lambda^2 + A_5.\varphi + A_6.\varphi^2 + A_7.h.\varphi + A_8.h.\lambda + A_9.\varphi.\lambda \quad (2)$$

where: Ti is the mean monthly temperature (i = 1, 2, 3 ..., 12); λ is the longitude in degrees; φ is the latitude

Table 1 - Location of the weather stations

Location	State	Latitude	Longitude	Altitude
Sobral (Sbr)	CE	-3°41'10"	-40°20'59"	69,4
Fortaleza (Frt)	CE	-3°43'02"	-38°32'35"	21,1
Guaramiranga (Grm)	CE	-4°15'48"	-38°55'59"	900,0
Jaguaruana (Jgr)	CE	-4°52'02"	-37°46'52"	12,2
Crateús (Crt)	CE	-5°10'42"	-40°40'39"	274,7
Quixeramobim (Qxr)	CE	-5°11'57"	-39°17'34"	191,7
Morada Nova (MN)	CE	-5°06'24"	-38°22'21"	52,1
Apodi (Apd)	RN	-5°39'51"	-37°47'56"	67,9
Mossoró (Msr)	RN	-5°11'15"	-37°20'39"	16,9
Tauá (Tau)	CE	-6°00'11"	-40°17'34"	402,6
Iguatu (Igt)	CE	-6°21'34"	-39°17'55"	217,2
São Gonçalo (SG)	PB	-6°27'00"	-38°07'48"	233,1
Florania (Flr)	RN	-6°07'38"	-36°49'06"	315,7
Campos Sales (CS)	CE	-7°04'28"	-40°22'34"	566,3
Picos (Pcs)	PI	-7°04'37"	-41°28'01"	206,4
Barbalha (Bar)	CE	-7°18'40"	-39°18'15"	415,0
Triunfo (Trf)	PE	-7°50'17"	-38°06'06"	1004,4
Monteiro (Mtr)	PB	-7°53'22"	-37°07'12"	599,2
Parnaíba (Par)	PI	-3°04'48"	-41°46'12"	79,5
Paulistana (Plt)	PI	-8°08'08"	-41°08'59'	359,6
Piripiri (Pri)	PI	-4°16'12"	-41°46'48"	161,12

Figure 1 - Spatial distribution of the weather stations



in degrees; h is the altitude in meters; and A_n are the regression coefficients.

The generated equations were evaluated by the coefficient of determination (R^2) and F- test at a 5% level of significance.

The regression coefficients obtained from the temperature models were applied to specify ET_o for the state of Ceará in the form of thematic maps on a monthly scale, using the Idrisi Andes© software, employing digital maps of longitude, latitude and altitude. For the altitude map, the digital elevation model (DEM) was used, obtained from the SRTM (Shuttle Radar Topography Mission) that resulted from the partnership between NASA (National Aeronautics and Space Administration) and NGA (National Geoespatial-Intelligence Agency), where the aim was to collect radar interferometry data with a view to acquiring detailed topographic models for latitudes between 56ºS and 60ºN.

The whole process of MDE refinement also counted on the help of topographic control data, aimed at validation of the data generated. Radar data were collected during an 11-day mission, and subsequently processed according to the methodology described by Rabus *et al*. (2003). Despite the spatial resolution of the SRTM being 30 m, the free SRTM images were resampled to a resolution of 90 m, except for the US. SRTM data are referenced to the WGS84 ellipsoid. The SRTM data used in this work were acquired at http://Srtm.csi.cgiar:org.

Solar radiation at the top of the atmosphere was determined using the methodology proposed by Allen *et al.* (1998) which considers the 15th day of each month as reference in the calculation of the average ET_o for each month.

