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Artigos

ANALYSIS OF DAILY PRECIPITATION IN THE STATE OF PARANÁ

ANÁLISE DA PRECIPITAÇÃO DIÁRIA NO ESTADO DO PARANÁ
ANALYSE DES PRECIPITATIONS QUOTIDIENNES DANS L'ETAT DE PARANÁ

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Abstract:

Rainfall was analyzed in daily resolution through the concentration index (CI) of Martin-Vide (2004). The 70 pluviometric series were obtained from the National Water Agency (ANA) through the HIDROWEBsite. The calculation of this index was performed using the R environment, with the precintcon subroutine. The study period was from 1976 to 2015.The results showed values between 0.51 and 0.71, latitudinally increasing fromnorth to south in the study area. The rainfall percentage also showed a gradient with increase from north to south in the state.

Keywords: Concentration ratio, daily precipitation, exponential curve.

Resumo:

A precipitação foi analisada em resolução diária através do índice de concentração (IC) de Martin-Vide (2004). As 70 séries pluviométricasforam obtidas da Agência Nacional de Águas (ANA) através do site da HIDROWEB. O cálculo deste índice foi realizado utilizando o ambiente R, com a sub-rotina do Precintcon. O períodode estudo foi de 1976 a 2015. Os resultados mostraram valores entre 0,51 e 0,71, aumentando latitudinalmente de norte a sul na área de estudo. O percentual de precipitação também mostrou um gradientecom aumento de norte a sul do estado.

Palavras-chave: Razão de concentração, precipitação diária, curva exponencial.

Résumé:

Les précipitations ont été analysées en résolution quotidienne à l'aide de l'indice de concentration (IC) de Martin-Vide (2004). Les 70 sériespluviométriques ont été obtenues auprès de l'Agence nationale de l'eau (ANA) via le site HIDROWEB. Le calcul de cet indice a été effectué à l'aide de l'environnementR, avec le sous-programme precintcon. La période d'étude était de 1976 a 2015. Les résultats ont montré des valeurs comprises entre 0,51 et 0,71, augmentant latitudinalement du nord ausud dans la zone d'étude. Le pourcentage de précipitations a également montré un gradient avec une augmentation du nord au sud dans l'état.

Mots clés: Ratio de concentration, précipitations journalières, courbe exponentielle.

INTRODUCTION

The analysis of the daily precipitation spatial distribution is a difficult task due to its discontinuity and great variability in space (CARRERA-HERNANDEZ and GASKIN, 2007). In the cartographic representationof the amount of precipitation, the use of proper techniques for spatial interpolation of data becomes necessary. The main problem in the rainfall data estimation is related to the availability of meteorological stations andtheir dispersion in the territory. This occurs mainly in mountainous areas where values are more difficult to estimate due to the topography (MORAL, 2009).

Several studies on precipitation variability have been carried out worldwide using various statistical procedures.A significant decrease in the number of rainy days and a significant increase in precipitation intensity values have been identified in many places of the world, such as China (REN et al. 2000; GONG and HO, 2002; ZHAI et al.2005) and America (KARL et al. 1996), for example. With regard to the Mediterranean area, several studies have been conducted to investigate trends in annual and seasonal precipitation on a large-scale (KUTIEL et al. 1996;PIERVITALI et al. 1998; XOPLAKI et al. 2006) for countries or entire regions (AMANATIDIS et al. 1993; ESTEBAN-PARRA et al. 1998; DE LUIS et al. 2000; FEIDAS et al. 2007; DEL RIO et al. 2011).

Analysis of precipitation with daily resolution is a matter of great interest due to hydrological problems resultingfrom high intensity and poor temporal distribution of precipitation in large areas of the world. These problems, in turn, are being produced by the concentration of high percentages of the total annual rainfall in a few rainydays very often separated by long periods of drought (MARTIN-VIDE, 1994). This interest is not just climatological, affecting other areas of the environment and society. For example, the level of "aggression" ofrainfall in the soil in areas with sparse vegetation, which is the case in many parts of the world, is directly related to the intensity and temporal distribution.

Higher rainfall concentration, represented by higher percentage of the total annual rainfall in a few rainy days,has potential to cause flood and drought, which can significantly impact water resources. Therefore, the amount and intensity of rainfall can make soil more vulnerable to erosion and increase instability. In particular, vulnerabilityto soil erosion will affect conditions for plant growth and agricultural practices, land use management change strategies (SCHOLZ et al. 2008), and slope instability can increase economic and life losses. According to Klikand Truman (2003), the knowledge of the temporal distribution of heavy rainfall is needed to assess the amount of runoff and soil loss. Changes in the rainfall temporal distribution can also modify river systems, groundwaterrecharge, water availability, hydropower production (AGUADO et al. 1992; PAREDES et al. 2006; LOPEZ-MORENO et al. 2009). For these reasons, it is important to analyze the statistical structure of rainfall rates based on theset of daily rainfall data.

