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Rainfall spatio-temporal distribution of Western Bahia

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Abstract: Rainfall is an element of great spatial and temporal variability, and its knowledge is essential for decision-making. This information is fundamental for the planning and management of irrigation systems, choice of planting and harvesting periods, among others. Prior and reliable knowledge of the pluviometric characteristics for agricultural planning can significantly reduce the risk of production loss. This study, through Tropical Rainfall Measuring Mission data, objectifies for the western region of the state of Bahia: to analyze spatio-temporal patterns of monthly, seasonal and annual rainfall; and study rainfall occurrence. The Tropical Rainfall Measuring Mission monthly product was calibrated with field data provided by the Agência Nacional de Águas. Two seasons are observed for the western region of Bahia: a wet season with well distributed rainy days, and a dry one where the rainfall in most months is close to none. Rainfall spatial distribution presents, for the majority of the months, higher volume of rainfall on the extreme west. The mean rainfall occurs with a probability level below 50%. The Tropical Rainfall Measuring Mission provides valuable information that should trend in agricultural, hydrological and water balance studies.

Keywords: Gamma distribution, hydrology, precipitation probability, water resources.

Distribuição espaço-temporal pluviométrica do Oeste Baiano

Resumo: A chuva é um elemento de grande variabilidade espacial e temporal, e seu conhecimento é essencial para tomadas de decisões na agricultura. Essa informação é fundamental para o planejamento e gerenciamento de sistema de irrigações, escolha de datas de plantio e colheita, entre outros. Conhecimento prévio e confiável das características pluviométricas para o planejamento agrícola pode reduzir significativamente o risco de perda de produção. Esse estudo, através de dados da Tropical Rainfall Measuring Mission, objetiva para a região oeste do estado da Bahia: analisar padrões espaço-temporais

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de chuva mensal, sazonal e anual; estudar a ocorrência de chuvas. O produto mensal Tropical Rainfall Measuring Mission foi calibrado com dados de campo fornecidos pela Agência Nacional das Águas. Foram observados dois períodos de chuva para a região oeste da Bahia: uma estação chuvosa com boa distribuição de dias chuvosos, e uma seca, onde a chuva mensal em geral é próxima à zero. A distribuição espacial da chuva apresenta, na maioria dos meses, volume precipitado superior no extremo oeste. A precipitação média ocorre com uma probabilidade inferior a 50%. O Tropical Rainfall Measuring Mission fornece informações valiosas que deve se tornar tendência em estudos agrícolas, hidrológicos e de balanço de água.

Palavras-chave: Distribuição gamma; hidrologia; probabilidade de precipitação; recursos hídricos.

Introduction

Knowledge about rainfall characteristics has fundamental importance in several sectors of society. In agriculture, this information is significant for the planning and management of irrigation systems, the periods of choice for planting and harvesting, water supply, ecosystem conservation, among other analysis that involve the water balance of hydrographic basins and the river flows disposal [1, 2].

Rainfall is an element of great spatiotemporal variability, and its knowledge is essential for decision-making in agriculture. The adverse effects of rainfall irregularity result in productivity drop, and can sometimes lead to total loss, affecting the country's economy [3].

In the agricultural environment, the acquisition of rainfall data is of utmost importance for studies regarding rainfall occurrence probability and spatial distribution [4]. Such studies are carried out based on historical series and bring a possibility to producers to plan the management of their crop by avoiding or minimizing the risk of production loss [5].

The use of orbital sensors for rainfall studies shows advantages over meteorological stations, since stations may poorly represent large areas extensions [6]. Satellites such as the Tropical Rainfall Measuring Mission (TRMM), launched in the end of 1997, provides a global precipitation measurement every 3 hours, playing fundamental role in hydrological studies.

The Western Bahia is within the Cerrado biome, which presents two well defineds seasons, where agriculture is only viable through irrigation [7]. Agribusiness's viability may be increased by sowing two rain-fed crops during the wet season ("double cropping"), though this technique requires previous comprehension of precipitation characteristics such as its frequency, probability and seasonal duration [8].

Prior and reliable knowledge of the pluviometric distribution for agricultural planning may significantly reduce the risk of losses in agricultural activities [9, 10]. Based on the stated the objective of this study was to use TRMM data to analyze spatial and temporal patterns of monthly, seasonal, and annual rainfall in the western region of Bahia.