To compare the results obtained by the Hargreaves and Samani equation (1985) and the temperature maps calculated by the digital terrain model, the ET_o was determined by the Hargreaves and Samani method (1985) for each location, based on climate data with the help of the REF-ET software (ALLEN, 2012). Estimates of ET_o by REF-ET software and those extracted from the generated maps were evaluated using simple error analysis (Equations 3 to 6).

$$EM = \frac{\sum_{i=1}^{n}(y_i - x_i)}{n} \quad (3)$$

$$EPE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i)^2}{n}} \quad (4)$$

$$EPM = \frac{EM}{\bar{x}}.100 \quad (5)$$

$$\xi = \frac{\bar{y}}{\bar{x}}.100 \quad (6)$$

where: ME is the mean error in mm day^{-1}; SEE is the standard error of estimation in mm day^{-1}; MPE is the mean percentage error in %; ξ is the ratio between the means in %, n is the number of data; y_i is the EToHSMaps, estimated by Hargreaves and Samani (1985) for maps; x_i is the $ET_{oHSREF-ET}$ estimated by Hargreaves using REF-ET; $\bar{x}$ and $\bar{y}$ are the averages of $ET_{oHSMaps}$ and $ET_{oHSREF-ET}$ for a given location respectively.

RESULTS AND DISCUSSION

The adjusted coefficients of determination of the regression equations for estimating mean monthly values for the minimum air temperature ranged from 0.98 in December to 0.92 in July; for the mean monthly values for the average air temperature they ranged from 0.98 in September and October, to 0.88 in February; for the mean monthly values for the maximum air temperature they were between 0.98 and 0.93 in April and October respectively (Table 2). It is worth noting that all the regression equations were significant at 5% significance by the F-test.

It was found that the R^2 values obtained for the minimum as well as for the average and maximum temperatures were similar. This is probably due to the low variability of temperature data in the months in which they occurred. It was also observed that the maximum monthly value for the coefficient of determination was equal to 0.98, not only for the minimum air temperature, but also for the maximum and average.

The values for R^2 for the equations to estimate the minimum air temperature showed lower values since, of the twelve adjusted equations, six had values of less than 0.95, the same happening with three of the equations for estimating the average air temperature and with one for estimating the maximum. With the equations for estimating the average air temperature it can be seen that the lowest value for the coefficient of determination ($R^2 = 0.88$) was obtained for the month of February, indicating lower precision of the estimates.

Pezzopane *et al*. (2004) studying the spatial distribution of air temperature in the state of Espírito Santo, obtained values for the adjusted coefficients of determination ranging from 0.88 to 0.94 for the minimum temperature, 0.89 to 0.92 for the average, and 0.94 to 0.98 for the maximum temperature. According to these authors, the fact of the coefficients of determination for the maximum temperature being higher than for the others, may be related to the greater uniformity of this climatic variable in the State.

The interval between February and July (Figure 2) presented the lowest demand for evapotranspiration in view of the absolute frequency distribution being offset to the left (lower values); almost all of the annual rainfall and the coldest months in the state being concentrated in this period.

