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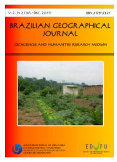

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Climatic variability and pluviometric trends in a humid tropical environment at Resende municipality- middle Paraíba do Sul river valley (Rio de Janeiro- Brazil)

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ABSTRACT

The global warming of the planet, motivated by an increase in the concentration of atmospheric CO2, is already a well-accepted trend among research works that analyze the different General Circulation Models (GCM). However, a smaller number of research works have been dedicated to analyzing the influence of this variability in the precipitation trends, and its consequences in the structure and functionality of geo-ecosystems. The present study aims at analyzing the regimen and the rainfall distribution trends in a city in the state of Rio de Janeiro during the course of the last 60 years. Daily, monthly, and yearly precipitation data were analyzed in an attempt to identify possible regimen changes based on the temporal comparison of data. Initially the annual precipitation trend line was identified, along with the average regimen of the three driest years, the three rainiest years, and the three intermediary years. After that, we analyzed the distribution regimen for dry days and months, the distribution of precipitation based on five intensity classes, and the inter-annual Precipitation Concentration Index (PCI). Among the results, the highlight is a progressive reduction trend of the total annual precipitation (approximately 8% during the course of the period in question, statistically significant at 0,05), which reinforces the role of regional circulation in the regulation of the local pluviometric totals. The results obviously indicate an intensification of the seasonality associated to an increase in the frequency of higher intensity rainfall events, which is accompanied by a reduction in the frequency of lower intensity events, which, in turn, are responsible for the hydrological stability of environmental systems. Therefore, the variation in the rainfall distribution regimen is fundamentally a result of the annual variability of most intense daily rainfall frequency, the consequences of which can refer both to an increase in the generation of natural disasters and in the modification of interspecific relation in geo-ecosystems.

PALAVRAS-CHAVE:
Precipitação
Análise de tendências
Variabilidade climática
Clima tropical

RESUMO – VARIABILIDADE CLIMÁTICA E TENDÊNCIAS PLUVIOMÉTRICAS EM AMBIENTE TROPICAL: UMA ANÁLISE A PARTIR DO MUNICÍPIO DE RESENDE – MÉDIO VALE DO RIO PARAÍBA DO SUL (RIO DE JANEIRO - BRASIL). O aquecimento global do Planeta motivado pelo aumento da concentração de CO_2 atmosférico, já é uma tendência bastante aceita entre as pesquisas que analisam os diferentes Modelos Gerais de Circulação (GCM). No entanto, um menor número de trabalhos têm se dedicado a analisar a influência de tal variabilidade nas tendências de precipitação e seu rebatimento na estrutura e funcionalidade dos geoecossistemas. O presente estudo visa analisar o regime e a tendência de distribuição das chuvas em um município do Estado do Rio de Janeiro nos últimos sessenta anos. Foram analisados os dados de precipitação diária, mensal e anual, buscando-se identificar possíveis mudanças de regime a partir da comparação temporal dos dados. Inicialmente, identificou-se a linha de tendência das precipitações anuais, o regime médio, o regime dos três anos mais secos, dos três anos mais chuvosos e de três anos intermediários. Posteriormente, foi analisado o regime de distribuição de dias e meses secos, distribuição da precipitação a partir de cinco classes de intensidade e o Índice de Concentração Interanual de Precipitação (PCI). Dentre os resultados, pode-se ressaltar uma tendência progressiva de redução dos totais anuais de precipitação (de aproximadamente 8% ao longo do período estudado, estatisticamente significativo a 0,05), reforçando o papel da circulação regional na regulação dos totais pluviométricos locais. Os resultados encontrados apontam nitidamente para uma intensificação da sazonalidade associada a um aumento na freqüência dos eventos de chuva de maior intensidade, o qual é acompanhado de uma redução na freqüência dos eventos de menor intensidade, os quais são responsáveis pela estabilidade hidrológica dos sistemas ambientais. Assim, a variação no regime de distribuição das chuvas resulta fundamentalmente da variabilidade anual da freqüência das chuvas diárias mais intensas, o que poderá vir a ter conseqüências tanto no que se refere a um aumento na geração de desastres naturais, quanto na modificação das relações interespecíficas dos geoecossistemas.

PALABRAS-CLAVES:
Análisis de tendencias
Variabilidad climática
Clima tropical

RESUMEN – VARIABILIDAD CLIMATICA Y TENDENCIAS PLUVIOMETRICAS EN EL AMBIENTE TROPICAL: UNA ANALISIS DESDE LA MUNICIPALIDAD DE RESENDE – MEDIO VALLE DEL RIO PARAÍBA DO SUL (RIO DE JANEIRO - BRASIL). El calentamiento global del Planeta, motivado por el aumento de la concentración de $CO2$ atmosférico ya es una tendencia bastante acepta entre las pesquisas que analizan los diferentes Modelos Generales de Circulación (GCM). Sin embargo, un pequeño número de trabajos tiene se dedicado a analizar la influencia de esta variabilidad en las tendencias de precipitación y su rebatimiento en la estructura y funcionalidad de los geoecosistemas. El presente estudio visa analizar el régimen y la tendencia de distribución de las lluvias en el municipio de Paraíba do Sul, en la provincia de Río de Janeiro, en los últimos sesenta años. Fueron analizados los datos de precipitación diaria, mensual y anual, buscándose identificar posibles cambios de régimen a partir de la comparación temporal de los datos. Inicialmente, se identificó la línea de tendencia de las precipitaciones anuales, el régimen medio, el régimen de los tres años más secos, de los tres años más lluviosos y de tres años intermediarios. Posteriormente, fue analizado el régimen de distribución de días y meses secos, distribución de la precipitación a partir de cinco clases de intensidad y el Índice de Concentración Interanual de Precipitación (PCI). Por los resultados, se puede resaltar una tendencia progresiva de reducción de los totales anuales de precipitación (de aproximadamente 8% a lo largo del periodo estudiado, estadísticamente significativo a 0,05), reforzando el papel de la circulación regional en la regulación de los totales pluviométricos locales. Los resultados encontrados apuntan nítidamente para una intensificación de la sazonalidad asociada a un aumento en la frecuencia de los eventos de lluvia de mayor intensidad, acompañado de una reducción en la frecuencia de los eventos de pequeña intensidad, los cuales son responsables por la estabilidad hidrológica de los sistemas ambientales. Así, la variación en el régimen de distribución de las lluvias resulta fundamentalmente de la variabilidad anual de la frecuencia de las lluvias diarias más intensas, lo que podrá venir a tener consecuencias tanto en el que se refiere a un aumento en la generación de desastres naturales, cuánto en la modificación de las relaciones interespecíficas de los geoecosistemas.

