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Characterization of Rainfall Patterns in the Semiarid Brazil
Caracterização dos Padrões de Precipitação no Semiárido Brasileiro

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Resumo

O Semiárido Brasileiro (SAB) é a região semiárida mais chuvosa do mundo, e sua economia é fortemente baseada na agricultura familiar, predominantemente em condições de sequeiro. A agricultura de sequeiro sofre influência da variabilidade climática na região, o que aumenta os riscos de perdas durante os períodos de seca. Deste modo, o objetivo deste estudo foi identificar ou padrões de precipitação e o número de dias com chuvas no período de 1979 à 2014, utilizando dados disponibilizados pelo *Global Precipitation Climatology Project* (GPCP). Utilizou-se técnicas estatísticas de Análise de Cluster com o intuito de criar grupos que são homogêneos no tocante da precipitação e também para o número de dias chuvosos dentro de cada mês. Para a verificação da classificação dos grupos homogêneos gerados na análise de cluster, aplicou-se a técnica estatística de análise discriminante. Foram gerados 4 grupos de precipitação pluvial para o SAB, definidos como SAB I, SAB II, SAB III e SAB IV, sendo o SAB I o mais chuvoso, o qual contempla os setores sul e leste do SAB, cuja precipitação média acumulada anual na ordem de 1000 mm. O SAB IV o segundo mais chuvoso estende-se no leste dos estados de Alagoas, Pernambuco, Paraíba e Rio Grande do Norte, todo o Ceará, oeste do Piauí, com totais médios anuais de 820 mm. O SAB II e SAB III são os mais secos, com 748 e 570 mm respectivamente. A classificação dos grupos de precipitação pluvial foi de 94%. Com relação ao número de dias chuvosos o setor leste e norte do SAB possuem os maiores números de dias chuvosos, em JFMA, totalizando 310 mm distribuídos em 81 dias. Para os setores oeste e sul do SAB observa-se o mesmo padrão no comportamento do número de dias chuvosos e precipitação, onde as maiores medias para NDJ com total de 451 mm para 64 dias e 55 dias respectivamente, os meses menos chuvosos em julho e agosto com 8 mm em 11 e 9 dias respectivamente. A classificação dos grupos de número de dias chuvosos foi de 95%.
Palavras-chave: Semiárido; Precipitação; Agricultura; dias chuvosos

Abstract

The Semiarid Brazil (SAB) is the wettest semiarid region of the world, and its economy is strongly based on family farming, predominantly in non-irrigated conditions. Dryland farming in this region is influenced by climate variability, which increases the risk of crop losses during periods of drought. Thus, the objective of this study is to identify rainfall and number of rainy days patterns in the period from 1979 to 2014, using data provided by the Global Precipitation Climatology Project (GPCP). Cluster analysis was used in order to define homogeneous groups in terms of precipitation and number of rainy days within each month. The statistical technique of discriminant analysis was used to verify the classification of homogeneous groups as defined by the cluster analysis. Four precipitation groups were created in the SAB, namely SAB I, SAB II, SAB III and SAB IV, where SAB I is the wettest one. It comprises the southern and eastern portions of the SAB and has an average annual accumulated rainfall of about 1,000 mm. The SAB IV is the second wettest group and extends throughout the east of Alagoas, Pernambuco, Paraíba and Rio Grande do Norte states, Ceará and western Piauí, with an average annual total of 820 mm. SAB II and SAB III are the driest groups, with 748 and 570 mm respectively. The accuracy of the classification of precipitation groups was 94%. Regarding the number of rainy days, the east and the north of the SAB present the largest number of rainy days, in JFMA, with a total of 310 mm distributed in 81 days. In the western and southern portions of the SAB the same rainfall and number of rainy days behavior patterns were observed. The highest means were registered in NDJ, with a total of 451 mm in 64 days and 55 days, respectively. As for the dry months, July and August registered rainfall means of 8 mm in 11 and 9 days, respectively. The accuracy of the classification of groups by number of rainy days was 95%.
Keywords: Semiarid; precipitation; agriculture; rainy days

1 Introduction

The Semiarid Brazil (SAB) is the wettest semiarid region of the world, even though its rainfall patterns are highly variable in time and space. Thus, the region is regularly struck by long and severe droughts, which cause considerable economic and social losses (Rao *et al*., 1993; Alves *et al*., 2005; Malvezzi, 2007). The economy of the SAB is strongly based on family farming, predominantly in non-irrigated conditions, which corresponds to approximately 80% of the total workforce. Due to high spatial and year-to-year rainfall variability, family farming becomes a high-risk activity, with heavy losses during extended dry periods.

Despite the frequent occurrence of droughts in the SAB (Rao *et al*., 1993), its inability to adapt to these events is evident, putting the population and their economic activities in a permanent state of vulnerability. During the drought from 2010 through 2013 there were agricultural productivity losses, critical water shortage, and a considerable loss of cattle and sheep, which are the main farming activities in the region (Burney *et al*., 2014; Gutiérrez *et al*., 2014).

The soils of the SAB are extremely fragile and susceptible to desertification, which makes climate factors crucial to dryland farming (Garcia-Franco *et al*., 2018; Coutinho *et al*., 2013). Agriculture in the SAB is limited to dryland farming and grazing, especially cattle and sheep (Lôbo *et al*., 2011; Sánchez *et al*., 2018). According to the IPCC (2001), the life cycle of crops is weather and climate dependent. Thus, the annual performance of agricultural productivity is highly influenced by a regions climate conditions. Crops have different water needs depending on their growth stage, which generally is consisted of germination, jointing, flowering, maturation and harvest (Francelli & Dourado-Nato, 2000). Marengo *et al*. (2017) point out that agricultural productivity associated with a strong dependence on rainfall makes the region one of the most vulnerable to droughts, especially the northern portion of the Bahia state, because of corn and bean crops.