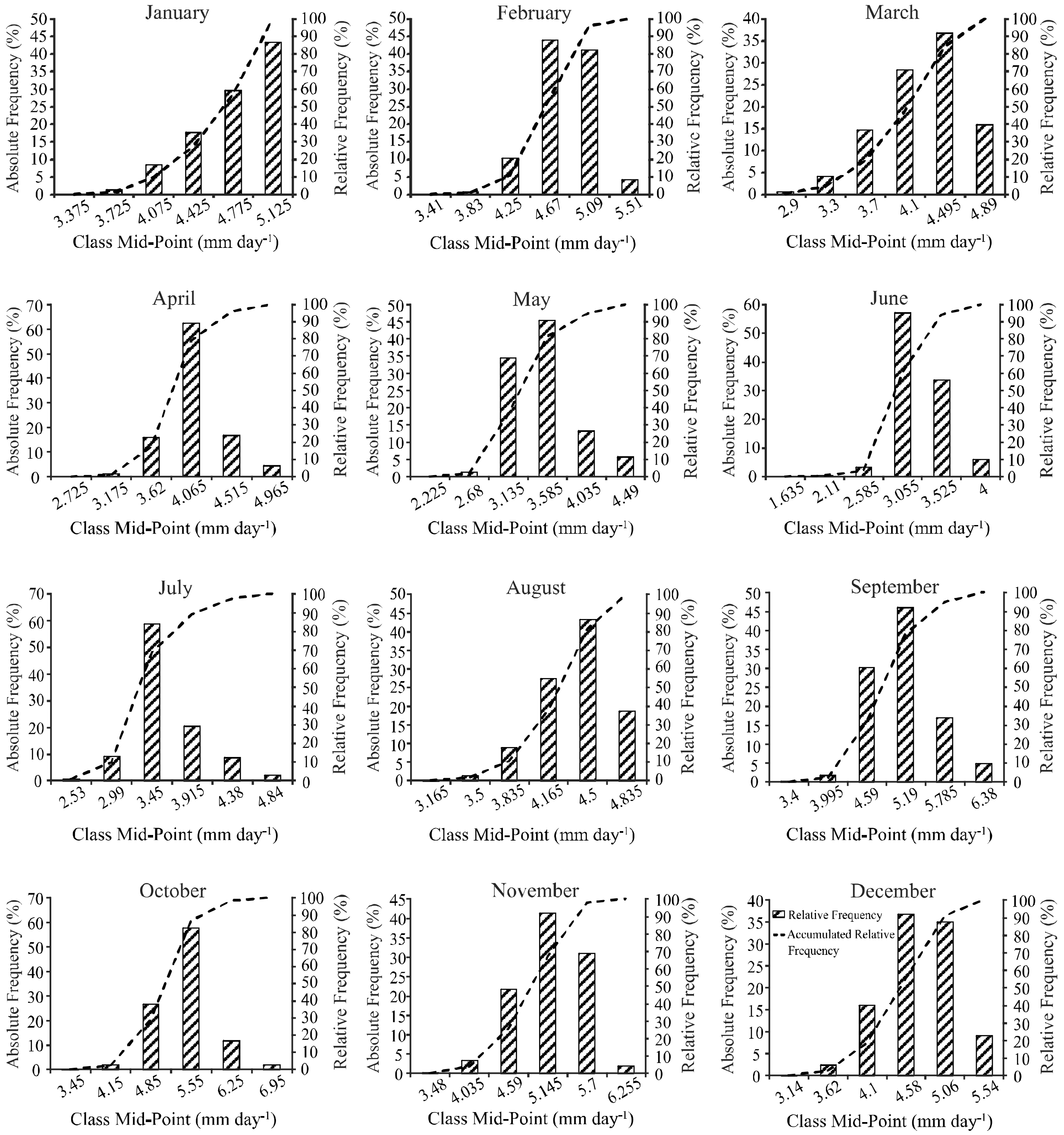
Also according to Figure 2, we observe that from August until January the relative frequency values are shifted to the right, i.e. higher values of ET_o. October was the month with the highest demand for evapotranspiration in view of the fact that 57.7% of the values are around 5.55 mm day^{-1}. Tabari *et al*. (2012) in different regions of Iran noted the month of highest demand with a monthly ET_o value of 534.4 mm month^{-1} was July, while the lowest value was 25.6 mm month^{-1} in January.

The inclusion of the digital elevation model in the spatialisation of Tx, Tn and Tmed using GIS, resulted in maps with greater detail and which represent the behavior of this variable as observed in the field and for different states in Brazil (BARDIN, PEDRO JÚNIOR; MORAES, 2010; MEDEIROS *et al*., 2005; PEZZOPANE *et al*., 2004). The maps of the estimates of maximum (Figure 3A), minimum (Figure 3B) and average temperatures (Figure 3C), for the month with the greatest demand for evapotranspiration, which according to Figure 2 was October, showed great geometric detail in accordance with the original detail of the digital elevation model, indicating that in studies that require more spatial details for temperature, it is necessary