Material and Methods

Study area

The study area of the present is the municipality of Correntina, in the state of Bahia (Figure 1). The municipality has an extension of 11.980 km^2 with coordinates of 13º 20' 34" South, 44º 38' 13" West and 575 m above sea level. The climate of the region, according to Köppen, is classified as Aw, tropical with dry winter [11].

Bahia's western region acquired relevance in the National scenario due to the great agricultural importance achieved in the last years, favoring the consolidation of

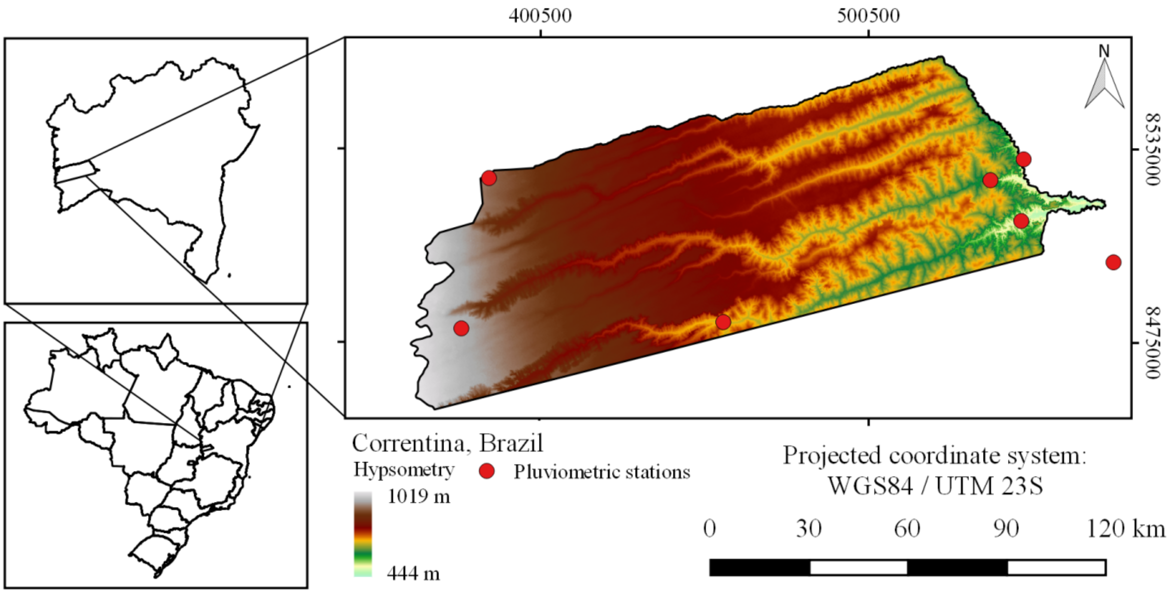

Figure 1: Hypsometry and location of area of study: Correntina, Brazil

several agricultural activities (Associação de Agricultores e Irrigantes da Bahia [AIBA], 2016). The region is located in the second largest biome of the country, presenting sections of great extension with well defined rainy period.

In this context, the Municipality of Correntina stands out for the production of soy and cotton, cultivated in large areas, making the region, from the agricultural point of view, one of the areas of economic interest in the country [12].

Data acquisition

The rainfall data used on the analysis was obtained by the TRMM and provided by the Nasa Goddard Earth Sciences (GES) Data and Information Services (DISC) for the period of 1998 to 2016. To achieve greater precision, field data provided by Agência Nacional de Águas (ANA) was used to calibrate TRMM monthly product. The criteria used to select ANA's stations were pluviometric stations within or near the limits of the municipality presenting at least 20 years of observations and less than 5% flaws (Table 1).

Prior the data analysis, filling of stations' monthly flaws and verification of the homogeneity of the series was done. The methods used to fill the pluviometric stations' monthly flaws were linear regression and regional weighting [13]. According to Pruski et al. [13], in order to use the linear regression method, a minimum coefficient of determination of 0.7 is required , otherwise the filling of the faults was performed by regional weighting.

Double-mass curves were used to verify data homogeneity. The double mass curve is a visual and simple method, widely used to study the consistency of trends in historical series. By plotting the cumulative precipitation of a station of interest in relation to the accumulated precipitation of neighboring stations, results approaching a straight line show a consistently proportional relation over time [14, 15].