Precipitation in the SAB is characterized by high spatial and temporal variability with the occurrence of extreme precipitation events being influenced by different meteorological systems acting in the region. These systems are consisted mainly of Squall Lines (SL), the Intertropical Convergence Zone (ITCZ), Easterly Waves Disturbances (EWD), Upper Tropospheric Cyclonic Vortices (UTCV), the South Atlantic Convergence Zone (SACZ), Frontal Systems (FS) and Mesoscale Convective Complexes (MCC) (Molion & Bernardo, 2002; Reboita *et al*., 2012). According to Marengo (2009), Hastenrath & Heller (1977) and Hastenrath (1984); the rainy season in the SAB region depends on the position and intensity of the ITCZ.

In this manner, the most important meteorological system regarding rainfall rates in the northern part of the SAB is the ITCZ, which determines whether there will be rainfall deficit or surplus. The frequency of occurrence of droughts in the region affects agriculture, with the reduction of river discharges and drinking water supply, impacting the efficiency of such economic activities (Silva *et al*., 2009). The economy in the SAB region is based mainly on dryland farming, where rainfall plays a key role in the success of crop harvest (Albiero *et al*., 2015; Silva *et al*., 2009; Graef & Haigis, 2001).

However, there are few studies regarding the characterization of rainfall patterns specifically in the SAB. Marengo *et al*. (2011) using weather data from 1970-1990, found that in its northern portion, where the most intense droughts of the region are registered, the rainy season takes place between February and May, while the dry season takes place between August and October. Marengo *et al*. (2011) also assess climate vulnerability, suggesting that the region presents 70% of water deficit yearly. Oliveira *et al*. (2016), in their study on climatology and trend analysis of precipitation extreme events in subregions of northeastern Brazil, identified two homogeneous precipitation groups in the northeastern portion of the SAB: Northern Semiarid (NS) and Southern Semiarid (SS), where annual accumulated rainfall rates of 654.09 and 810.42 mm were observed in the NS and the SS, respectively.

On that account, climatic conditions are important factors for farming and agricultural productivity in the SAB. Temporary crops cultivated by family farmers in a dryland system tend to experience losses in productivity, regulated by water deficit or surplus. Understanding climatic conditions is extremely important because such knowledge is a tool that enables farmers to better plan when, what and how much to plant, according to soil water conditions, which usually present low water availability to crops due to the dry season happening before the rainy season. In this study, annual accumulated rainfall data were used, as well as the count of rainy days per month, for the period from 1979 to 2014, in the entire region of the SAB. Thus, the objective of this study is to identify the behavior patterns of rainfall and of the number of days with observed rainfall over 36 years in the entire region of the SAB.

2 Data and Methods

2.1 Study Area

The studied region is the Semiarid Brazil region (SAB), which covers an area of 982,563.3 km², which is equivalent to approximately 10% of the total land area of Brazil and 89.5% of the Northeast region of Brazil. The SAB comprises 1,135 municipalities in eight states of the Northeast region of Brazil (Alagoas, Bahia, Ceará, Paraíba, Pernambuco, Piauí, Rio Grande do Norte and Sergipe), in addition to the north of the Minas Gerais state, located in the Southeast region of Brazil (Figure 1) (MIN, 2005). The delimitation of the region was carried out by the Ministry of National Integration (MIN, 2005) considering the following criteria: maximum 800 mm annual rainfall, aridity index lower than 0.50 or drought risk greater than 60%.

The SAB is the wettest semiarid region of the world, with an average rainfall of about 800 mm concentrated during the months of February through May, average temperature higher than 23°C and reference evapotranspiration exceeding 2,000 mm/year (Rodrigues da Silva *et al*., 1998; Marengo *et al*., 2011; Moscati & Gan, 2007).

2.2 Data

For the characterization of rainfall in the SAB, monthly accumulated rainfall data for the period from 1979 to 2014 were used. Precipitation data (mm day^{-1}) were obtained from the Global Precipitation Climatology Project (GPCP), described in detail by Chen *et al*. (2008). Data processing was carried out using the method of Shepard (1968). Willmott *et al.* (1985) reported that the Shepard Method was the best interpolation method for 0.5° lat/lon global grids with over 24,000 long-term average rainfall observations. In this study, data were selected with a spatial coverage of 0.5° x 0.5°, comprising a total of 338 grid points, in which each point contains a time series consisted of 36 years of daily data.

2.3 Methods

2.3.1 Cluster Analysis

Cluster analysis was used in order to characterize areas with homogeneous precipitation, i.e., similar rainfall rates within each group in relation to annual totals (with no seasonality). Additionally, cluster analysis was also used to identify homogeneous groups regarding the number of observed rainy days, considering the 338 grid points within the whole of the SAB. In this study, the Euclidean distance was used, which compares two sample elements for each variable (year) belonging to the vector of observed values, in which the distance between two elements X_l and X_k, $l \neq k$ is defined by:

$$d(X_l, X_k) = [(X_l - X_k)'(X_l - X_k)]^{1/2} = \left[\sum_{i=1}^{p}(X_{il} - X_{ik})^2\right]^{1/2} \quad (1)$$

A distance matrix between X_l and X_k is given by $(X_l - X_k)'(X_l - X_k)$ element characteristic vector (matrix identity pxp). Where p= 1,2, …, i; X_{il} value of variable l for element i; X_{ik} value of variable k for element i.