Table 2 - Regression coefficients of the equations for estimating the monthly values for average, maximum and minimum air temperatures with their respective coefficients of determination (R^2)

Month	A0	A1	A2	A3	A4	A5	A6	A7	A8	A9	R^2
Average temperature											
Jan	70.39	0.07	-6.6E-06	1.56	0.01	6.75	-0.35	-1.5E-03	1.9E-03	0.26	0.96
Feb	-243.97	0.12	-7.8E-06	-14.33	-0.19	8.75	-0.23	-9.1E-04	3.1E-03	0.28	0.88
Mar	196.60	0.04	-4.2E-06	7.86	0.09	6.90	-0.06	-6.7E-04	1.3E-03	0.19	0.93
Apr	111.99	-0.05	2.6E-06	4.89	0.07	-4.53	0.16	-1.0E-06	-1.0E-03	-0.16	0.95
May	421.54	-0.03	-2.4E-06	19.72	0.25	3.35	-0.03	-7.0E-04	-4.8E-04	0.08	0.95
Jun	308.96	0.01	-5.2E-06	12.04	0.12	16.28	-0.06	-7.2E-04	4.9E-04	0.42	0.97
Jul	20.47	0.05	-2.6E-06	-0.59	-0.01	5.24	-0.09	1.8E-04	1.4E-03	0.16	0.97
Aug	-34.28	0.05	-7.2E-06	-3.22	-0.05	5.65	-0.27	-1.5E-03	1.4E-03	0.21	0.95
Sep	229.05	0.03	-4.4E-06	9.70	0.11	8.07	-0.24	-4.4E-04	9.7E-04	0.28	0.98
Oct	-167.46	-0.05	4.0E-08	-9.62	-0.12	-0.99	0.01	-2.8E-05	-1.1E-03	-0.01	0.98
Nov	544.17	-0.01	-1.2E-07	27.33	0.35	-2.36	-0.33	-1.0E-03	1.3E-04	0.04	0.97
Dec	170.92	0.01	1.8E-06	8.75	0.12	-6.00	-0.20	-3.8E-04	4.2E-04	-0.08	0.94
Maximum temperature											
Jan	21.59	-0.09	5.2E-07	3.77	0.10	-31.57	-0.17	-1.6E-05	-2.0E-03	-0.73	0.96
Feb	155.71	-0.10	3.6E-06	10.27	0.18	-28.53	-0.12	5.1E-04	-2.2E-03	-0.67	0.97
Mar	121.73	-0.01	-1.3E-06	6.60	0.10	-13.09	-0.23	1.6E-04	-5.0E-05	-0.25	0.95
Apr	200.89	-0.10	3.6E-06	11.37	0.18	-19.52	-0.01	3.8E-04	-2.3E-03	-0.47	0.98
May	673.78	-0.15	3.9E-06	34.90	0.47	-17.30	0.06	2.6E-04	-3.5E-03	-0.44	0.95
Jun	899.34	-0.12	1.2E-06	46.59	0.62	-15.93	-0.19	-6.6E-04	-2.8E-03	-0.35	0.96
Jul	643.19	-0.12	1.5E-06	34.49	0.48	-21.31	-0.13	-3.9E-04	-2.8E-03	-0.50	0.97
Aug	162.08	-0.07	5.5E-06	12.32	0.22	-35.30	-0.42	9.6E-04	-1.6E-03	-0.75	0.97
Sep	223.72	-0.09	8.8E-06	16.15	0.28	-39.01	-0.17	2.3E-03	-2.1E-03	-0.89	0.96
Oct	122.48	-0.12	6.6E-06	10.24	0.20	-37.60	-0.11	1.0E-03	-2.9E-03	-0.89	0.93
Nov	137.00	-0.07	5.0E-06	10.83	0.20	-34.41	-0.18	7.2E-04	-1.5E-03	-0.78	0.96
Dec	-91.71	-0.05	2.6E-06	-1.78	0.02	-29.77	-0.39	5.0E-04	-1.0E-03	-0.61	0.97
Minimum temperature											
Jan	-28.50	-0.04	-2.7E-06	-4.31	-0.07	9.49	0.22	-7.8E-04	-7.0E-04	0.17	0.95
Feb	-13.21	0.03	-3.9E-06	-3.65	-0.07	12.21	-0.20	-1.0E-03	8.5E-04	0.36	0.94
Mar	91.89	-0.07	-6.0E-06	1.34	-0.01	8.95	0.10	-1.2E-03	-1.7E-03	0.18	0.94
Apr	-3.25	-0.02	-3.2E-06	-2.96	-0.06	8.67	0.14	-3.8E-04	-2.7E-04	0.18	0.95
May	-30.56	0.01	-3.4E-06	-4.73	-0.08	10.93	0.26	1.9E-04	2.2E-04	0.21	0.95
Jun	-164.60	-0.01	1.3E-07	-11.43	-0.17	11.42	0.12	5.5E-04	-2.2E-04	0.25	0.93
Jul	-7.52	0.01	-9.2E-06	-4.79	-0.10	21.13	-0.11	-1.7E-03	3.2E-04	0.54	0.92
Aug	-201.48	0.03	-4.8E-06	-13.79	-0.21	17.19	-0.18	-1.3E-03	9.1E-04	0.47	0.94
Sep	50.94	0.09	-1.0E-05	-1.05	-0.05	20.46	-0.50	-1.6E-03	2.4E-03	0.64	0.97
Oct	26.58	0.05	-8.4E-06	-3.69	-0.10	29.08	-0.03	-1.3E-03	1.4E-03	0.73	0.97
Nov	-173.68	-0.04	-6.8E-06	-12.74	-0.19	17.32	0.15	-1.1E-03	-9.2E-04	0.39	0.94
Dec	-23.08	-0.03	-7.4E-06	-4.26	-0.08	11.86	-0.06	-1.4E-03	-6.3E-04	0.30	0.98