1 Introduction

In historical and geological timescales, the rainfall regimen has presented a variability of up to hundreds of years, as revealed by the studies carried out by Thompson et al (1985). However, during the last few years, thanks to the evolution of predictive models (MAVROMATIS and JONES, 1998), the disclosure of information on the distortions in the expected climatic behavior for many regions of the planet has become more and more frequent (WANG and SCHIMEL, 2003) both in specialized literature and in general public media. These distortions have been attributed, at least in part, to the effects that the increase in mean global temperature has had over the general atmosphere circulation (ARNELL, 2003). Besides the association with natural phenomena of variability in atmospheric dynamics (PHILANDER and FEDOROV, 2003), this Global warming is also said to originate from an potential increase in the temperature elevation rates on regional and or local scales, and deriving from the environmental changes which are marked, on the one hand, by an intense expansion of industrial and urban centers (LAHMER et al, 2001), and, on the other hand, that a high retraction rates of remaining forests (BRUIJNZEEL, 1988).

In this context lies the southeastern region of Brazil, where the first great devastation cycle of the Atlantic forest began, with the coffee growing monocultures in the mid 18th-century (DEAN, 1996) causing catastrophic geo-environmental impact (COELHO NETTO, 1999).

Investigating the geo-hydroecological resultant of the coffee cycle in the middle region of Paraíba do Sul River valley, Dantas and Coelho Netto (1993), referring to historical documents of the time, detected evidence of alteration in the rainfall distribution regimen which, until then, was marked by well-distributed rainfall throughout the year. These documents report the occurrence of unexpected droughts, as well was the formation of " mud rivers" during intense storms.

These historic facts seem to have been ignored during the last decades, for the Atlantic forest is currently being devastated at extremely high rates, especially around the urban clusters which have suffered strong demographic pressure, as can be seen in recent reports by IBAMA (2002) and GEOHECO/SMAC-RJ(2000). Thus, the most recent environmental changes can be expected to induce both quantitative and qualitative cumulative effects on the local and/or regional climates, which will be visible through the distribution and variability of rainfall regimens (SUPPIAH and HENNESSY, 1998) that mirror the end product of air mass circulation.

In the last few years, studies have accumulated evidence that the inter-annual precipitation variabilities are, in some way, synchronized with and related to a periodic oscillation of the atmosphere-ocean system in the equatorial Pacific (GUARIGUATA e KATTAN, 2002). However, as much as the recent alterations in rainfall regimen represent an unstable combination between natural and unnatural causes (WANG e SCHIMEL, 2003), the current transformations in the methods of soil usage have certainly played an important role in the acceleration of this process. In Brazil's case, the intensity and the frequency with which extreme climatic events have been registered in the last few decades, especially in the southern-central region of the country, leave no room for doubt concerning human participation in the worsening of these circumstances (BRANDÃO,1992).

This study has attempted to assess long-term pluviometric records (of the last six decades) in view of an assessment of the annual pluviometric distribution trends during the course of the century, combined with an analysis of daily and monthly rainfall distribution regimen variability.

Trend investigation, according to Hurst (*apud* MEIS et al, 1981), reduces the randomness of distributions, thus allowing for analysis of the actual variability of the mean values calculated as significant for larger intervals.

2 Study area and regional climatic aspects

The study area for the aforementioned geo-ecosystems is the middle Paraíba do Sul River valley, where the city of Resende is located (Resende Station, 550 m/a.n.m.). It is an urban/industrial area in the state of Rio de Janeiro (Brazil) – Figure 1- located between 42° and 44° W, 22° and 24° S.

Throughout the year, the region is dominated by the action of southeastern trades , which on their route to the South American continent, and incorporate heat and humidity, thus constituting the Atlantic tropical mass. The invasion of polar winds (Atlantic Polar Mass) through the interior topographical depressions, or along the coast, allows for the formation of cold fronts which originate regionally extended rainfalls (NIMER, 1971). Monteiro (1969) points out that, although the cold fronts occur more frequently in the winter, and it is generally in the summer period that greater disturbances occur in the atmospheric dynamics, generating stronger rainfalls.

Several authors (POVEDA and MESA, 1997; NOBRE and SCHUKLA, 1996; GRIMM et al, 2000) have demonstrated that alterations in the superficial water temperatures in Pacific Ocean (phenomena known as El Niño and La Niña) have further consequences in the inter-annual precipitation variability in the southern and southeastern regions of Brazil (STUDZINSKI, 1995). During the periods in which El

Niño is active, the Jet Current produced by the High Pressures of the eastern Pacific tends to constitute an obstacle to the advance of cold fronts in subtropical latitudes (GRAHAM and WHITE, 1988). In these periods, the intense precipitations registered in the southern regions of the country are accompanied by the reduction in the number of rainfall events in the southeast during the summer. Increasing drought periods, combined with the concentration of vapors produced by the region's high temperatures, establish the ideal conditions for extreme precipitation events to take place during post-El Niño periods, when conditions for the advance of the Atlantic Polar Front are restored. This is especially true when an El Niño event is followed by a La Niña event, when the Atlantic Polar Mass is strengthened and the frontal rainfall generation mechanisms are intensified.