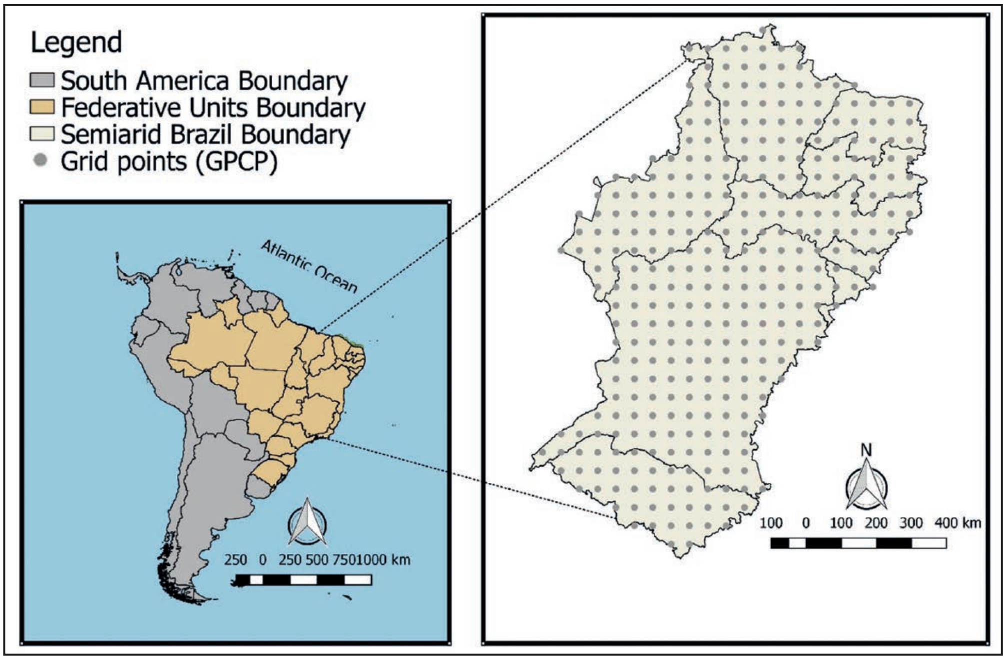

Figure 1 Location of the Semiarid Brazil region.

The Ward method evaluates the dispersion within each group, i.e. the smaller the distance between grid points, the greater the similarity. This method has been thoroughly used and is based on the change of variation between and within groups, considering the square of the Euclidean distance as a measure of dissimilarity (Mingoti, 2005; Johnson & Wichern, 2007; Wilks, 2006). Thus, the distance between the clusters C_1 and C_2 is given by:

$$d(C_1,C_2) = \left[\frac{n_l\, n_i}{n_l + n_i}\right] (\bar{X}_{l.} - \bar{X}_{i.})'(\bar{X}_{l.} - \bar{X}_{i.}) \quad (2)$$

where n_i and n_l number of elements in each cluster; $(\bar{X}_{l.} - \bar{X}_{i.})'(\bar{X}_{l.} - \bar{X}_{i.})$ is the cluster centroid for l and i.

2.3.2 Discriminant Analysis

After defining homogeneous precipitation groups and homogeneous number of rainy days groups with the cluster analysis, the discriminant analysis was used in order to verify the classification made a priori. The analysis consists of a comparison between a sample element in relation to its potential group, which is generally carried out by means of a linear combination derived from the following equation (Mingoti, 2005; Johnson & Wichern, 2007):

$$Z_{ik} = \beta_{0i} + \beta_{li}X_{lk} + \cdots + \beta_{ji}X_{JK} \quad (3)$$

where, Z_{ik} is the discriminant score, β_{0i} is the constant of the function, β_{ji} is the weight of the independent variable j and discriminant of the function i.

In this study, this technique was used with the objective of measuring the accuracy of the classification by groups proposed by the cluster analysis.

3 Results

Studies on the characterization of rainfall patterns are important for the knowledge and implementation of management actions in a variety of sectors, including family farming. These types of farms, particularly those which use dryland systems, are susceptible to the influence of climate variability in the SAB. This study is divided in 2 stages, in which the first stage consists of the rainfall characterization by means of statistical analysis considering annual accumulated rainfall. In the second stage the analysis was carried out using the number of rainy days per month. In both stages 338 grid points were considered for the period from 1979 to 2014.

3.1 Climatology

Figure 2 shows the average monthly rainfall in the SAB during the period from 1979 to 2014. One can note that August (Fig. 2 H) is the driest month in the SAB, given that rainfall rates are lower than 5.0 mm in almost half entire region.

In October (Fig. 2 J) the rainy season begins in the southern, southwestern and western portions of the SAB, which encompass northern Minas Gerais, southern, southwestern and central Bahia, in addition to the southeast of the Piauí state. In this area, accumulated rainfall is mostly of the order of 60 mm. In a small southwest area these values exceed 100 mm. In the rest of the region, during the month of November, rainfall is less than 30 mm. In the northern portion, precipitation is as low as 5 mm.

During November (Figure 2 L) and December (Figure 2 M), precipitation intensifies in the southern and southwestern portions, where accumulated rainfall is predominantly greater than 80 mm, peaking at 140 mm in the southwestern area. In November, rainfall in the central part of the SAB is less than 30