To evaluate the daily precipitation variation, statistical indexes can be used. In this work, the concentrationindex (CI) was used. In Spain, Martin-Vide (2004) calculated CI and then explored the spatial patterns that clearly divide mainland Spain into two regions: eastern portion, which has high rainfall concentration, with 25.0% of rainy days providing 70.0 % or more of the total annual rainfall and the rest of the country, which presents more regular amounts of daily rains. Zhang et al. (2009) calculated CI based on annual rainfall series in thePérolas River basin, also assessing possible trends of this index for each season. Li et al. (2010) estimated CI values for the Kaidu River basin, individualizing a region in southern Xinjiang with the highest CI values(most of the annual precipitation deriving from 25.0 % of the rainiest days).

Rainfall analysis with daily resolution in Algeria, for example, is a subject of great interest. This type ofanalysis is justified by the existence of serious environmental risks in the Mediterranean, such as flooding and soil instability resulting from high percentages of total annual rainfall falling on a few very rainy days. Thus,the area has long periods of drought (MARTIN-VIDE, 1994) and uneven rainfall distribution in large areas of the western Mediterranean (CORTESI et al. 2012).

Africa has often shown rainfall and drought variability, leading to food shortages. It is reported that a deviationof 10.0 % of seasonal rains of the long-term average rainfall leads to a reduction of 4.4 % in food production in Africa. The trends reported by IPCC on the climate of India are in accordance with observations of the Departmentof Meteorology of India and the Indian Institute of Tropical Meteorology. In India, there has always been an erratic trend in monsoon rains during the last century, although there have been some emerging regional standards.

Finally, as a rule, it has been suggested that the trends of precipitation observed in many parts of the worldhave the same trend signal with daily events (EASTERLING et al. 2000). Furthermore, Karl and Trenberth (2003) suggested that even without any change in total precipitation, there was an increase in the frequency of intensedaily precipitation in warmer climates, a fact that would have led to increased precipitation concentration.

The aim of this study was to analyze the daily precipitation for the state of Paraná, considering thatthis variable on a daily scale has not been widely explored in Brazil and because this is a transition region with summer marked by convective rains.

MATERIAL AND METHODS

About 70 pluviometric series were used (Figure 1), which were obtained from the National Water Agency (ANA) using the HIDROWEB site. Based on a larger set of series (200 rainfall series), it was possibleto fill the gaps of series selected for this analysis. The filling was performed using the PREFANN subroutine generated from the R environment. This subroutine groups several series with close latitudes, longitudes and altitudesand obtain a filled rainfall series or with the fewest possible gaps (POVOA, 2014).

The PRECINTCON subroutine was also used for the calculation of indexes for the three frequencies mentioned above (POVOA.2014).

Considering the spatial distribution, it was possible to define the period for this study: 1976 to 2014.

It is known that the distribution of frequencies of daily precipitation values is adjustable through negativeexponential curves (BROOKS and CARRUTHERS, 1953). There are many days with little rain and a few days with heavy rainfall, thus reducing the frequency exponentially. In order to assess the relative contribution of the rainiestdays, an index called daily precipitation concentration index was proposed (Concentration Index, CI), (MARTIN-VIDE, 2004).

Therefore, the daily amounts of precipitation are classified into classes of 1.0 mm (or 5.0 mm or 10.0 mm) inlength, beginning with [0.1-0.9] in ascending order [1.0 to 1.9] [2.0 to 2.9], etc. The resulting distribution frequency clearly shows an exponentially negative curve.

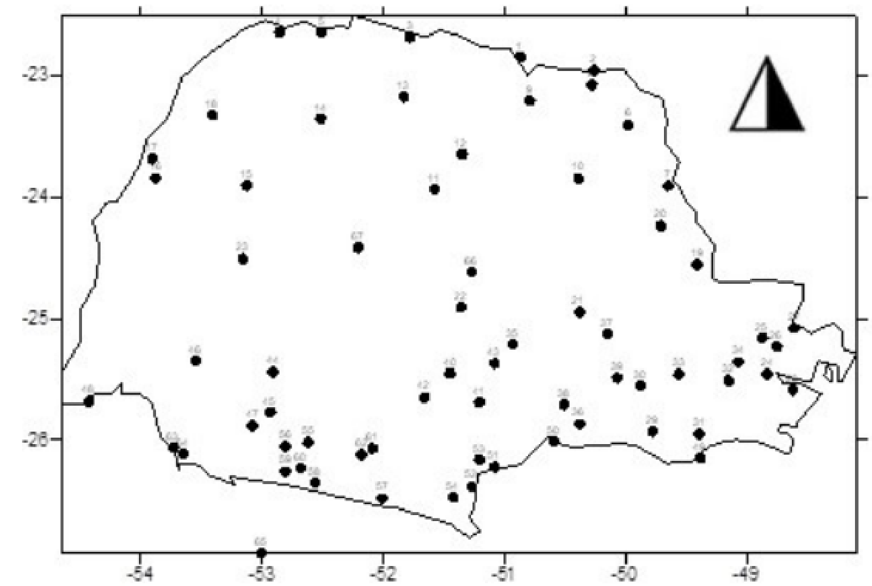

FIGURE 1
Location of rainfall stations in the state of Paraná.