Nimer (op.cit.) also points out that the barriers set by the mountainous area to the circulation of air masses cause quantitative variations in frontal rains, besides favoring local rainfall events. The locally comprehensive convective rains are also strongly linked to the generation of *heat islands* in large metropolis, being equally capable of augmenting the effects of frontal rainfall mechanisms (MONTEIRO, 1976; BRANDÃO, 2001). Changes in the land use patterns transform the aerodynamics and radioactive properties of the surface, thus altering the behavior of temperature and humidity of the air layer nearest to the transformed area. In the areas, the parameters for thermal comfort are particularly altered (GÓMEZ et al, 2001), under the influence of what Oke (1987) calls "urban canopy layer", that is, the lowest layer in the atmosphere, where the city's geometry and its respective urban functions combine.

The interaction between regional climatic dynamics and what Oke (1987) calls "Urban Boundary Layer" (total construction area) causes alterations in the atmospheric variables, modifying the behavior of temperature (CHANDLER, 1962; MENDONÇA, 1994) as well as intensity and distribution of rainfalls (BRANDÃO, 1994 and 2001) in urban areas.

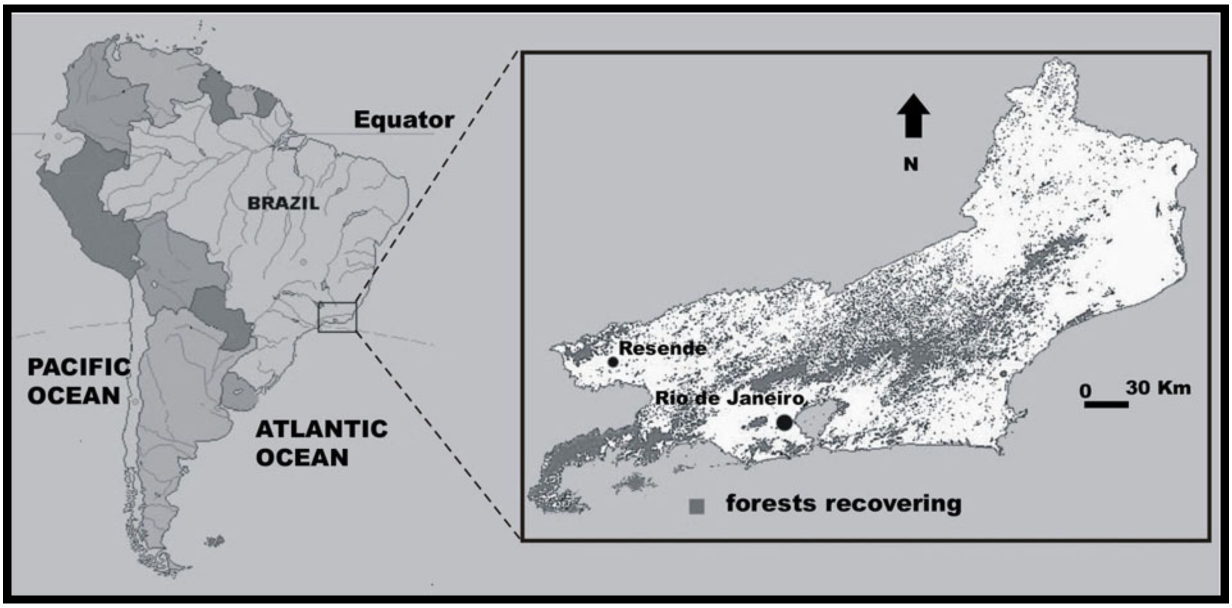


Figure 1. Location of the city of Resende.

In previous studies based on a long historic series from the Resende Station (National Meteorology Department – Ministry of Agriculture; 1912 to 1977 series) Meis et al. (1981) demonstrated the existence of a cyclical trend alternating between periods with higher and lower humidity rates on a scale of decades. However, in the broader context of secular variations, there was evidence of a slight reduction trend in annual rainfalls. The periods with the highest humidity were associated to an increase in the frequency of the class of stronger daily rainfalls, over 30 mm/day. This last observation confirmed the model proposed by Coelho Netto (1979) for the Tijuca Massif, where the total annual rainfall variation are strongly controlled by the stronger daily rainfall frequency, over 100mm/day, as observed in a short time series (1967 to 1978) from the Alto da Boa Vista Station (INMET). After that, with the increase in this same time series and in another series obtained in the Capela Mayrink Station, located only 500m from the Alto da Boa Vista Station, this same model was confirmed (COELHO NETTO, 1985).

3. Methodology

The data used in this research was provided by the National Meteorology Department (INMET), and represent the total group of data on daily rainfall for the 1937 – 2000 period in the city of Resende.

Taking into account the speed of the current environmental changes, and in view of the assessment of the possible implications of these changes in the variability of the rainfall regimens, we chose to combine analyses of annual precipitation rhythm and variability during the course of the historical series, as suggested by Monteiro (1976). In order to do so, we assessed the secular or historic trend by calculating the linear regression line, as suggested by Daveau et al. (1977). This procedure was repeated for each decade in the historical series.

The significance of the all results of correlation were tested with the test *t Student* .

As for the monthly rainfall distribution, the regimen variability analysis included the temporal series for the period in question. That regimen was then compared to the mean monthly regimen of the three most extreme years (dry and rainy), which were selected due to their having above-average monthly values, added to the standard deviation (rainiest years) or below-average monthly rates minus the standard deviation (driest years). In addition to that, the mean monthly deviations (both positive and negative) for each of the decades being studied, for the extreme years (the three driest and the three rainiest years), and for the 'normal' years (with annual precipitations closer to the series' average) were calculated and analyzed with the purpose of identifying possible regimen changes.