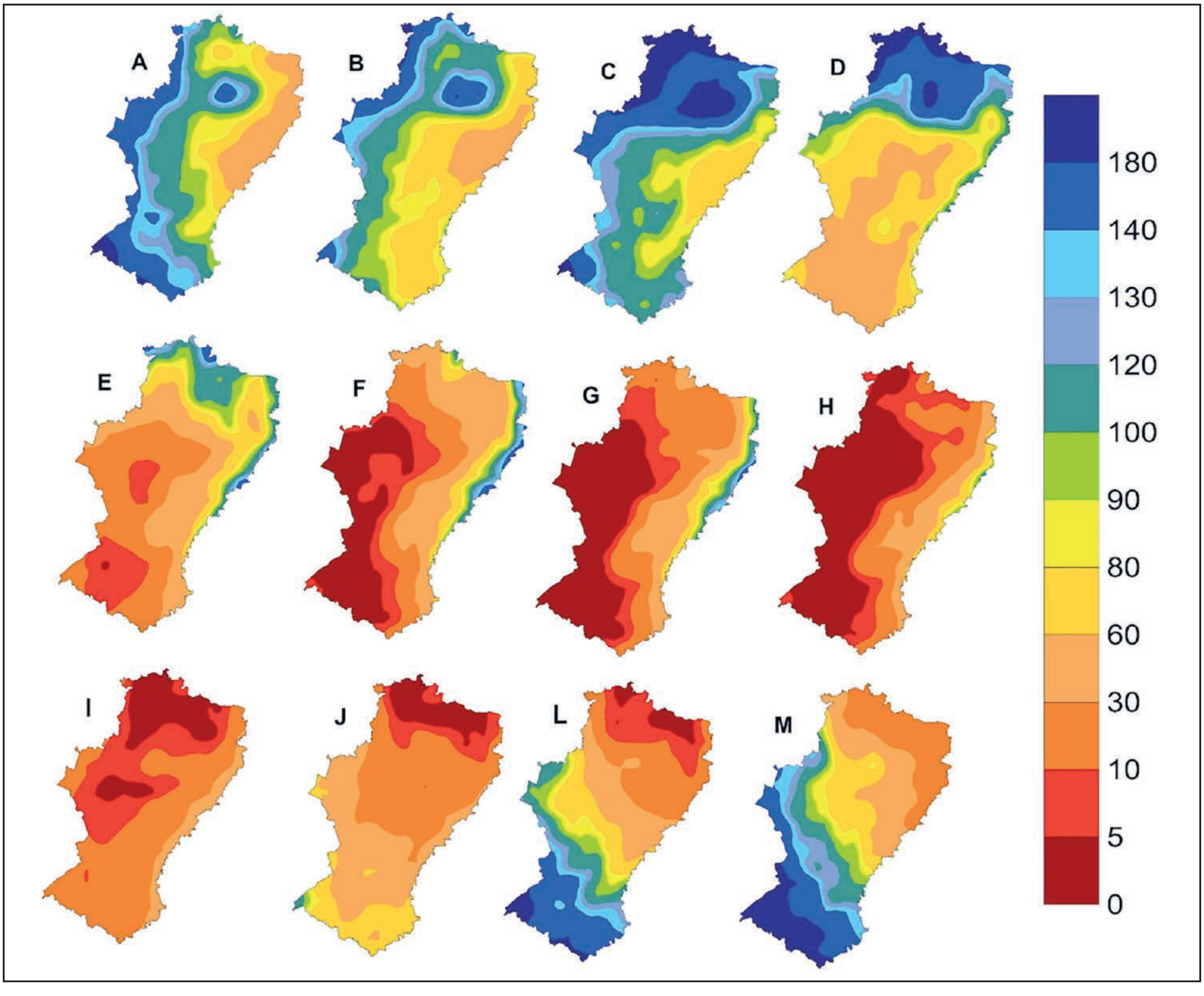

Figure 2 Average monthly rainfall (mm) in the SAB during A January, B February, C March, D April, E May, F June, G July, H August, I September, J October, L November and M December, from 1979 to 2014.

mm, while in the north it is less than 10 mm. During December, it appears that the area with precipitation exceeding 80 mm expands, encompassing the central portion of the SAB. On the other hand, accumulated rainfall in the northern portion exceeds 20 mm.

Nevertheless, the months of January (Figure 2 A), February (Figure 2 B) and March (Figure 2 C) are the wettest in the SAB. The northern portion is the wettest, where precipitation is as large as 100 mm. During this period the ITCZ acts more intensely in this region, when the band of clouds reaches its southernmost position (Hastenrath, 1984, 2012). Although the ITCZ is located in the Northern Hemisphere (NH) most of the year, between March and April it shifts to the far south, when the Tropical Atlantic Ocean temperature gradient is weaker (Hastenrath & Lamb, 1977; Hastenrath, 2012). An eventual abnormal behavior of this system can cause extreme precipitation events in the region, with the occurrence of either droughts or severe storms. Its position is related to the seasonal shift of warm sea surface temperatures (Cavalcanti, 2012). In wet years, Souza & Cavalcanti (2009) showed that the rainy season in the northern part of the Northeast Brazil is related to the position of the ITCZ. Uvo (1998) points out that in dry years the ITCZ shifts to the north in February and early March, while in May it is located further south.

Precipitation in the southern portion of the region (Bahia countryside) happens mostly during the period from November until February, being associated with frontal systems (Kousky, 1979). Chaves & Cavalcanti (2001) found that periods of intense rainfall in the southern portion of the Northeast Brazil are associated with the South Atlantic Convergence Zone (SACZ) dislocating to the north. It is known that the SACZ is a cyclonic vortex formed by moisture convergence in the Atlantic (Kodama, 1993).

During the period considered in this study, the most intense precipitation occurs in the northern part of the SAB, in which monthly precipitation exceed 200 mm, especially in Ceará, western Paraíba and northwestern Piauí.

In April, the beginning of the dry season takes place in the southern portion of the SAB. It is also noted a decrease in precipitation intensity in the central part and the upkeep of high rainfall rates in the northern portion, which still exceed 200 mm. During May, rainfall still occurs in the northern SAB, but with lower intensity if compared to April rates. In April, the dry season is already well established in the southern and southwestern portions of the SAB. Furthermore, in June the dry season is established throughout the entire western part of the SAB. In this month the occurrence of more intense rainfall is limited to the east and the north, where rates do not exceed 60 mm. In the months of July, August and September precipitation decreases considerably and is limited to the eastern coast strip.

It is observed that during January the most intense precipitations in the SAB occur in its southwestern part (southwest of Bahia and northwest of Minas Gerais) with accumulated rates exceeding 100 mm. This region is under the influence of the SACZ, an axis of clouds that usually remains stationary from 4 to 10 days, but may persist for up to 20 days, and contributes to precipitation over the region during summer (Kodama, 1992; Kousky, 1988). It is noted that SACZ begins to be acting in the region from November (Figures 2L and 2M). The occurrence of precipitation ranging from 80 to 200 mm in the western part of the SAB, particularly in Piauí, Ceará and Bahia, is also noted. The occurrence of precipitation in this region at this time of the year represents the onset of the rainy season, which begins in November and December. During the months from June to September the dry period is established in the entire semiarid region.