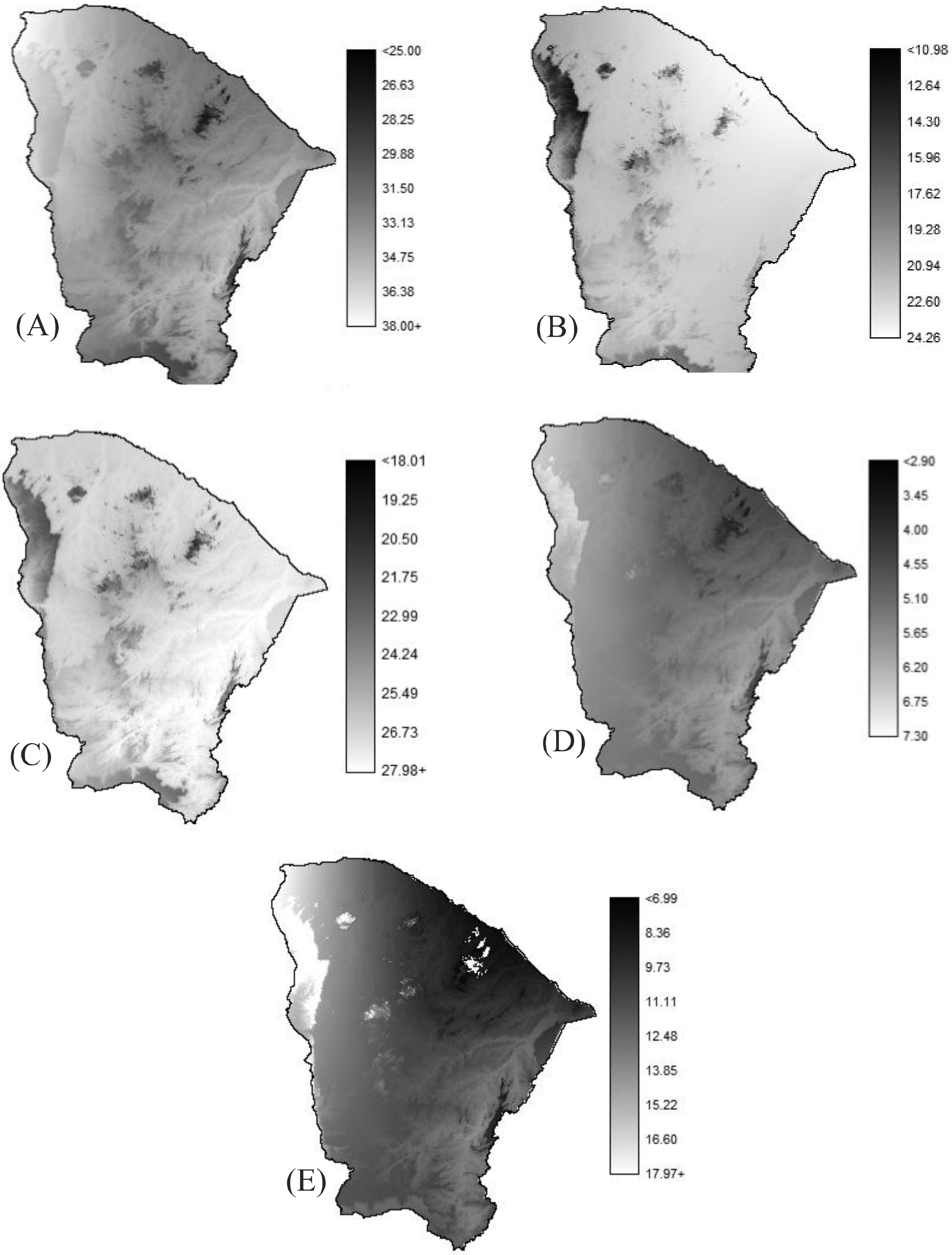
Figura 2 - Frequency histograms for ET_o