Data calibration

The TRMM monthly product was calibrated through linear regression using data from the pluviometric stations corresponding to the period of 1998 to 2011 (calibration set). The validation of the adjusted product was performed for the period of 2012 to 2016 (validation set). The split between data for calibration and validation followed the 70-30 thumb rule [16]. The performance of the calibration was evaluated for the validation

Table 1: Pluviometric Stations from ANA's network within or near Correntina, Brazil.

Station	Code	Latitude	Longitude	Available data
Mocambo	1344002	-13.2778	-44.5589	1946-2016
Correntina	1344014	-13.3364	-44.6522	1973-2016
Colônia do Formoso	1344015	-13.5667	-44.3061	1963-2016
Arrojado	1344016	-13.4508	-44.5656	1977-2016
Santa Maria da Vitória	1344017	-13.4006	-44.1975	1946-2016
Arrojolândia	1345000	-13.7342	-45.4033	1982-2016
Fazenda Planato	1346006	-13.7519	-46.1400	1982-2016
Fazenda Prainha	1346007	-13.3303	-46.0622	1982-2016

set using the mean error (ME), mean absolute error (MAE), root mean square error (RMSE) and Nash-Sutcliffe efficiency index (NSE) [17] were calculated.

Rainfall analysis

The adjusted TRMM monthly product was used to determine the temporal distribution of annual rainfall, as well as mean monthly rainfall and standard deviations for the municipality. The rainfall spatial distribution on the municipality extension was obtained by calculating the mean product for each month, allowing further analysis of seasonal and annual variations.

For better understanding of rainfall occurrence, the average number of rainy days and the expected rainfall at the probability levels of 10, 30, 50, 70, and 90% were calculated. The TRMM daily products presenting a mean rainfall of 5 mm over the municipality were counted as rainy days. The number of rainy days for each year and month were averaged for the annual and monthly periods.

The Gama distribution [18], which presents good performance in the adjustment to rainfall data [19, 20], was chosen to verify the minimum rainfall probability of occurrence throughout the year at the probability levels of 10, 30, 50, 70 and 90%. The Kolmogorov-Smirnov goodness-of-fit test may be applied to verify the adequacy of the Gamma distribution to the data series [21]. Since the data tested here is the same data used to derive the parameters from the distribution, this test is as well-known as the Lilliefors test [22, 23].

A flowchart is presented in Figure 2 for easier comprehension of the study process.

Results and Discussion

Data calibration

The field data and TRMM measurements presented a Pearson's simple correlation coefficient (r) of 0.885, proving the great relationship between the variables. The plot of the calibration is presented in Figure 3, along with the calibration coefficient.

The performance evaluation of TRMM calibration (Table 2) showed improvement of the data precision, which can be explained by the increase of Nash-Sutcliffe index, indicating that the calibrated TRMM data better explains the rainfall field observations. The validation presented for MAE and RMSE values a slight melioration after the calibration. The ME of calibrated data is closer to 0, meaning the model would not overestimate the rainfall measurements as previously.

Rainfall temporal distribution

Correntina's rainfall temporal distribution is shown in Figure 4a, as well as the monthly averages of rainfall and their standard deviations (Figure 4b).

November, December and January were the months with the highest registered mean rainfall, with values of 173.2, 183.6 and