The next step was analyzing the evolution of dry and rainy days for each year in the historical series, calculating the trend line for both. Classes of frequency were also established for dry days, referring to the period in-between two consecutive rainfall events. In order to do so, we adopted the same intervals used by Coelho Netto (1985), which are comprised of five classes: 1 to 3 days, 4 to 7, 8 to 11, 12-15, >15 days. The aim of these analyses was to evaluate a possible concentration trend in rainfall events during the period that would cause alterations in the hydrological resultant of the landscape (DUNNE and LEOPOLD, 1978). These analyses were supplemented by calculating the evolution of the number of dry months per year (in which the precipitation was < 100mm). In tropical ecosystems, these are months during which, according to Windsor (1990), the low precipitation values cause temporary changes in Carbon (C) fixaton from the atmosphere, thus altering the flow of matter within the geo-ecosystems.

The possible upward trend in the period between rainfall events that was detected in the previous stage of the study led us to use the Precipitation Concentration Index (PCI) in order to evaluate possible alteration trends in the monthly rainfall regimen within the researched series. The purpose of this index is to compare the distribution of rainfalls in different months of the year (DE LUÍS et al, 2001). It is defined as:

$$PCI = 100\frac{\sum_{i=1Pi^2}^{12}}{(\sum_{i=1Pi}^{12})^2}$$

where *Pi* represents the total precipitation for month "i". Thus, PCI value under 10 indicate a uniform distribution of precipitation during the course of the year. The values between 11 and 20 correspond to areas with strong seasonality. Values above 20 indicate substantial monthly regimen variability.

As in the treatment of dry days, the analysis of the evolution of daily precipitation involved the establishment of the frequency of five intensity classes (0,2-10mm; 10,1-20; 20,1-50; 50,1-100 e >100mm), taking into account the total period, the extreme years and the average distribution of each one of the classes during the months of the year. We considered as rainfalls events only those in which precipitation was >0,1mm. As a supplement to the previous stage, the objective if this step was to check the behavior of both lower-intensity rainfalls (which are responsible for maintaining conditions of hydrological stability in forest geo-ecosystems) and higher-intensity rainfalls (which are responsible for originating extreme events associated to the occurrence of great natural disasters).The dynamics of each class was compared to the others, and the respective trend line was calculated for each of them;

Considering that the first class to be adopted (0,2-10mm) essentially represents the rain that is intercepted and stored in the canopies (LLORENS and GALLART, 2000), some of the analyses were carried out taking into account the behavior of medium-intensity rainfalls (>10<50mm – which guarantee the hydrological stability of the landscape system) and very intense rainfalls (>100mm – which cause great instability in the system).

4 Results and discussion

In spite of the high annual precipitation (an average of 2229 mm), which is typical of tropical climates, the analysis of rainfall distribution in the city of Resende during the course of the last 62 years clearly shows a downward trend in these total annual values (figure 2), a trend that has been getting stronger by the decade. An analysis of the movable average (taken on base 5 in order to mitigate the highest oscillations and normalize the sample series) allowed us to observe that the ten-year pluviometric cycles pointed out by Meis et al (1981), in which drier and rainier periods alternate, has still been the case in the last decades, but with an significant increase in negative deviations in comparison to the series average, a fact that conditions the downward angle of the regression line (with r = -0,27 and *t* Student = -2,20, statistically significant at α =0,05) . As a consequence of this process, two of the three driest years in the whole series occurred during the last decade (1992 and 1995).

Despite the expectations of a large part of the literature that the urban-industrial expansion might be associated to an upward trend in the levels of local precipitation (Drew, 1986) due to an increase in condensation nuclei and aeolic turbulence generated in frictional contacts with buildings (GOLDREICH, 1985), the 8% decrease in the trend line inclination points in the opposite direction, corroborating trends indicated by other authors, both for tropical regions (ÂNGELO et al, 2003; WALSH, 1996) and for extratropical ones (DE LUÍS et al, 2001). This further reinforces the idea that the local pluviometric variability reflects changes in the global or regional atmospheric dynamics (LINDNER et al, 1997). The existence of such a trend had already been pointed out by Meis et al (1981) and, more recently, by Figueiró et al

(2003) in comparing pluviometric profiles on different scales within the state of Rio de Janeiro.

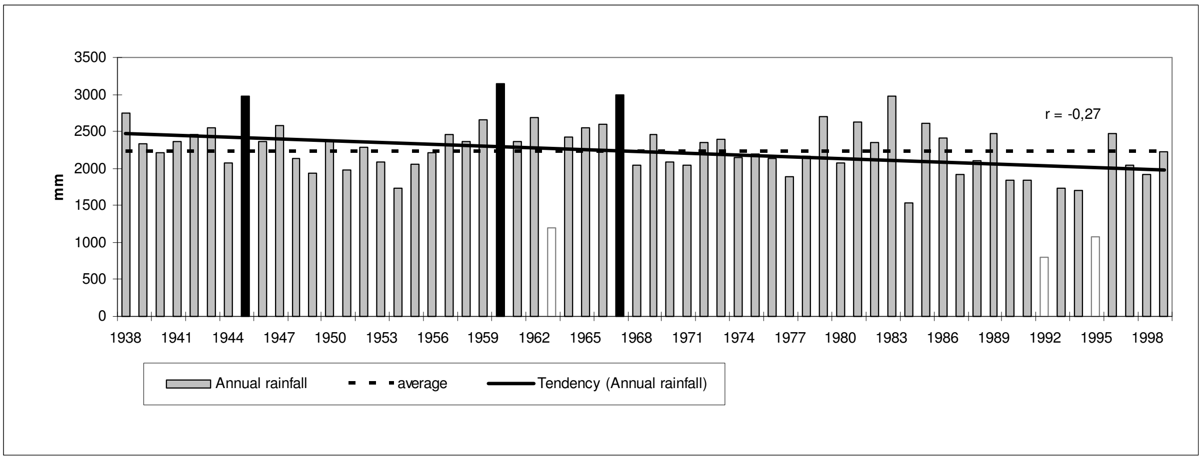


Figure 2. Annual precipitation distribution in the Resende Station between 1937 and 2000, as well as trend line. The dark bars highlight the three rainiest years and the light bars highlight the three driest years.