In the southern portion of the SAB rainfall starts in October, intensifying in November and December, particularly in the northwestern Minas Gerais and extending through Bahia. During this period the main meteorological systems acting are the frontal systems that interact with the tropical convection that settles in the central part of South America during spring and summer and end up forming the SACZ.

In order to identify homogeneous precipitation regions in respect of annual accumulated rainfall (in order to remove data seasonality), the cluster analysis technique suggested the creation of 4 groups, which are presented in Figure 3. Group 1, namely SAB I, covers the southeast and the south of the SAB. In this group, average accumulated rainfall is of the order of 956 mm.

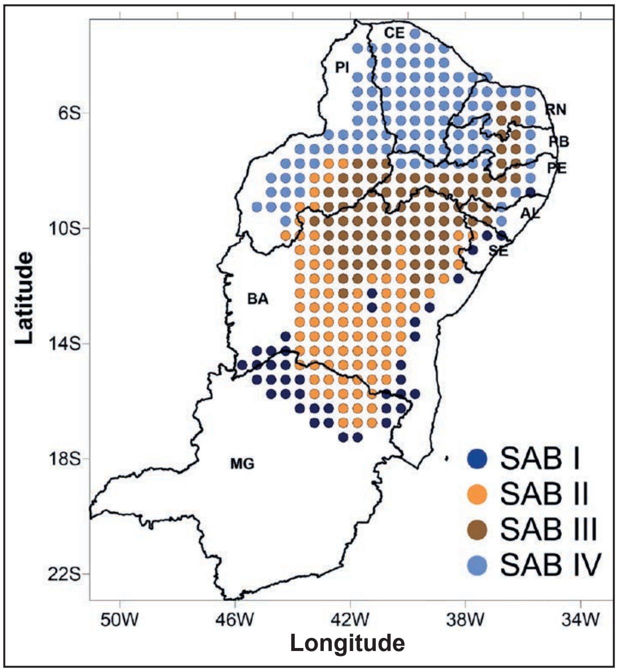

Figure 3 Spatial distribution of homogeneous precipitation areas, from 1979 to 2014.

The SAB I is a transition area between wetter regions and regions with a more semiarid like climate. These areas are the Atlantic Forest in the east and the Cerrado in the south, which climates vary from humid to sub-humid (Souza & Oliveira, 2006). Another evidence of the transitional aspect of the region SAB I is the lack of continuity in its points, which can be better noted in the eastern part of the SAB. One of those obvious discontinuities is the isolated group of points on the border between SAB II and SAB III. These points have considerably higher precipitation if compared to their surroundings, what is probably associated with terrain elevation, since they are located over the Chapada Diamantina, in the Bahia state. The precipitation that occurs in the eastern part of the SAB I is modulated mainly by frontal systems, whereas the precipitation of the southern part is directly influenced by the SACZ (Cavalcanti *et al*., 2012)

The region named SAB IV is the second rainiest region with average annual totals of 820 mm. SAB IV extends from the east of Alagoas, Pernambuco, Paraíba and Rio Grande do Norte states, throughout Ceará, western Piauí, northern Minas Gerais and southern Bahia, comprising a total of 112 grid points. According to Oliveira *et al*. (2016), Northeast Brazil subregions present similar climate variability, but they differ in terms of rainfall intensity. Furthermore Grimm & Tedeschi (2009) report that El Niño and La Niña events can influence the volume of rain over the Northeast region of Brazil, which encompasses 89.5% of the municipalities of the SAB (IBGE, 2010).

Groups 2 (SAB II), with 92 points, and 3 (SAB III), with 94 points, present the lowest average accumulated rainfall of the region, with rates of 748.46 and 570.51 mm, respectively. The SAB II region comprises the south of Bahia and the northernmost portion of Minas Gerais. The SAB III, which is drier, covers the north of Bahia, eastern Piauí, the west of Pernambuco and Alagoas, and the central part of Paraíba and Rio Grande do Norte. This region often experiencies severe droughts (Hastenrath & Heller, 1977; Cavalcanti, 2009). The rainy season of the SAB III occurs from March to May, when the interhemispheric southward gradient of sea surface temperature (SST) is weakest and the ITCZ reaches its southern position, generally during April (Hastenrath, 2006).

Figure 4 shows the monthly accumulated rainfall boxplot in the period from 1979 to 2014, by groups as defined by the cluster analysis. In this way, it is noticed that in the SAB I the rainy season starts in October intensifying from November until March and declining as soon as April. From May to September the dry season is established in the region. The same behavior is observed in the SAB II, with the rainy season starting in October and ending in April. Oliveira *et al*. (2016), in a study assessing the annual progression of precipitation during the driest season (JJA), observed that the annual rainfall variability can be clearly identified throughout the subregions, with the dry and wet seasons well defined in the southern portion of the SAB. However, in the SAB III, the rainy season starts in November and remains strong until March, while the dry season is established from April to October. In the region belonging to the SAB IV group the rainy season starts in December intensifying until April, declining in May and with its dry season taking place in June until November. According to Ratisbona (1976) in this sector the rainy season corresponds to the period when the ITCZ assumes its southernmost position. In terms of monthly means, it is observed that in groups 1 and 2 the highest values are found in November (spring), December and January (summer). In group 3, the highest means are observed in January, February (summer) and March (autumn).

On the other hand, in Group 4 (north of the SAB), the highest means are observed in February (summer), March and April (autumn). Reboita *et al*. (2012); Molion & Bernardo (2000); point out that the ITCZ is the main atmospheric system acting over this region, and that during this period it is located in the Southern Hemisphere and that ends up contributing to the formation of mesoscale convective systems. During the months from June until September the dry season is established in the entire semiarid region.