Based on the knowledge of the Gini coefficient, Martín-Vide (1984) formulated the Concentration Index (CI) specifically for the study of daily precipitation of the Spanish Mediterranean coast.CI is a synthetic indicator to calculate the degree of precipitation concentration. Moreover, it is an estimate of the degree of aggressiveness or torrential rain. Its results have been extended to the Iberian Peninsula (MARTIN-VIDE,2004; SANCHEZ-LORENZO and MARTIN-VIDE, 2006), with results that show a high daily rainfall concentration in the eastern portion of the Iberian Peninsula (0.63 to 0.70), with moderate concentrations (<0.58) in the rest ofthe territory.

The concentration index, as suggested by Martin-Vide (2004), was used to determine the relative impact of differentprecipitation classes, e.g., more intense precipitation observed in the daily precipitation heterogeneity (MARTIN-VIDE, 2004; ZHANG et al. 2009; LI et al. 2010; COSCARELLI and CALOIERO, 2012).

In a given time and place, the probability of small daily amounts of rainfall is greater than large daily amountsof rainfall. In other words, starting with the lowest class of daily rainfall, the absolute frequencies of daily precipitation decrease exponentially as it moves to the consecutive intervals (BROOKS and CARRUTHERS, 1953, MARTIN-VIDE,2004).

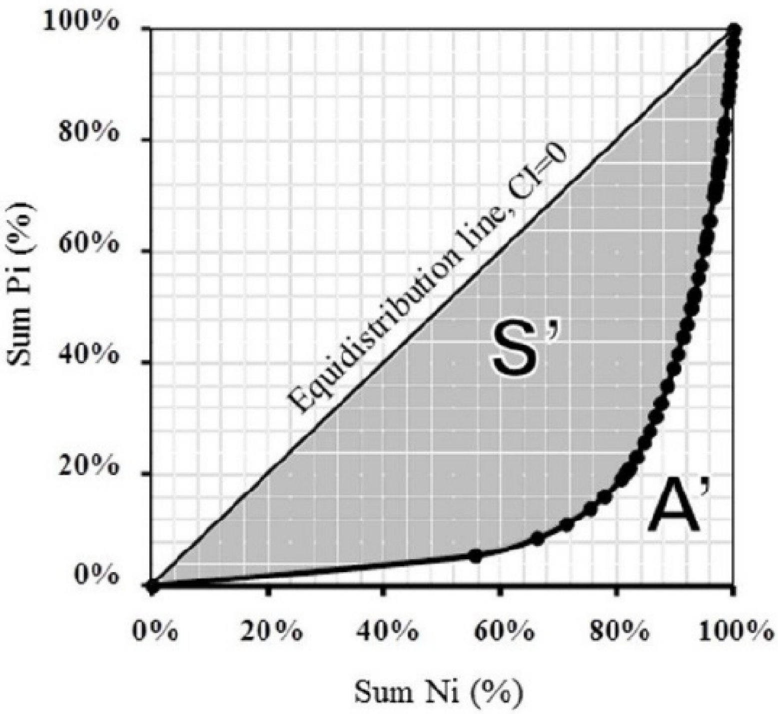

FIGURE 2
Exponential curve of the number of precipitation days (Sum Ni) versus accumulated rainfall (Sum Pi). The solid black line is the equidistribution line.

According to Coscarelli and Caloiero (2012), to determine the relative impact of different classes of daily precipitation and to evaluate the weight of the greatest daily event inthe total amount of precipitation, it is necessary to analyze the cumulative precipitation percentages (Y) that contributed to the percentages accumulated of days (X) during the occurrence of Y (RIEHL, 1949; OLASCOAGA, 1950; MARTIN-VIDE, 2004; ZHANG et al. 2009; LI et al. 2010). If the daily events are classified in descending order and Xj is the Jth of the greatest event, Yj s the fraction of the annual precipitation provided by the major events from 1st to Jth. If the Yj events are expressed as percentiles and Y in terms of the percentage of annual precipitation, Y and X are connected by an exponential law (RIEHL, 1949; OLASCOAGA, 1950):

$Y = aX \exp(bx)$

Based on the study by Riehl (1949); Olascoaga (1950); Martin-Vide, (2004); Zhang et al. (2009) and Coscarelliand Caloiero (2012), it was assessed whether the accumulated percentage of precipitation Pi contributing to the cumulative percentages of days Ni during the occurrence of Pi according to the following steps:

(1) Classification of the precipitation class limits (class interval equal to 1mm),

(2) Counting the number of days with rainfall interval for each class interval (i = 1, 2 ... n) and calculating the associated amount of rainfall,

(3) Calculating the cumulative sum of output items: step 2, (4) counting the cumulative percentage of rainy days and the associated amount of rainfall based on step 3.

If the cumulative percentage of rainy days (Sum(Ni)) is a function of cumulative percentage of amounts of rain (Sum(Pi)) an exponential curve expressed by (Sum(Ni)) versus (Sum(Pi)) is obtained (Martin-Vide 2004):

Sum(Pi)=a*Sum(Ni)exp(b*(Sum(Ni))

With a and b being called regression coefficients.