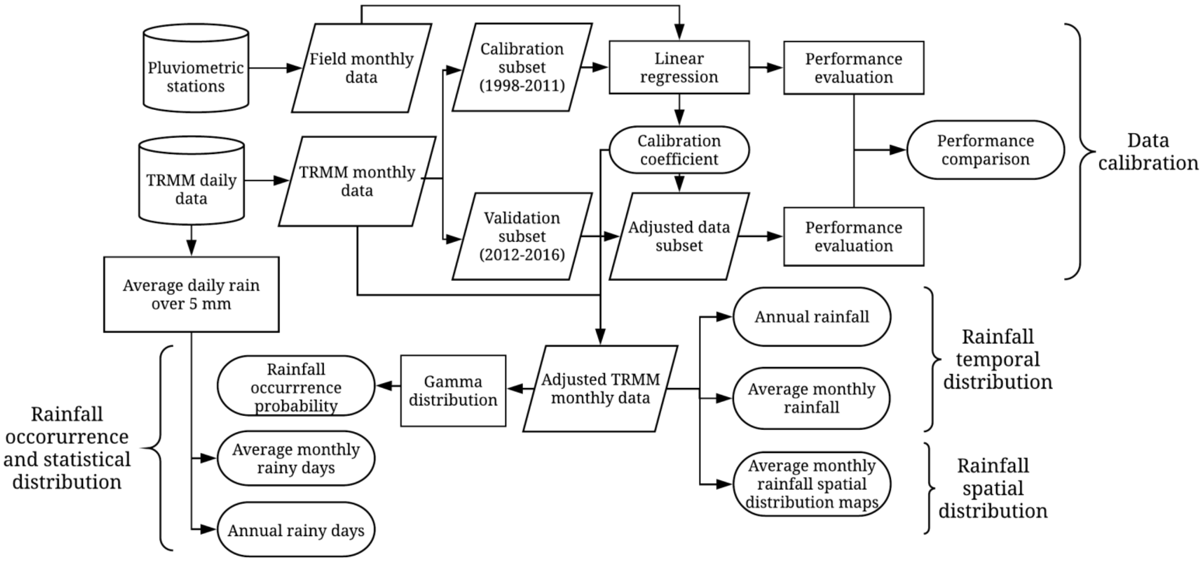

Figure 2: Flowchart of research methodology.

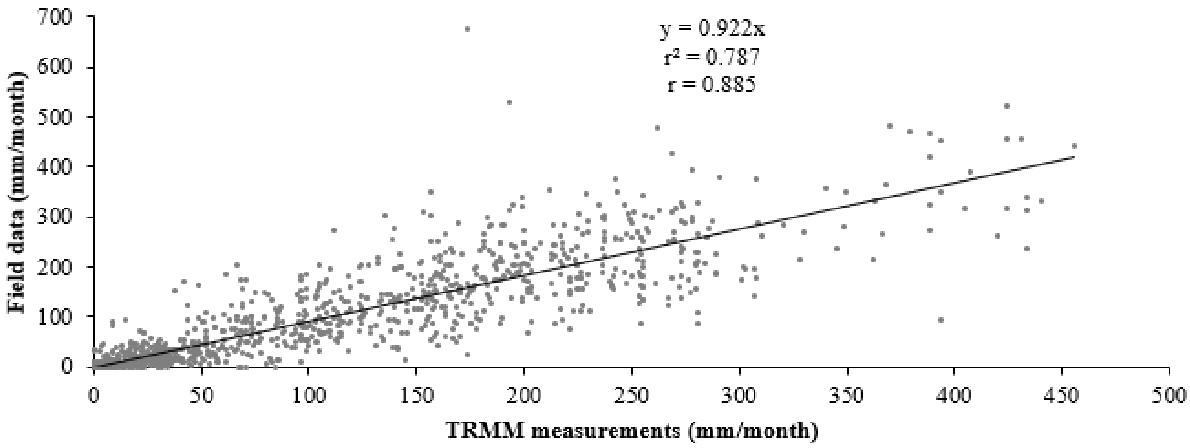

Figure 3: Calibration of TRMM data using pluviometric stations within or near Correntina, Brazil.

144.6 mm, respectively. It's possible to observe two well defined seasons, a wet one from November to April and a dry season from May to October.

In the 19 years evaluate the annual rainfall ranged from 620.5 to 1336.2 mm with average of 947.9 mm, coherent with the results presented for the region by Dourado et al. [24]. The wet season ranged from 478.0 and 1237.7, with average of 838.9 mm, which represents 88.5% of the mean annual rainfall.

Rainfall spatial distribution

The TRMM precipitation measurements images made possible the analysis of the rainfall spatial variation throughout the year (Figure 5). In general, the rainfall concentrates on higher altitude areas, which means an increase of rainfall on the western of Correntina. The west side presented a positive mean deviation of up to 100 mm during the wet season, and 20 mm during the dry season. The central-eastern side of the municipality showed a negative mean deviation of 40 during the wet season, while during the dry season the negative mean deviation was predominant in the central part.

Table 2: Performance evaluation of TRMM data calibration for Correntina, Brazil.

	ME[1]	MAE[2]	RMSE[3] (mm/month)	NSE[4]
Uncalibrated TRMM data	-5.6	28.6	48.7	0.773
Calibrated TRMM data	-0.8	27.8	47.9	0.792

[1]ME = mean error; [2]MAE = mean absolute error; [3]RMSE = root mean square error; [4]NSE = Nash-Sutcliffe index.