Regarding variability in all groups, that is, in the entire region of the SAB, there is little precipitation variability in the period from May to October.

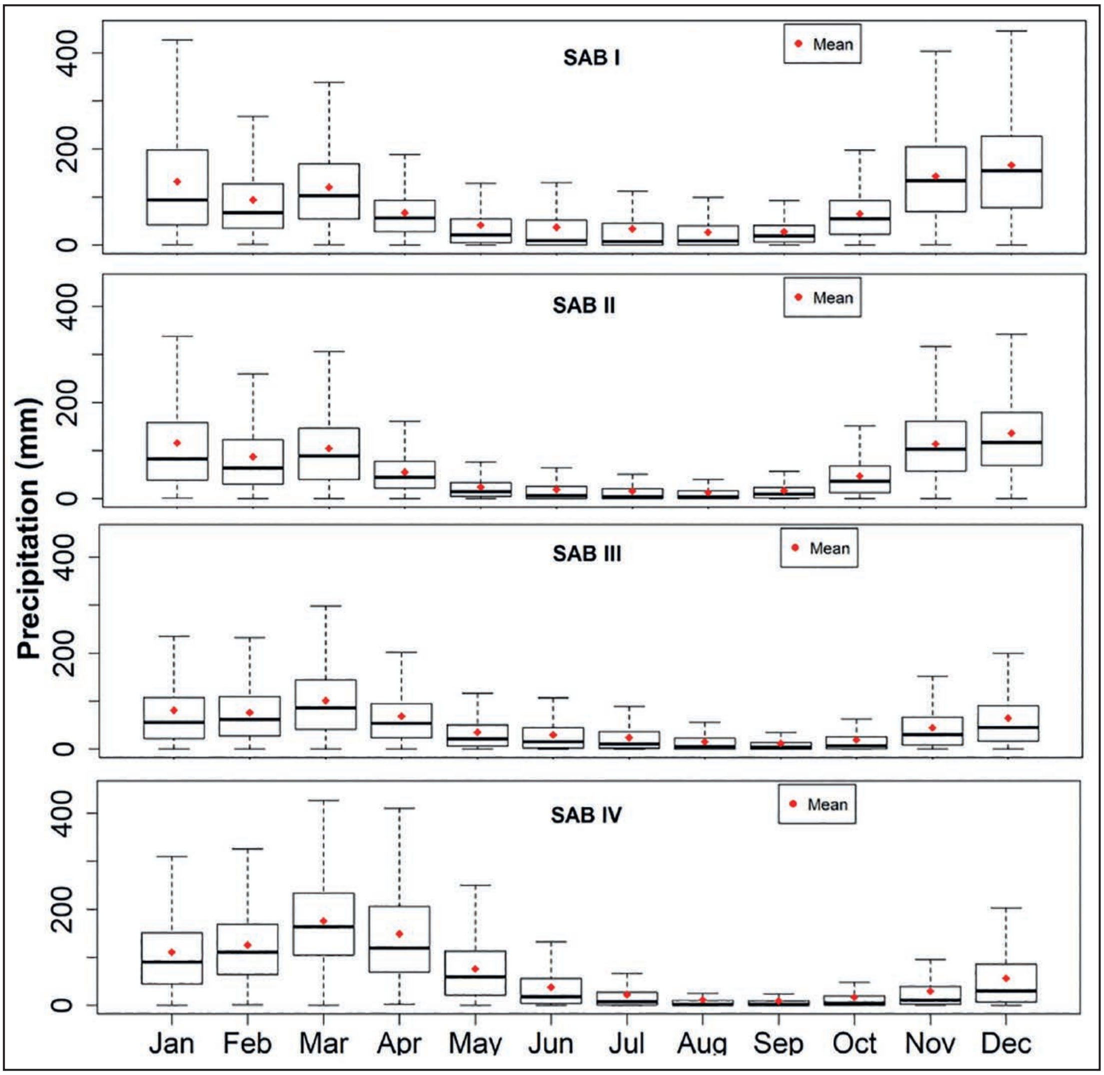

Figure 4 Monthly accumulated rainfall boxplot by group in the period from 1979 to 2014.

After the definition of homogeneous precipitation groups by means of cluster analysis, the discriminant analysis technique was used to test the classification of regions (SAB I, SAB II, SAB III and SAB IV). Table 1 shows that, overall, 94% of the previous cluster analysis classification was confirmed. In SAB I, 37 grid points were accurately classified, while 3 points were considered as belonging to the SAB II region, representing a total accuracy of 93%. In the SAB II region, 82 points were correctly classified, while 4 grid points were considered part of the SAB I region; 5 points part of the SAB III and 1 point part of the SAB IV, representing a total accuracy of 89%. In the SAB III group there were 91 correct classifications and 3 considered as part of the SAB II, with a total accuracy of 97%. In the SAB IV the total accuracy was of 95%, with 106 correct classifications, 1 point considered part of the SAB II and 5 points considered part of the SAB III.

Allocated Group	Correct group [a]				TOTAL
	SAB I	SAB II	SAB III	SAB IV	
SAB I	37	04	00	00	-
SAB II	03	82	03	01	-
SAB III	00	05	91	05	-
SAB IV	00	01	00	106	-
Total N	40	92	94	112	338
Correct N	37	82	91	106	316
Ratio	0.93	0.89	0.97	0.95	-

[a]94% of grouped grid points accurately classified
Table 1 Classification of groups by discriminant analysis

Besides total rainfall, another extremely important information for agricultural purposes is the length of the rainy season or the number of days with observed precipitation. This information allows agricultural zoning, the definition of planting seasons and the overall planning of the crop calendar. It is also key information for the crops genetic improvement sector to comply the length of the phenological growth stage of crops with the length of the rainy season. In order to meet this demand, a study on the number of days with rain was carried out, identifying homogenous areas (grid points) in relation to the number of rainy days. Cluster analysis suggested the definition of 4 groups. Figure 5 shows the spatial distribution of such homogeneous groups. Group 1, classified as "High", covers the eastern region until Minas Gerais, with 99 (29.29%) points and mean of 19.64 rainy days. Group 3, "Medium", has 14.96 rainy days and encompasses the entire Ceará state, west of Rio Grande do Norte and Paraíba and northern Piauí. Group 2, labelled as "Low", covers 89 (26.33%) grid points and has a mean of 13.96 rainy days comprising western Bahia and northern Minas Gerais. Group 4, "Very Low", covers 62 (18.34%) points with a mean of 12.64 rainy days encompassing the north of Bahia, south of Piauí and extending through the west of Pernambuco.