The equation is called concentration curve or Lorenz curve, which has been widely used in many areas (SHAW andWHEELER, 1994). It was observed that this curve is plotted with both axes ranging from 0 to 100 %, giving a total area of 10,000. Thus, the Gini index (2S/(10,000) was used to quantify the degree of concentration, where S is the area contained by the quadrant bisector and the Lorenz curve The integral defined of the exponential curve between 0 and 100 is the area under the curve A:

$$A^{'} = \left[\frac{a}{b} e^{b*Sum(N_i)} (Sum(N_i) - \frac{1}{b}) \right]_0^{100}$$

#FIG8EN.JPG

Based on areas and compressed by the curve, the equidistribution line and Ni (=100) is the difference between 5,000 and the value of A Coefficients a and b can be estimated by the least squares method. Then, the concentration index CI, similar to the Gini index, can be defined as:

$$CI = \frac{S^{'}}{5{,}000} = \frac{(5{,}000 - A^{'})}{5{,}000}$$

#FIG9EN.JPG

Therefore, the CI value is the fraction of and the surface area of the lower triangle bounded by the equidistribution line (MARTIN-VIDE, 2004). CI indicates the contribution of extreme precipitation for certain lengths of time.

Extreme precipitation is associated with flooding; therefore, CI has scientific and practical merits, as it allowsa better understanding of flood events in a given area of study.

DISCUSSION OF RESULTS

The CI values for frequency interval of 1.0 mm were calculated for all pluviometric series. Table I shows the values of coefficients and of the standard precipitation and CI, for each series. CI valuesranged from minimum of 0.50 (code 2351050) to maximum of 0.71 (code 2653007).

Table 1 also reports the precipitation percentages provided by the highest quartile of rainy days calculated usingequation (1). These percentages range from 60.9 % (corresponding to the minimum CI value) to 75.0 % (corresponding to the maximum CI value). This 75.0 % corresponds to concentration index of 0.70. It corresponds to heavy dailyrainfall concentrated in a few days (25.0 % of the rainy days contributes with 75.0 % of the total precipitation). This situation can lead to erosion, depending on the soil condition, i.e. exposed or without any protection,and flood in the region where CI is greater than 0.60 with the presence of rivers or in cities, due to the waterproof process. There is a variation of 14.1 % of rain, which shows a very different behavior in the state of Paraná,with more concentrated rains from the midwestern region of the state to the eastern and southern regions and much more regular daily rainfall, which is characteristic of the northern, western and southern regions of the studyarea, Figure 1.

The values of the determination coefficients (R^2) although not shown in the tables below, showing that the correlation coefficients between observed and simulated cumulative curves for all rainy days were greater than 0.98.

Code	a	b	CI (%)	Rainfall	Code	a	b	CI (%)	Rainfall
2250028	0.0767	0.0255	0.53	62.8	2251041	0.0906	0.0240	0.51	61.2
2250033	0.0415	0.0319	0.58	66.6	2252015	0.0545	0.0288	0.56	65.4
2252017	0.0760	0.0257	0.52	61.8	2349059	0.0744	0.0259	0.53	62.8
2349064	0.0557	0.0286	0.56	65.4	2350002	0.0599	0.0279	0.55	62.2
2350023	0.0529	0.0290	0.56	65.4	2350062	0.0581	0.0282	0.55	62.2
2351020	0.0635	0.0274	0.54	63.4	2351037	0.0804	0.0253	0.53	62.8
2351050	0.0864	0.0248	0.50	60.9	2352036	0.0699	0.0268	0.52	62.1
2353002	0.0853	0.0247	0.51	61.2	2353003	0.0496	0.0298	0.56	65.4
2353019	0.0732	0.0262	0.53	62.8	2353032	0.0535	0.0291	0.55	62.2
2449021	0.0588	0.0281	0.55	62.2	2449040	0.0538	0.0289	0.53	62.8
2450056	0.0554	0.0286	0.56	65.4	2451029	0.0263	0.0364	**0.60**	68.3
2453001	0.0785	0.0253	0.53	62.8	2454016	0.0404	0.0319	0.58	66.6
2451038	0.0479	0.0302	0.56	65.4	2452044	0.0619	0.0276	0.55	62.2
2452044	0.0619	0.0276	0.55	62.2	2548000	0.0290	0.0346	0.53	62.8
2548000	0.0290	0.0346	**0.62**	69.2	2548001	0.0668	0.0266	0.55	62.2
2548003	0.0469	0.0301	0.58	66.7	2548036	0.0441	0.0267	**0.70**	74.7
2548049	0.0601	0.0275	0.56	65.4	2549017	0.0837	0.0262	0.54	63.4
2549040	0.0745	0.0256	0.54	63.4	2550000	0.0807	0.0248	0.53	62.8
2550001	0.0658	0.0268	0.55	62.2	2550003	0.0643	0.0271	0.55	62.2
2550035	0.0593	0.0279	0.55	62.2	2550042	0.0789	0.0251	0.53	62.8
2551000	0.0504	0.0298	0.56	65.4	2551001	0.0695	0.0290	0.56	65.4
2551024	0.0548	0.0287	0.55	62.2	2551038	0.0532	0.0262	0.54	63.4
2552000	0.0758	0.0256	0.53	62.8	2552001	0.0368	0.0328	0.58	66.7
2553029	0.0702	0.0263	0.54	63.4	2553046	0.0539	0.0290	0.56	65.4
2554002	0.0301	0.0349	0.59	67.9	2554020	0.0393	0.0320	0.58	66.6
2649018	0.0136	0.0424	**0.66**	72.1	2650006	0.0253	0.0340	**0.68**	72.7
2651000	0.0218	0.0379	**0.62**	69.5	2651003	0.0318	0.0342	**0.60**	68.3
2651004	0.0443	0.0309	0.57	66.3	2851026	0.0420	0.0315	0.57	66.3
2652007	0.0474	0.0301	0.57	66.3	2652009	0.0591	0.0280	0.55	62.2
2652010	0.0558	0.0286	0.56	65.4	2652011	0.0531	0.0291	0.56	65.4
2652012	0.1067	0.0221	0.52	61.8	2652013	0.0673	0.0269	0.54	63.4
2652026	0.0933	0.0235	0.52	61.8	2652027	0.0663	0.0269	0.54	63.4
2653009	0.0497	0.0261	**0.68**	70.1	2653014	0.0997	0.0320	0.57	66.3
2653007	0.0341	0.0292	**0.72**	75.0	2653023	0.0794	0.0250	0.53	62.8