As pointed out by Cavelier and Vargas (2002), along with the changes in regional circulation, the decrease in annual precipitation can also be at least partly associated to the reduction in evapotranspiration that originates from the loss of large extensions of forest area in the last decades. According to Nepstad et al (1994) replacing forests with fields significantly reduces the foliar surface during dry months, diminishing the transfer of water to the atmosphere, and, consequently, reducing the participation of convective rains in the local hydrological balance (BOSCH and HEWLETT, 1982). Even though there are no available records regarding the percentage with which the convective processes participate in the local pluviometric total, one can assume these processes are, at the very least, not significant enough to act as a compensating mechanism to the frontal rainfall reduction determined by the alterations in regional circulation.

The analysis of the monthly precipitation regimen allows one to visualize the region's climatic seasonality, which is not interrupted even during the rainiest years (figure 3). There are two features, however, that should be pointed out regarding monthly precipitation analysis; on the one hand, the differentiated variability of pluviometric deviations of the extreme years in relation to the series average. On the other hand, the transformation incurred by these deviations during the course of the analyzed decades.

Regarding the first observation (the comparison between pluviometric deviations in extreme and intermediary years), one can observe in Figure 4 that the deviations in monthly precipitation distribution tends to follow the total annual trend, with a prevalence of positive deviations throughout the rainiest years; a prevalence of negative deviations throughout the driest years, and, finally, a cyclical alternation between positive and negative deviations around the average, during the normal years. This could seem like a fairly obvious observation if it weren't for the peculiar variability of pluviometric deviations during the rainiest years (Figure 4a).

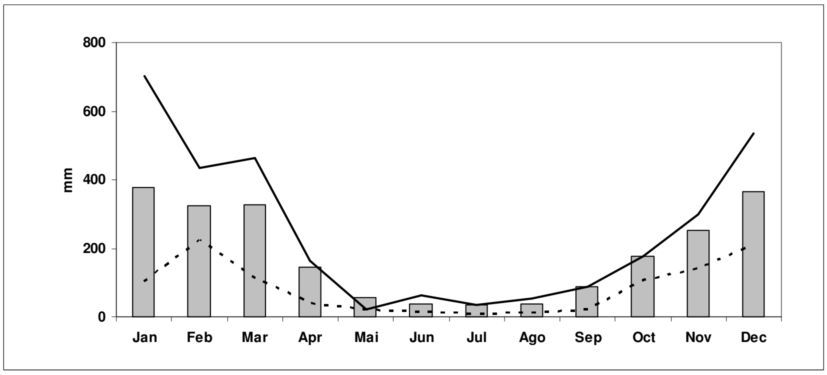
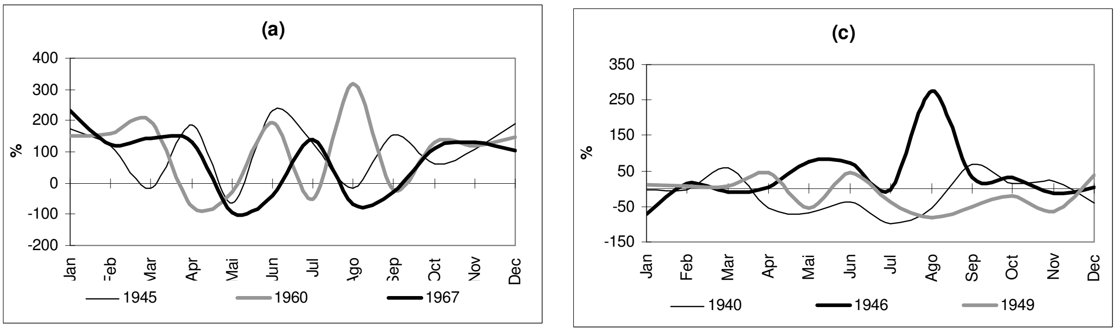


Figure 3. Average monthly rainfall regimen for the Resende Station (1937-2000), also highlighting the average regimens of the rainiest years (continuous line) and of the driest years (traced line).

Considering that the origin of the rainiest years is related to the increase in the frequency of frontal rains in the southeastern region, especially in the summer months (MONTEIRO, 1973), the analysis of pluviometric deviations in the three rainiest years gives room for the interpretation of two notable features of these dynamics: first, the evidence showing that summer months are the indicators and regulators of the occurrence of rainy years. This evidence can be clarified by the prevalence of large positive deviations, especially in the first two months of the year – a fact that does not occur either for the driest years nor for normal years. These results demonstrate that seasonality in the areas of interaction between polar and intertropical systems is related to the occurrence of strong frontogenesis precipitation during the summer. In the years when the Polar Mass is obstructed by the strengthening of the Atlantic Tropical Mass, the absence of large-scale concentrated rainfalls in the southeastern region provides for a greater uniformity trend in the average monthly precipitation regimen.

In the years when the Atlantic Polar Mass presents a broader penetration, the seasonality trend returns, with a concentration of the most intense precipitations in the summer. These deviations, which originate mostly from the Atlantic Polar Front pulsating over the southeastern region, are associated to the occurrence of the more intense events that generate natural disasters, as pointed out by Coelho Netto (1985) and Brandão (2001).



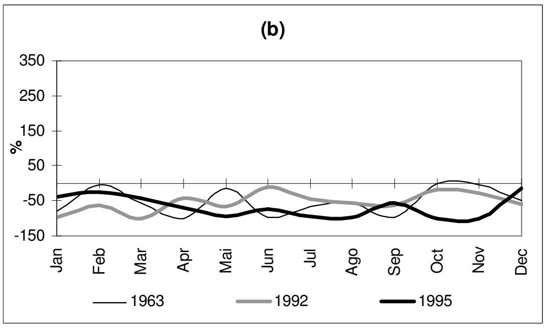


Figure 4. Charts showing monthly pluviometric deviations (% in relation to the average), both positive and negative, during the course of the three rainiest years (a), the three driest years (b) and the three normal years, which are closest to the average (c). In the latter chart, the positive deviation presented in August, 1946 is interpreted here as a pluviometric exception within the selected sample, and not representative of the trends under analysis

Secondly, it is possible to observe that the rainiest years, in contrast with the driest and intermediary years, still present the largest positive and negative variations around the average throughout the year, which clearly denotes that the disturbances that the Polar Front causes in the Atlantic Tropical Mass propagate cyclically and with great intensity throughout the year, although, as mentioned above, with greater intensity in summer months.