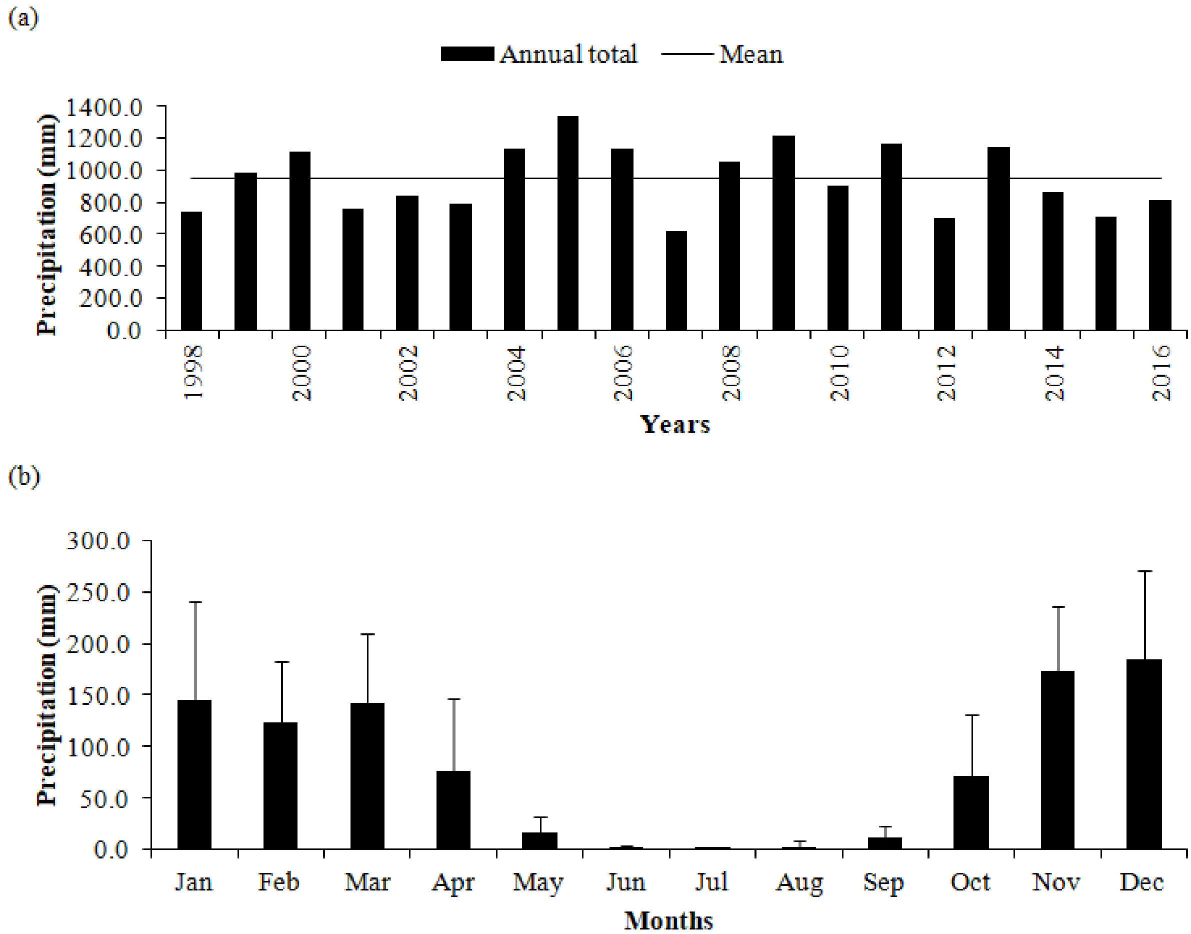

Figure 4: Temporal rainfall distribution for the municipality of Correntina, Brazil: annual totals (a); monthly averages of rainfall and their standard deviation (b).

The mean rainfall ranged from 783 to 990 mm during the wet season and from 90 to 135 mm during the dry season.

Recent studies [24–27] have worked with field data interpolation, which provides a general idea on how the spatial variation occurs. The downside of interpolative methods is that, to represents reality, a significant number of pluviometric stations in field is needed, which for many areas isn't available.

In view of the fact that the TRMM data isn't punctually acquired, it better represents the rainfall spatial distribution. The TRMM has a time series of about 20 years, and as times goes by, it acquires more relevancy in agricultural and hydrological studies.