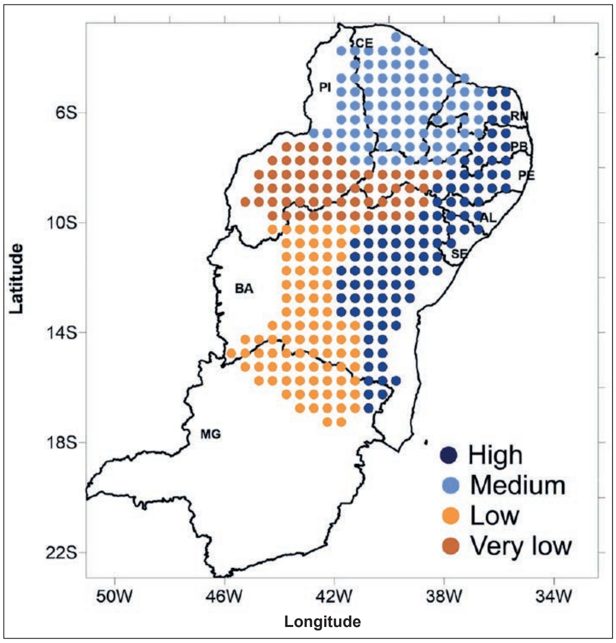

Figure 5 Spatial distribution of homogeneous areas considering the number of rainy days, from 1979 to 2014.

The discriminant analysis for the High, Medium, Low and Very Low, considering the number of rainy days, shows that the High (Eq. 3) has the largest linear discriminant function. That is, its coefficients contribute the most to the classification of observed data. The largest non-standard coefficients are used to formulate the actual prediction equation used to classify new samples. In this study the linear discriminant function for each group is given as follows:

$$D_1 = -333{,}75 - 14{,}86 \cdot Jan + 1.36 \cdot Feb + 39{,}14 * Mar - 9{,}57 * Apr - 6{,}42 * May + 12{,}7 * Jun - 15{,}4 * Jul + 18{,}53 * Aug + 6{,}73 * Sep - 27{,}05 * Oct + 9{,}11 * Nov + 12{,}7 * Dec \tag{3}$$

$$D_2 = -274{,}03 - 12{,}56 * Jan - 2{,}01 * Feb + 37{,}58 * Mar - 8{,}84 * Apr - 6{,}77 * May + 13{,}31 * Jun - 14{,}58 * Jul + 16{,}06 * Aug + 4{,}87 * Sep - 23{,}58 * Oct + 8{,}2 * Nov + 12{,}04 * Dec \tag{4}$$

$$D_3 = -327{,}98 - 10{,}33 * Jan - 2.36 * Feb + 38{,}16 * Mar - 7{,}21 * Apr - 5{,}18 * May + 9{,}98 * Jun - 11{,}75 * Jul + 13{,}15 * Aug + 8{,}75 * Sep - 26{,}09 * Oct + 7{,}69 * Nov + 11{,}22 * Dec \tag{5}$$

$$D_4 = -293{,}38 - 11{,}63 * Jan - 0.98 * Feb + 37{,}28 * Mar - 8{,}33 * Apr - 6{,}43 * May + 11{,}54 * Jun - 13{,}54 * Jul + 15{,}8 * Aug + 6{,}6 * Sep - 25{,}72 * Oct + 7{,}64 * Nov + 12{,}24 * Dec \tag{6}$$

Regarding overall classification, Table 2 shows that 95% of the previous classification carried out by cluster analysis was confirmed. In High there were 97 correct classifications and 2 grid points were considered as belonging to the Very Low region, representing a total accuracy of 98%. In the Medium region 79 classifications were deemed correct, and 10 grid points were considered part of the Very Low region, with a total accuracy of 89%. In the group of the Low region there were 85 correct classifications, while 3 points were considered as part of the Very Low region, representing a total accuracy of 97%. Finally, the Very Low region presented 59 correct classifications and 3 points were considered as belonging to the Medium region, with a total accuracy of 95%.

Allocated Group	Correct group [a]				TOTAL
	High	Medium	Low	Very Low	
High	97	00	00	00	-
Medium	00	79	00	03	-
Low	00	00	85	00	-
Very Low	02	10	03	59	-
Total N	99	89	88	62	338
Correct N	97	79	85	59	320
Ratio	0.98	0.89	0.97	0.95	-

[a] 95% of grouped grid points accurately classified
Table 2 Results of the classification

Figure 6 shows that throughout the annual cycle (12 months) the highest monthly means for the groups 1 and 3 are found, as previously reported, in JFMA, with maximum rates being observed in March. Group 1 "High" presented a total of 310 mm distributed in 81 days and group 3 "Low" presented a total of 589 mm distributed in 96 days, considering the 4-month period JFMA. In this period the ITCZ is located further south of its usual position, contributing to higher precipitation rates and number of rainy days (Uvo & Nobre, 1989). After this period, rainfall rates decline in group 1 throughout the entire eastern portion of the SAB. August and September are the driest months with a total rainfall of 65 mm in 39 days. The same behavior pattern is observed in groups 2 "Medium" and 4 "Very Low", with the highest means taking place in NDJ, with a total of 451 mm in 64 days and 55 days, respectively. The driest months in these regions are July and August with 8 mm in 11 and 9 days, respectively. The increase in the number of rainy days during this period is associated with the formation of the South Atlantic Convergence Zone (SACZ) (Uvo & Nobre, 1989).