to run the equations on similarly detailed topographic maps Combining maps of the spatial distribution of ET_o with the spatial distribution of the meteorological variables will provide an important basis for the study of hydrological and climate modelling (AHMAD *et al*., 2005; FOOLADMAND; HAGHIGHAT, 2007; KONGO *et al*., 2011).

The thematic map of maximum air temperature (Figure 3A) showed values varying from 25 °C to 38 °C. It was also found that for almost all regions of the state of Ceará, the values seen were over 30 °C, with the exception of an area located in the Serra de Guaramiranga, which cuts across the towns of Redenção, Pacoti, Guaramiranga, Baturité and Aratuba, where the values for the maximum temperature were between 25 °C and 27 °C, these values being associated with the higher altitudes in that area. The estimates of minimum temperature ranged between 10.1 °C and 24.3 °C for the month of October (Figure 3B). It's possible to see that low temperatures occurred in the regions of mountains and plateaus that cross the states of Ceará and Piauí, such as Serra Grande, the Chapada do Araripe and Serra Dois Irmãos. However, the average temperature varied between 18 °C to 28 °C, with 50.7% of the area of the state having a temperature of 26.1 °C (Figure 3C).

Figure 3 - Maps of temperature and reference evapotranspiration in the month of maximum demand, for the state of Ceará: (A) maximum temperature; (B) minimum temperature; (C) mean temperature; (D) ET_o; (E) temperature range



The spatial modeling of ET_o gives an understanding of the spatial and temporal variability of the demand for water in different regions of the state (Figure 3D). Xu *et al*. (2006) state that spatial distribution maps provide valuable information for the planning and management of water resources in a basin or region, since the spatial distribution of the seasonal and annual values for ET_o is an important component of the hydrological cycle. From Figure 3D it can clearly be seen that the areas with a lower value for ET_o in the peak month are in the region of Serra de Guaramiranga, while the smallest values of ET_o were observed in the region of the Chapada da Ibiapaba (Serra Grande), going against the more obvious result, where the highest values of ET_o should be in the driest part of the state, which lies in the central region. Two hypotheses can be raised to explain this result. The first can be attributed to the lack of weather stations in the region of Serra Grande when calibrating the regression equations for the temperatures, the region therefore being dependent on the neighboring stations of Sobral and Crateús in Ceará, and Parnaíba, Piripiri and Picos in Piauí (Figure 2). The second might be associated with the actual Hargreaves and Samani equation (1985) and its sensitivity to temperature variation, considering that the Serra Grande presented the highest values for thermal range (Figure 3E).