On the other hand, the comparative analysis of the pluviometric deviations throughout the researched decades (figure 5), corroborates the trend pointed out in the previous stage, i.e., the reduction of annual pluviometric totals. An analysis of the first chart (5a) allows one to clearly visualize the movement of positive deviations found in the first decade (1938 -1949) towards a prevalence of negative deviations during the last decade (1989-2000). This characterizes a path in the direction of a landscape with a smaller hydro availability, and, consequently, with different levels of alteration on the system's hydrological regulation mechanisms. The chart for intermediary decades (5b) portrays the intermediary conditions that occur during the transition from one scenario to the other.

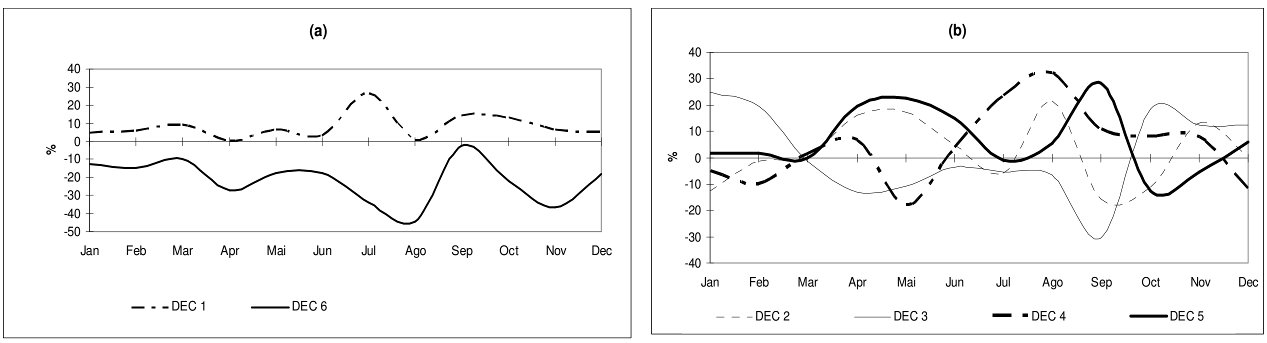


Figure 5. Comparative charts showing pluviometric deviations between: (a) the first decade (DEC 1) and the last decade (DEC 6); and (b) intermediary decades (DEC 2 to 5) of the study.

The possibilities for regimen alterations that originate from the changes pointed out in the monthly precipitation distribution during the course of the analyzed decades have led us to employ the Precipitation Concentration Index (figure 6) in order to assess the existing trends for the typical tropical seasonality conditions in the researched area.

Although the results found still warrant the characterization of a weakly marked climatic seasonality (values between 11 and 20), typical of tropical climate areas with a short dry season, the regression line is already showing a slight inclination (β_1=0.02) toward a more distinct seasonality in the future (values above 20), typical of drier regimen climates. The isolated analysis of this factor does note represent a significant alteration trend in local hydrological controls (*t Student* = 1,49 <α 0,05); however, the articulation of these conditions with the analysis of daily rainfall distribution variation constitutes, as we shall see ahead, a worrisome picture for the future conditions of this location and several others that present similar pluviometric tendencies.

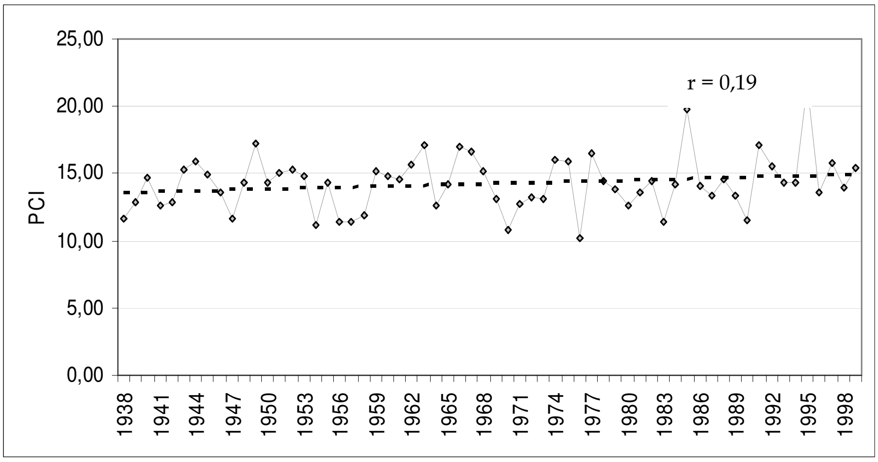


Figure 6. Precipitation Concentration Index distribution (PCI), calculated for each of the years in the series of data under analysis, and the trend line (tested with *t* Student).

Before analyzing the daily rainfall distribution, however, we worked on identifying the evolution of the months that are considered 'dry' in the context of hydric availability for the physiological processes of forest communities. In order to do so, we followed the methodology proposed by Windsor (1990) and went on to select all months with precipitation under 100mm, and then calculated the trend line for this group of months (figure 7). According to Zots and Andrade (2002), monthly precipitations below the aforementioned value are enough to promote adaptation changes, albeit temporary, especially in carbon fixation mechanisms of most vascular plants.