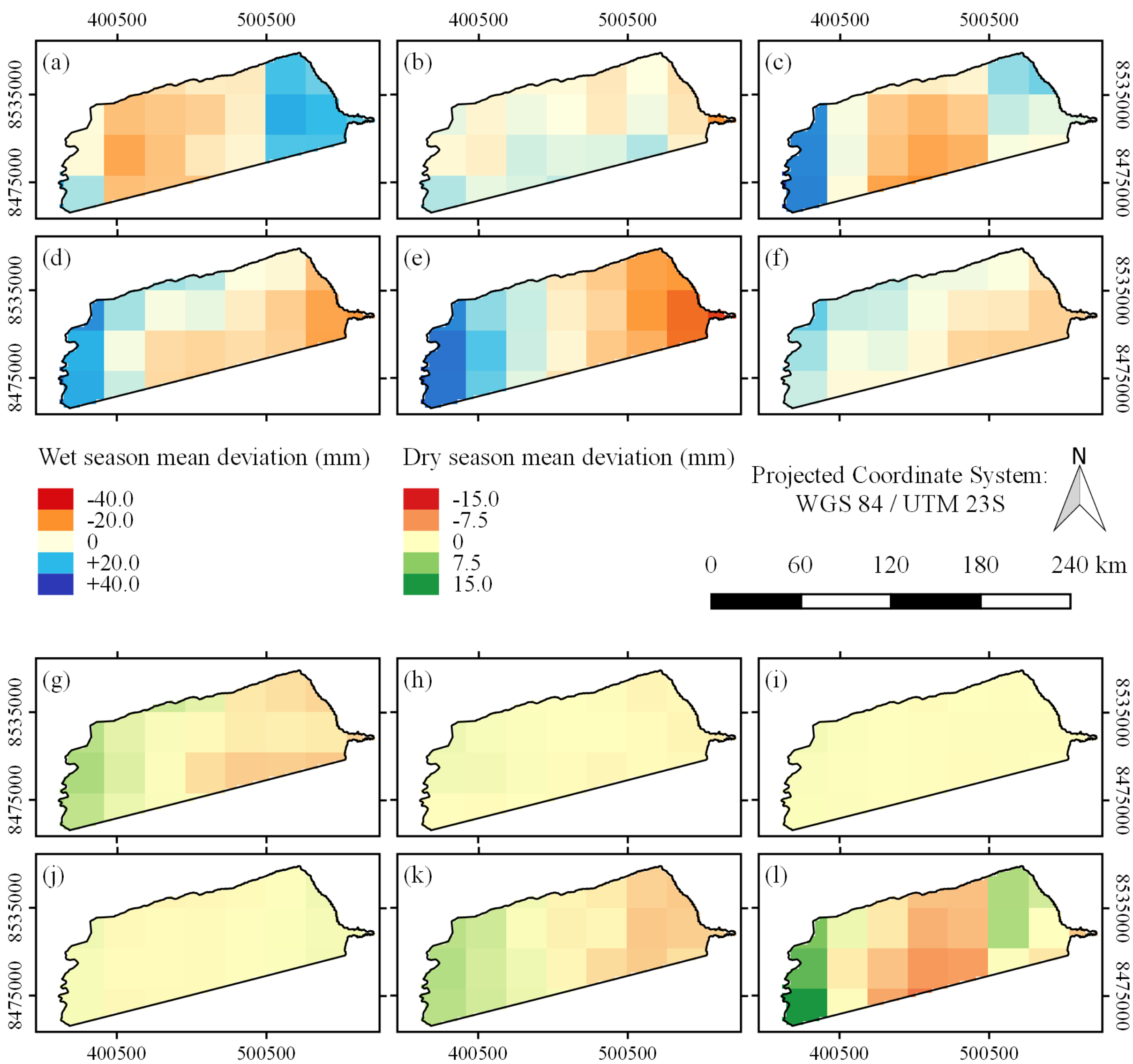

Figure 5: Rainfall spatial variation for the wet and dry seasons: November (a); December (b); January (c); February (d); March (e); April (f); May (g); June (h); July (i); August (j); September (k); and October (l).

In this scenario, the TRMM shows many advantages over standard methods. The TRMM spatial resolution presents not only pixels which dimensions are in general smaller than the average distance between pluviometric stations in Brazil, but it also provides a product that covers the entire tropical and subtropical regions of the planet [28]. A detailed review from Jiang and Wang [29] discuss the current role of satellite-based remote sensing data in the hydrological and climatic scenarios. The authors highlight that products, such as the TRMM, are not only important in characterizing ungauged regions, but have also further enhanced the knowledge of processes in many distributed hydrological models. For instance, Yuan et al. [30] found satellite rainfall estimates to perform better than gauged-based precipitation in the simulation of river streamflow. Zhang et al. [31] also documented the adjusted TRMM data to better perform than uncalibrated TRMM and rain gauges in streamflow simulations.