TABLE 1

Values of constants and of exponential curves, CI (= 1.0 mm) and percentage of rainfall that contributed with 25.0 % of the rainiest days.

Table 2 shows the CI values for the frequency interval of 5.0 mm, and the a and b values and percentage of rainfall that occurred within the study area. It can be observed that the CI values for the intervalof 1.0 mm are generally greater than the CI values for the interval of 5.0 and 10.0 mm.

It also shows that the concentration index values for the frequency interval of 5.0 and 10.0 mm show no CI valuesgreater than 0.60. In Table 1 for 72 rainfall series analyzed, only 9 showed CI values above 0.60. i.e., 12.5% of the series. In Table 2, this value corresponding to CI> 0.60 is of five rainfall series, i.e., 6.9 %.

Code	a	b	CI (%)	Rainfall	Code	a	b	CI (%)	Rainfall
2250028	0.0920	0.0235	0.52	61.8	2251041	0.1055	0.0223	0.51	61.2
2250033	0.0608	0.0277	0.55	62.2	2252015	0.0711	0.0261	0.54	62.9
2252017	0.0915	0.0237	0.52	61.8	2349059	0.0945	0.0233	0.52	61.8
2349064	0.0699	0.0262	0.54	63.4	2350002	0.0765	0.0254	0.54	63.4
2350023	0.0716	0.0259	0.55	62.2	2350062	0.0725	0.0259	0.54	62.9
2351020	0.0777	0.0252	0.53	62.8	2351037	0.0908	0.0231	0.51	61.2
2351050	0.1041	0.0226	0.51	61.2	2352036	0.0920	0.0237	0.52	61.8
2353002	0.1024	0.0226	0.51	61.2	2353003	0.0672	0.0267	0.54	63.4
2353019	0.0987	0.0229	0.52	61.8	2353032	0.0715	0.0261	0.54	63.4
2449021	0.0784	0.0251	0.54	63.4	2449040	0.0737	0.0257	0.54	63.4
2450056	0.0789	0.0250	0.54	63.4	2451029	0.0548	0.0287	0.56	65.4
2453001	0.0905	0.0238	0.52	61.8	2454016	0.0549	0.0287	0.56	65.4
2451038	0.0662	0.0268	0.55	62.2	2452044	0.0755	0.0255	0.54	63.4
2452044	0.0619	0.0276	0.55	62.2	2548000	0.0290	0.0346	0.53	62.8
2548000	0.0375	0.0323	0.59	67.9	2548001	0.0668	0.0266	0.55	62.2
2548003	0.0569	0.0282	0.56	65.4	2548036	0.0441	0.0267	**0.70**	74.7
2548049	0.0601	0.0275	0.58	66.6	2549000	0.0809	0.0248	0.53	62.8
2549001	0.0553	0.0286	0.56	65.4	2549003	0.0586	0.0245	0.56	65.4
2549019	0.0845	0.0244	0.53	62.8	2549017	0.0838	0.0262	0.54	63.4
2549040	0.0745	0.0256	0.54	63.4	2550000	0.0807	0.0248	0.53	62.8
2550001	0.0658	0.0268	0.55	62.2	2550003	0.0643	0.0271	0.55	62.2
2550035	0.0593	0.0279	0.55	62.2	2550042	0.0789	0.0251	0.53	62.8
2551000	0.0719	0.0261	0.54	63.4	2551001	0.0823	0.0246	0.53	62.8
2551024	0.0648	0.0270	0.55	62.2	2551038	0.0702	0.0262	0.54	63.4
2552000	0.0839	0.0258	0.53	62.8	2552001	0.0536	0.0289	0.56	65.4
2553029	0.0803	0.0249	0.53	62.8	2553046	0.0662	0.0268	0.55	62.2
2554002	0.0507	0.0295	0.56	65.4	2554020	0.0515	0.0293	0.57	66.3
2649018	0.0310	0.0342	**0.60**	68.3	2650006	0.0445	0.0282	**0.66**	69.2
2651000	0.0430	0.0310	0.58	66.6	2651003	0.0542	0.0287	0.56	65.4
2651004	0.0649	0.0270	0.55	62.2	2851026	0.0707	0.0261	0.54	63.4
2652007	0.0579	0.0281	0.56	65.4	2652009	0.0731	0.0259	0.54	63.4
2652010	0.0697	0.0263	0.54	63.4	2652011	0.0666	0.0267	0.55	65.5
2652012	0.0970	0.0230	0.52	61.8	2652013	0.0828	0.0247	0.53	62.8
2652026	0.1095	0.0218	0.52	61.8	2652027	0.0770	0.0253	0.54	63.4
2653009	0.0835	0.0207	**0.68**	70.1	2653014	0.0582	0.0281	0.55	62.2
2653007	0.0419	0.0272	**0.70**	74.7	2653023	0.0762	0.0255	0.53	62.8