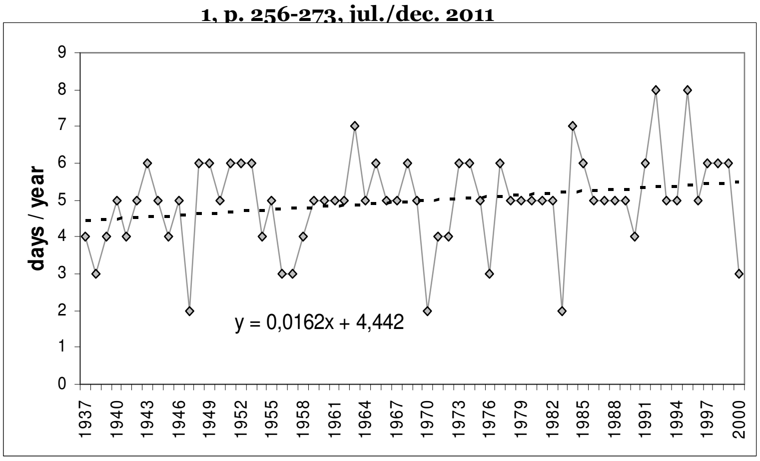


Figure 7. Evolution of the number of dry months per year and the respective trend line (tested with *t* Student).

The analysis of the above chart allows us to identify an unambiguous upward trend (>1%, statistically significant with t = α 0,05 [1,96]) in the number of dry months per year, which ultimately represents an expansion of the dry season. While the dry period in normal years lasts approximately 4 months (from May to August), during the dry years the drought period lasts 6 months (from April to September), a trend that can be adopted by the 'normal' years if the downward trend in pluviometric totals continues to favor the drought period increase, as suggested by the regression line.

However, considering that the number of dry days per year has remained nearly constant throughout the series (Figure 8) and, considering also that the frequency of larger intervals between consecutive rainfall events has not presented a significant extension trend (table 1) we can conclude that the downward trend in the annual pluviometric totals, with an extension of the dry season, is occurring through a substitution of higher intensity events for lower intensity events, which are concentrated in the summer – a fact that will be proven in the analysis of rainfall class frequency during the course of the researched period.

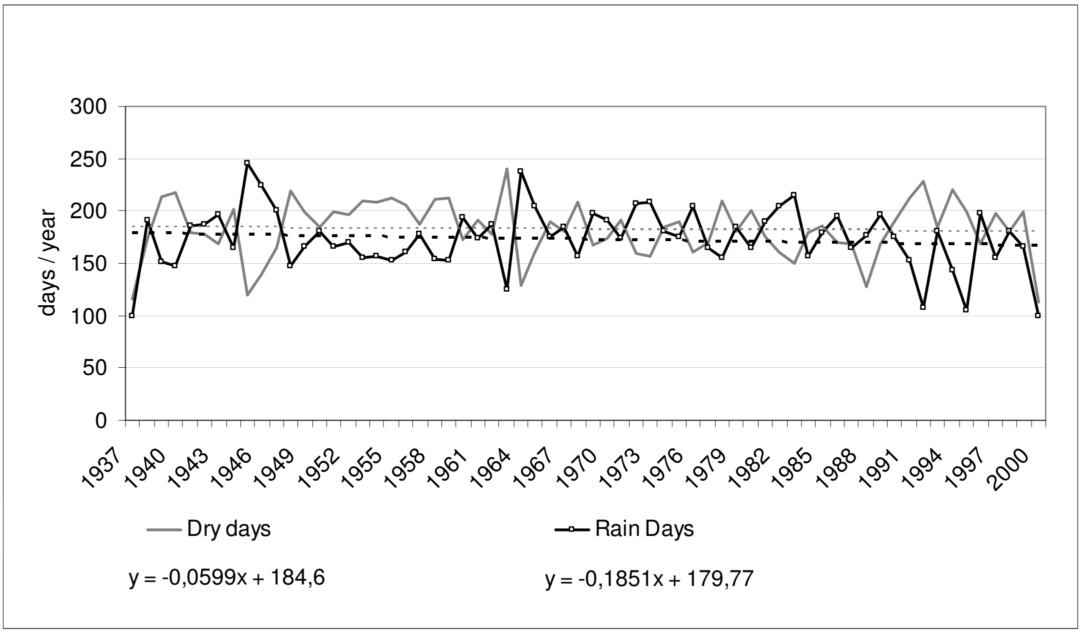


Figure 8. Distribution of the number of dry and rainy days per year, with the respective trend lines. The slight downward trend is not statistically significant (with t < α 0,05).

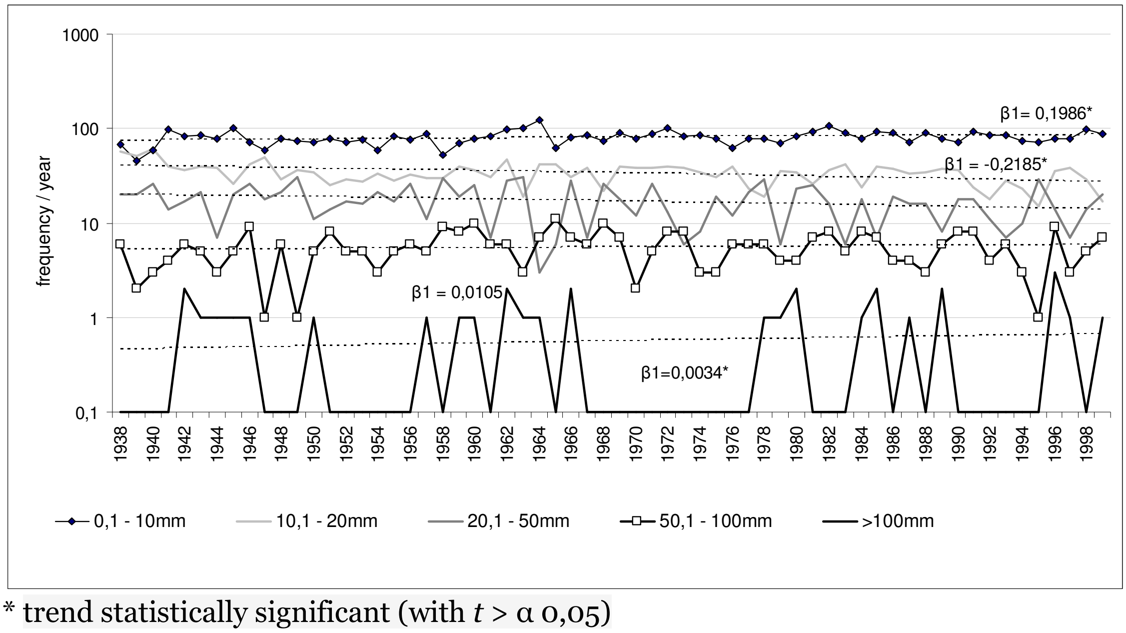
Table 1. Simple frequency of classes of dry days per decade throughout the researched period