Rainfall occurrence

The number of annual rainy days in the

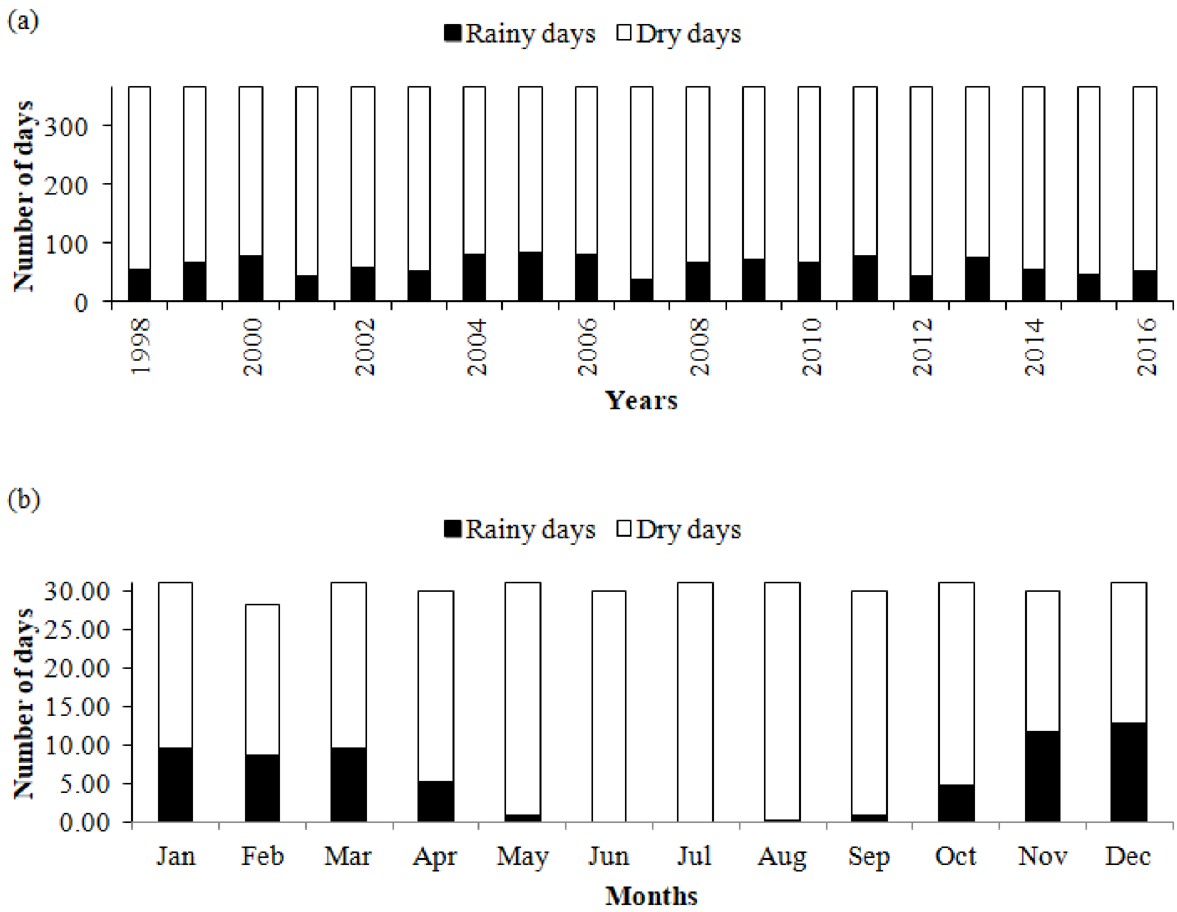

Figure 6: Historical number of annual rainy days (a) and monthly average rainy days (b) for the municipality of Correntina, Brazil.

time series analyzed ranged from 39 to 84 days (Figure 6a), with mean of 63 rainy days. The year with least rainy days was 2007, which also is the year with lowest registered rainfall of the series.

The monthly average rainy days (Figure 6b) were highest on November and December, 11.6 and 12.6 days, respectively. From May to September the number of average rainy days is below 1, only by the end of the dry period, on October, the number o average rainy days is greater than 1, which indicates how important irrigation is for agriculture viability during the period.