TABLE 2

Values of constants and of exponential curves, CI (= 5.0 mm) and percentage of rainfall that contributed with 25.0 % of the rainiest days.

Code (%)	a	b	CI	Rainfall	Code	a (%)	b	CI	Rainfall
2250028	0.1076	0.0220	0.53	62.8	2251041	0.1212	0.0209	0.51	61.2
2250033	0.0813	0.0248	0.53	62.8	2252015	0.0889	0.0239	0.53	62.8
2252017	0.1087	0.0219	0.52	61.8	2349059	0.1112	0.0217	0.52	61.8
2349064	0.0862	0.0242	0.53	62.8	2350002	0.0934	0.0234	0.52	61.8
2350023	0.0862	0.0241	0.53	62.8	2350062	0.0861	0.0241	0.53	62.8
2351020	0.0919	0.0235	0.53	62.8	2351037	0.0112	0.0217	0.51	61.2
2351050	0.1212	0.0209	0.51	61.2	2352036	0.1058	0.0222	0.51	61.2
2353002	0.1187	0.0211	0.51	61.2	2353003	0.0881	0.0239	0.53	62.8
2353019	0.1156	0.0213	0.52	62.1	2353032	0.0892	0.0238	0.53	62.8
2449021	0.0934	0.0234	0.53	62.8	2449040	0.0925	0.0235	0.52	61.8
2450056	0.9421	0.0233	0.53	62.8	2451029	0.0869	0.0241	0.53	62.8
2453001	0.1026	0.0225	0.52	61.8	2454016	0.0736	0.0257	0.54	63.4
2451038	0.0853	0.0245	0.53	62.8	2452044	0.0892	0.0238	0.53	62.8
2452044	0.0619	0.0276	0.55	62.2	2548000	0.0290	0.0346	0.53	62.8
2548000	0.0533	0.0289	0.56	65.4	2548001	0.0813	0.0247	0.53	62.8
2548003	0.0720	0.0259	0.54	63.4	2548036	0.0570	0.0243	**0.68**	73.2
2548049	0.0703	0.0261	0.55	62.2	2549000	0.0989	0.0228	0.52	62.1
2549001	0.0777	0.0253	0.54	63.4	2549003	0.0831	0.0245	0.53	62.8
2549019	0.0979	0.0230	0.52	61.8	2549017	0.0995	0.0228	0.52	61.8
2549040	0.0968	0.0230	0.52	61.8	2550000	0.0922	0.0235	0.52	61.8
2550001	0.0818	0.0247	0.53	62.8	2550003	0.0834	0.0245	0.53	62.8
2550035	0.0920	0.0235	0.52	61.8	2550042	0.0963	0.0231	0.52	61.8
2551000	0.0909	0.0237	0.52	61.8	2551001	0.0980	0.0229	0.52	61.8
2551024	0.0805	0.0249	0.53	62.8	2551038	0.0884	0.0239	0.53	62.8
2552000	0.0968	0.0231	0.52	61.8	2552001	0.0705	0.0261	0.54	63.4
2553029	0.0899	0.0237	0.53	62.8	2553046	0.0817	0.0247	0.53	62.8
2554002	0.0686	0.0265	0.54	63.4	2554020	0.0686	0.0264	0.55	62.2
2649018	0.0524	0.0291	0.56	65.4	2650006	0.0607	0.0253	**0.63**	70.4
2651000	0.0650	0.0690	0.55	62.2	2651003	0.0747	0.0256	0.54	63.4
2651004	0.0810	0.0248	0.53	62.8	2851026	0.0890	0.0238	0.53	62.8
2652007	0.0746	0.0256	0.54	63.4	2652009	0.0844	0.0244	0.53	62.8
2652010	0.0818	0.0240	0.53	62.8	2652011	0.0849	0.0243	0.53	62.8
2652012	0.1067	0.0221	0.52	61.8	2652013	0.0990	0.0228	0.52	61.8
2652026	0.1128	0.0214	0.52	61.8	2652027	0.0923	0.0235	0.53	62.8
2653009	0.0997	0.0190	**0.67**	71.5	2653014	0.0784	0.0252	0.53	62.8
2653007	0.0496	0.0257	**0.69**	72.3	2653023	0.0862	0.0242	0.53	62.8

TABLE 3

Values of constants and of exponential curves, CI (= 10.0 mm) and percentage of rainfall that contributed with 25.0 % of the rainiest days.