Figure 4 - Trend analysis of ET_o obtained from the map and observed at the stations

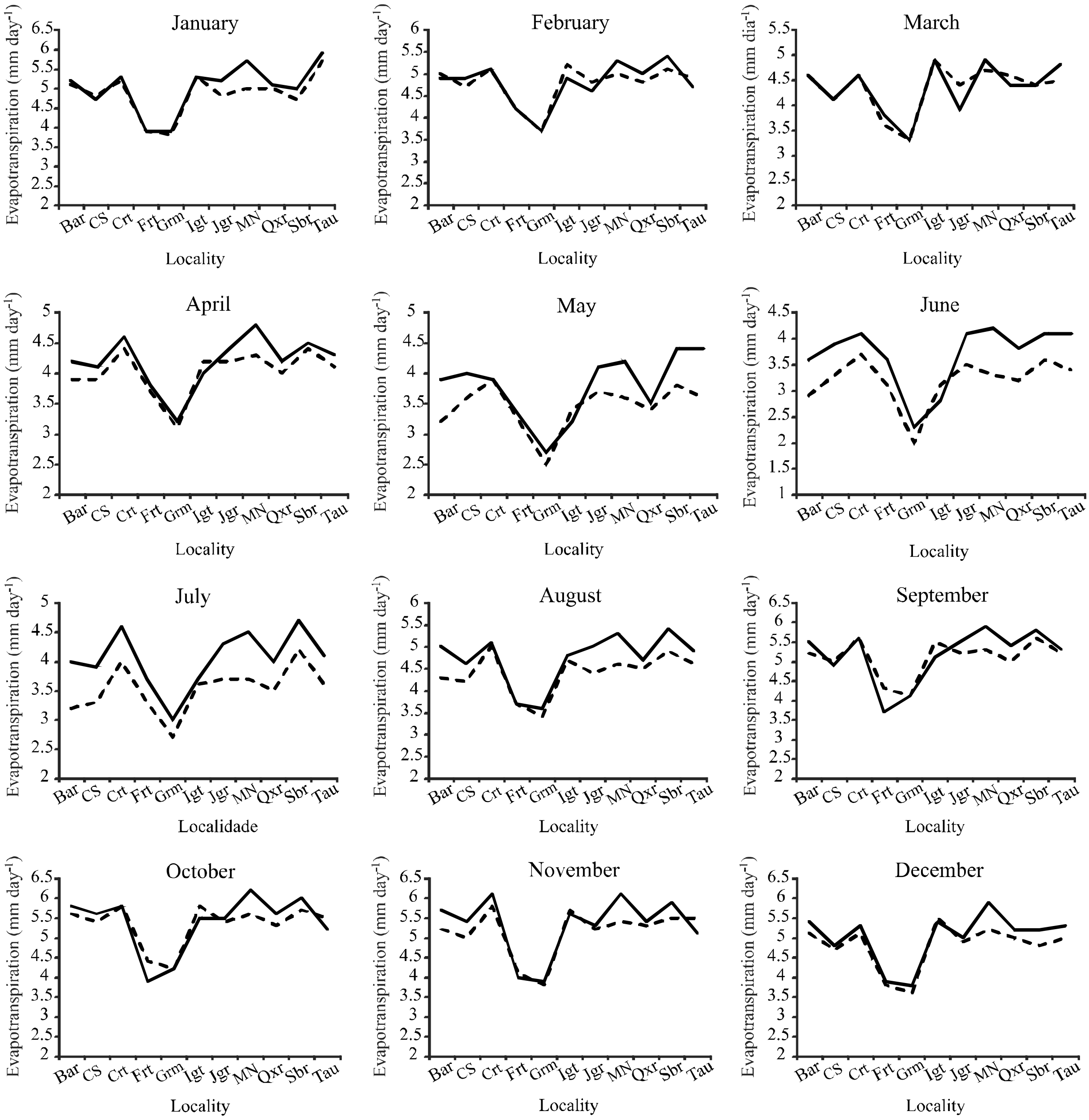


Figure 4 shows the comparison between the ET_o obtained from the temperature maps for the pixel containing a station, and the values obtained from the climatic data at that station. Comparison of the results between the methods tested, clearly shows variability from one location to another. It can be seen that for the stations of Morada Nova, Quixeramobim and Sobral the values obtained by the proposed method were always lower than those obtained by REF-ET, except in March. While the stations in Fortaleza and Iguatu presented the best results throughout the year, with closer values between methodologies.

It is worth noting that the Hargreaves and Samani equation (1985) tends to overestimate ET_o in humid regions and underestimate it in very dry regions and in those regions with higher wind speeds (TEMESGEN; ALLEN; JENSEN, 1999; XU; SINGH, 2002). Therefore, the Hargreaves and Samani equation (1985) requires local calibration before being applied to estimate ET_o in any particular region (BAUTISTA, BAUTISTA, 2009; GAVILAN *et al*., 2006; FOOLADMAND; HAGHIGHAT, 2007).

Analyzing the values of ξ, It can be seen that in four months only, the values of ET_o were underestimated when obtained from the temperature map in relation to the ET_o obtained by REF-ET (Table 3). The proposed methodology for estimating ET_o by the Hargreaves and Samani equation (1985) from altitude data produced satisfactory estimates, considering that seven months showed values that had been under or overestimated by less than 5% (ξ).