In Table 3 is presented the expected rainfall at different levels of probability. August was the only month with poor adherence to the Gama distribution, which was caused by the series of null values of rainfall registered for period.

The knowledge of the temporal distribution and probable precipitation is important to carry out an efficient planning of supplementary irrigation, aiming at the efficient use of water resources, allowing more reliable decision making [9]. Based on these information, the project designer, assuming an acceptable level of probability, may better scale the irrigation system [32].

Irrigation projects are usually dimensioned from average rainfall; however, it is noted that the probability of the average precipitation occurring remained below the expected level of 50%. This is due to the fact that the rainfall distribution presented a high goodness of fit to the gamma distribution. In this case, the use of average precipitation as a design criterion results in its under sizing, which may lead to the failure of the activity [33]. For this rea-

Table 3: Expected rainfall at different probability levels and average values in the monthly and annual time scale for Correntina, Brazil.

Period	Mean rainfall (mm)	p-value*	Expected rainfall at probability levels (mm)				
			90%	70%	50%	30%	10%
January	144.6	0.83	42.8	83.4	123.9	175.9	273.5
February	123.8	0.98	56.1	87.1	114.4	146.9	203.8
March	142.7	0.81	67.2	102.1	132.6	168.6	231.2
April	76.6	0.98	10.8	31.3	56.5	93.1	169.1
May	16.1	0.84	2.0	6.1	11.5	19.5	36.4
June	1.3	0.21	0.0	0.1	0.4	1.2	3.7
July	0.5	0.05	0.0	0.1	0.3	0.6	1.3
August	2.1	0.00	0.0	0.0	0.0	0.5	5.9
September	12.3	0.33	2.0	5.4	9.4	15.0	26.5
October	71.0	1.00	12.8	32.5	55.1	86.7	150.2
November	173.2	0.63	98.7	135.3	165.6	200.0	257.6
December	183.6	0.85	84.1	129.8	169.3	217.7	300.9
Wet season	838.9	0.98	604.8	729.0	824.4	927.8	1091.8
Dry season	108.9	0.91	25.5	56.3	89.2	133.1	218.3
Annual	947.9	0.63	692.8	828.7	932.7	1045.0	1222.5

*Kolmogorov-Smirnov goodness of fit test for Gamma distribution.

son, Castro and Leopoldo [34] suggests that the rainfall at the probability of 75% should be used in the design of irrigation systems. The gamma distribution did not present a good fit for the months of July and August, though these months presented insignificant heights of rainfall at most probability levels.

Pires et al. [35] stated that, in central-northern Brazil, the early sowing of soy right after the sanitary break (second half of September), though economically attractive, would come with higher climatic risks. This risk is clear for the Western Bahia, as amounts precipitated is very low in September (Table 3), even considering the 10% probability level.

In recent years, the soybean sanitary break has moved further into October, which results in less climatic risk, especially in the rainier region. The late sowing, however, reduces chances and profitability of double-cropping [8].

In the state of Bahia, the break for herbaceous cotton ends on 20 November, which would comprise the sowing period of lowest climatic risk [36], once it's the first month of the wet season and presents second highest number of monthly rainy days. On the other hand, irrigated cotton should be preferably planted up to the first half of January, given that supplementary irrigation is available at the beginning of the dry season during the development of the crop, especially at the time of flowering and bud formation.

At 50% probability, the rainy season presents a sufficient water supply to meet the demand of the main crops grown in Bahia: soybean, cotton, beans, corn and rice. Cultures which demands vary between 450 and 850 mm [37]. In these cases, irrigation rather be used during occasional dry spells and at the beginning and ending of the wet season. As for the dry season, crops depend almost exclusively on irrigation.

Conclusions

This study focused on characterizing rainfall spatial and temporal distribution across the municipality of Correntina, in Western Bahia. Satellite precipitation estimates presented good correlation to rain gauges, which were used to calibrate rainfall for the region. Rainfall temporal distribution region presented two well-defined seasons; a wet season, with a good distribution of rainy days, and a dry season, when the rainfall in most months is close to none. In addition, rainfall spatial distribution showed a tendency to come in higher volumes at higher altitudes, in the extreme west.

The mean rainfall occurs with a probability level below 50%, and, therefore, to safely design irrigation systems, rainfall values at higher probabilities should be considered. The Tropical Rainfall Measuring Mission has proven in this in many other works to improve the comprehension of rainfall spatial distribution, which is a clear reason for its recent popularization in hydrological and climatological studies.

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