Figure 3 shows daily concentration index above 0.60 in eight of the 70 rainfall series analyzed. Although the number of series with CI values above 0.60 is not high, these values show one of the mostcharacteristic features of rain: its high concentration. Thus, part of the state of Paraná showed high rainfall concentration in a few rainy days, suggesting careful soil management, especially considering that thisstate has a very significant agricultural potential.

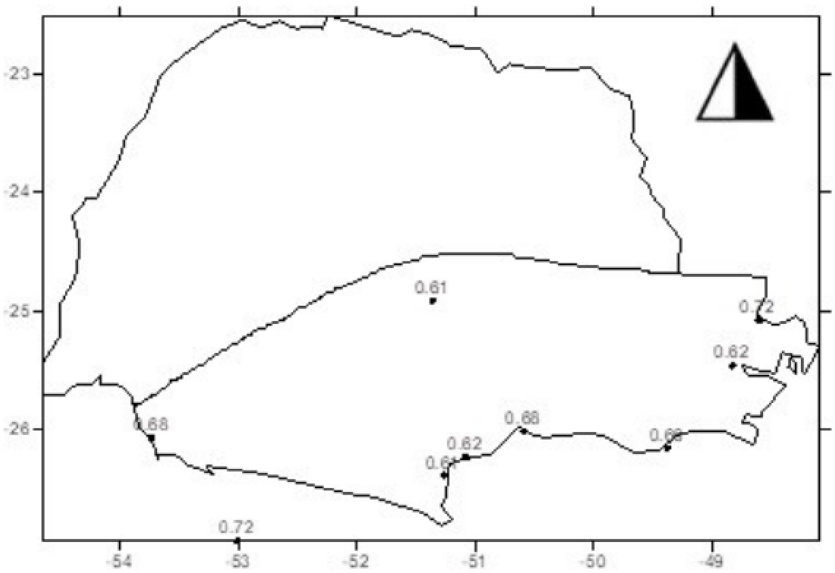

FIGURE 3
CI values greater than 0.60.

Figures 4-7 show the percentages for 10.0, 20.0, 30.0 and 50.0 % of rain (for CI = 1.0 mm), also showing a pattern of higher rainfall percentages, always from the northeastern to southeastern regions.

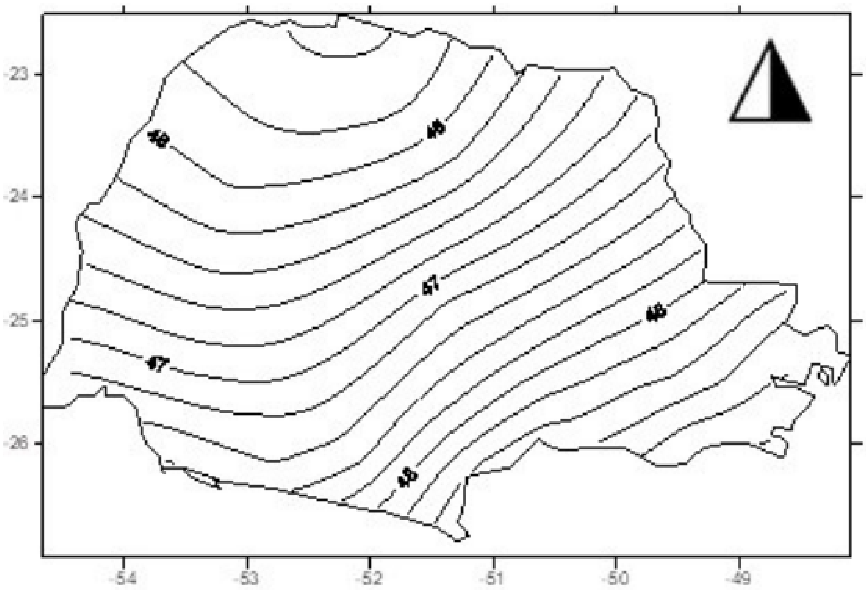

FIGURE 4
10.0 % of the precipitation (CI = 1.0 mm).