Table 3 - Ratio of the mean (ξ), mean error (ME), standard error of estimation (SEE) and mean percentage error (MPE) between ET_o estimated with the digital elevation model ($ET_{oHSMaps}$), and the REF-ET software ($ET_{oHSREF-ET}$) as estimated by Hargreaves and Samani (1985)

Month	Statistical índices			
	ξ	ME	SEE	MPE
January	96.80	-0.17	0.29	3.62
February	99.80	-0.02	0.21	3.28
March	100.20	0.00	0.21	3.00
April	96.00	-0.17	0.25	4.88
May	91.70	-0.34	0.48	9.40
June	87.10	-0.50	0.61	14.85
July	87.40	-0.52	0.58	12.64
August	93.00	-0.35	0.44	7.01
September	99.30	-0.07	0.36	5.45
October	99.60	-0.05	0.33	4.81
November	96.90	-0.18	0.37	5.25
December	95.60	-0.23	0.31	4.74

Taking into consideration only the average of all the locations for each month, the values of ME ranged from 0.0 to -0.52 mm d^{-1}, with a mean of -0.22 mm d^{-1} (Table 3). SEE values ranged from 0.21 to 0.61 mm d^{-1} with a mean value of 0.31 mm d^{-1}. Ratios between the mean values (ξ) obtained with the two methods, showed that the greatest underestimation observed was 12.9% (June). Considering only the months of June and July, when the ET_o values obtained from the map showed the greatest underestimates, the values obtained for the mean percentage error (MPE) were 14.85 and 12.64% for the months of June and July respectively.

CONCLUSIONS

1. The proposed methodology did not show good results in the coldest months of the year (June and July) in the state of Ceará;
2. The methodology proposed for spatialising ET_o by means of the Hargreaves and Samani equation (1985) using temperature maps obtained by the SRTM digital elevation model, proved to be a viable alternative in view of the results of the statistical analysis when compared to the standard method.

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