4 Conclusion

The SAB region aggregates the worst indicators of economic development in Brazil. SAB's main economic activity is the production of grains (mainly corn and beans, which are its basic food) and livestock production. These activities is based on family farming. However, these activities depend

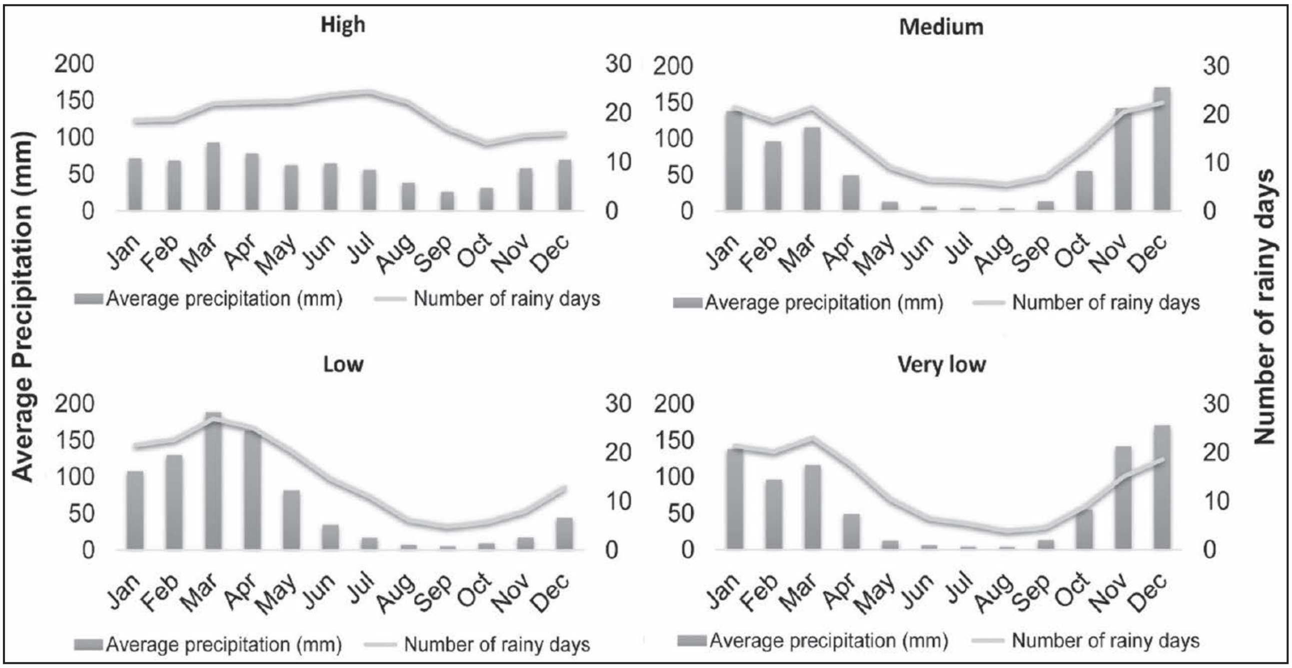

Figure 6 Average monthly precipitation and number of rainy days in the SAB, 1979-2014.

substantially on weather and climate conditions, especially precipitation. Thus, knowledge of precipitation patterns on the SAB is importance, since it will provide technical-scientific support for subsidies for the elaboration of public policies to mitigate and adapt to climatic variations.

Annual climatological precipitation in the 1979-2014 period in the SAB starts in October in its southwestern portion, extending to the southern part and most of the west throughout November and December. In January, rainfall covers, in addition to the above-mentioned areas, the west and north of the SAB. Starting in April, rainfall rates in the southern region begin to decline and in the months of June and July the occurrence of high rainfall volumes are limited to the eastern portion of the SAB. August and September are the driest months.

According to the cluster analysis the SAB presents 04 regions with homogeneous precipitation named SAB I, SAB II, SAB III and SAB IV. However, Oliveira *et al.* (2016) conducted an analysis of extreme precipitation climatology in subregions of the Brazilian Northeast and found only two subregions in the semi-arid region (Northern Semi-arid and Southern Semi-arid). It is noteworthy that this study was carried out for the entire Northeast region and the SAB is only one subregion located in the interior of the Northeast. The rest of the northeast region (except the SAB) has a humid climate in the eastern part (coastal region) and in the western part (transition with the Amazonian forest).

The mean annual precipitation of each group outlined in this study is 956 mm (SAB I) with rainy season from October to March; 748 mm (SAB II) and 570 mm (SAB III), which are the driest and rainy regions from October to April and November to March, respectively; The region known as SAB IV, which contemplates the northern sector of the SAB, is the second most rainy region with a total annual average of 820 mm, has a rainy season of December intensifying until April, the highest rainfall averages in this sector is in February following until May, corroborating with a climatic analysis of the SAB region that can be seen in Marengo *et al.* (2011). Regarding homogenous precipitation areas in relation to annual accumulated rainfall, the classification of groups presented an overall accuracy of 94%.

With respect to the number of rainy days, the eastern and northern portions of the SAB presented the largest number of rainy days, in JFMA, with a total of 310 mm distributed in 81 days (Group 1 - east) and 589 mm in 96 days (Group 3 - north). In the west and south portions of the SAB the same behavior pattern was noticed regarding the number of rainy days and precipitation rates. The highest means were observed in NDJ with a total of 451 mm in 64 days and 55 days, respectively. The driest months were July and August with 8 mm in 11 and 9 days, respectively.

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