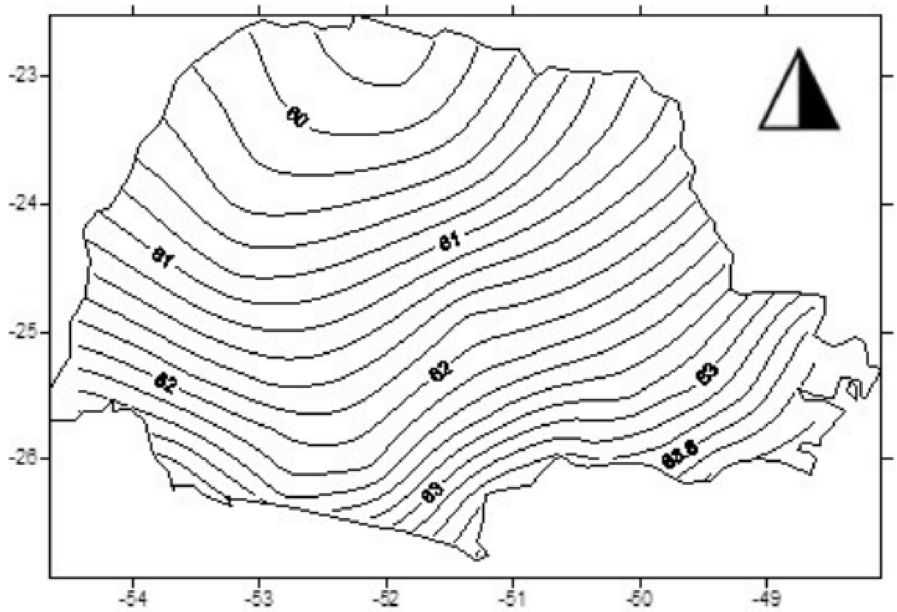

FIGURE 5
20.0 % of the precipitation (CI = 1.0 mm).

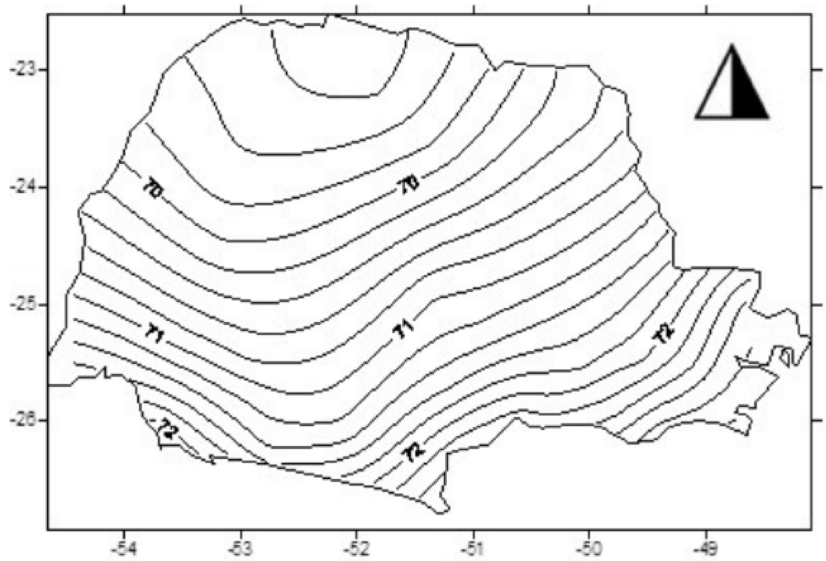

FIGURE 6
30.0 % of the precipitation (CI = 1.0 mm).

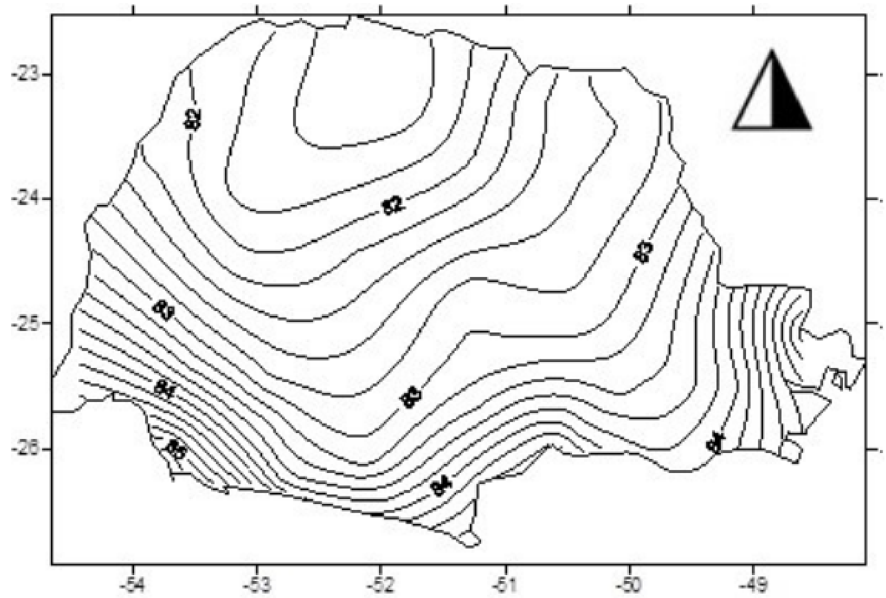

FIGURE 7
50.0 %of the precipitation (CI = 1.0 mm).

CONCLUSIONS

The daily rainfall concentration is a climatic variable of great interest to express the daily precipitation irregularity, especially the concentration or accumulation in a few rainy days. This concentrationindex is a useful indicator of the erosive capacity of rain, the danger of flood and torrential rains.

Rain showed a marked gradient from northeastern to southwestern regions of the state of Paraná and CI valuesgreater than 0.60 from the central portion to the southern and eastern regions of the study area, i.e., high concentration in a few rainy days.

The concentration index exceeds the value of 0.60 in several rainfall series, reaching at some points 0.72, reflectingthat in a few very rainy days, there is a high contribution of the annual precipitation (25.0 % of the rainiest days contribute with 75.0 % of the total rain).

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