	1938 - 1949	1950 - 1959	1960 - 1969	1970 – 1979	1980 - 1989	1990 - 2000	β_1	Average	SD (%)
CL 1 **1-3 days**	455	343	185	350	347	377	-6,08*	343	26
CL 2 **4 a 7 days**	117	95	98	106	90	105	-1,91*	102	9
CL 3 **8-11 days**	37	41	39	32	35	40	-0,29*	37	9
CL 4 **12-15 days**	9	16	21	12	11	17	0,46*	14	31
CL 5 **>15 days**	11	15	15	5	8	10	-1,03*	11	37

* trend is not statistically significant (with $t < \alpha$ 0,05)

Daily precipitation, as mentioned earlier, was divided into five classes according to intensity (figure 9), and for each of them the respective trend line was calculated in order to identify the direction in which it was evolving.

The comparative analysis of the rainfall classes took into account three large groupings: low-intensity rainfalls (class 1), representing the rainfalls that most of the time is intercepted and stored by canopies, being returned to the atmosphere through evaporation; higher-intensity rainfalls (classes 4 and 5), representing low frequency and high intensity events that potentialize natural disasters (DEHN and BUMA, 1999), and that contribute very little to the maintenance of hydrologic stability in the geo-ecosystem, since the water volume produced is rapidly lost by the system in the form of superficial and sub-superficial draining. Finally, the intermediary rainfalls (classes 2 and 3), which are responsible for the hydric 'feeding' of the system, both by making water available to the litter-top soil-roots subsystem, and by refilling reserves with infiltrated water.



* trend statistically significant (with $t > \alpha$ 0,05)

Figure 9. Chart showing frequency of rainfall classes (on a logarithmic scale) and their respective trend lines.

A general analysis of the above chart allows us to confirm the hypotheses that the reduction in annual pluviometric totals is a consequence of a reduction in the intensity of events, and not in number. In this case, what can be seen is an increase in higher-intensity rainfall events, especially class 5 events, and a decrease in intermediary events, which have presented a significant reduction in frequency, especially during the last decade.

It is evident that class 1 rains have presented a relative regularity with a slight upward trend in the last two decades researched, possibly due to an increase in condensation nuclei generated by urban-industrial growth. However, considering that these lower-intensity rainfalls barely affect the soil/vegetation set (since they tend to be retained on the upper levels of canopies), it is exactly the downward trend in class 2 and 3 rainfalls that is cause for worry.

For the sake of analysis these two classes were unified. Their distribution during the course of the summer and winter seasons for each year in the researched series is represented in figure 10. Even though these medium-intensity rains appear relatively well-distributed throughout the year (figure 11) precisely because they are more linked to convective movements than to the action of Frontal systems, it is precisely in the summer periods that their strongest downward trend can be registered (β_1= -0, 88 with $t < \alpha$ 0,05, against a -0.06 downward trend in winter months), since, in summer months, their participation is being replaced by high-intensity rains (class 5), of which 80% of events are concentrated between December and March (figure 11).

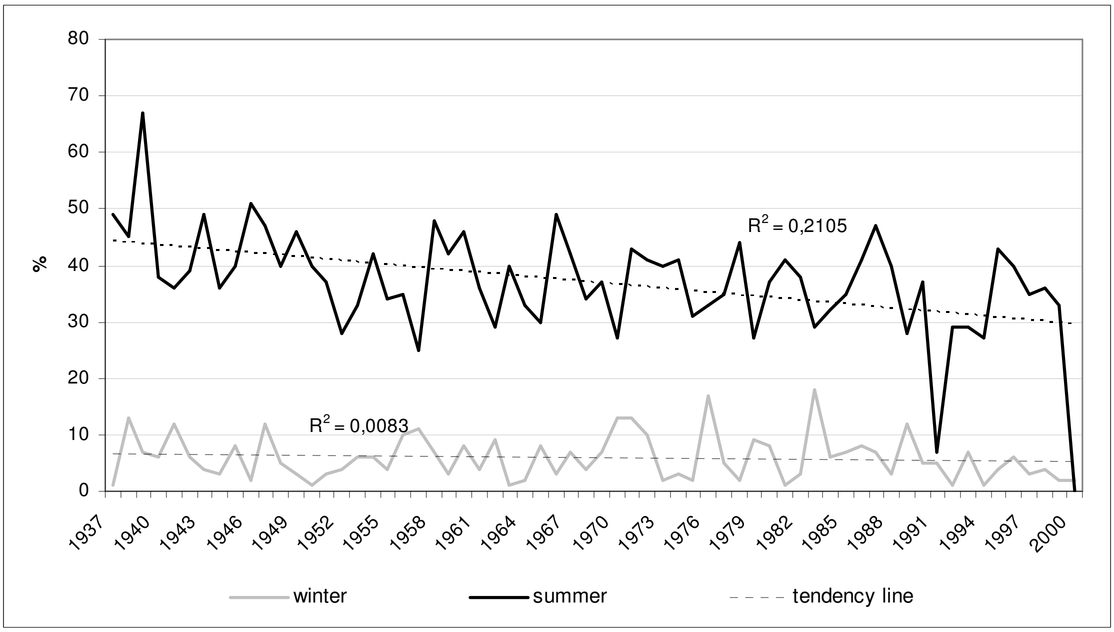


Figure 10. Percentage distribution of medium-intensity events (>10<50mm) during summer and winter, and their respective trend lines.

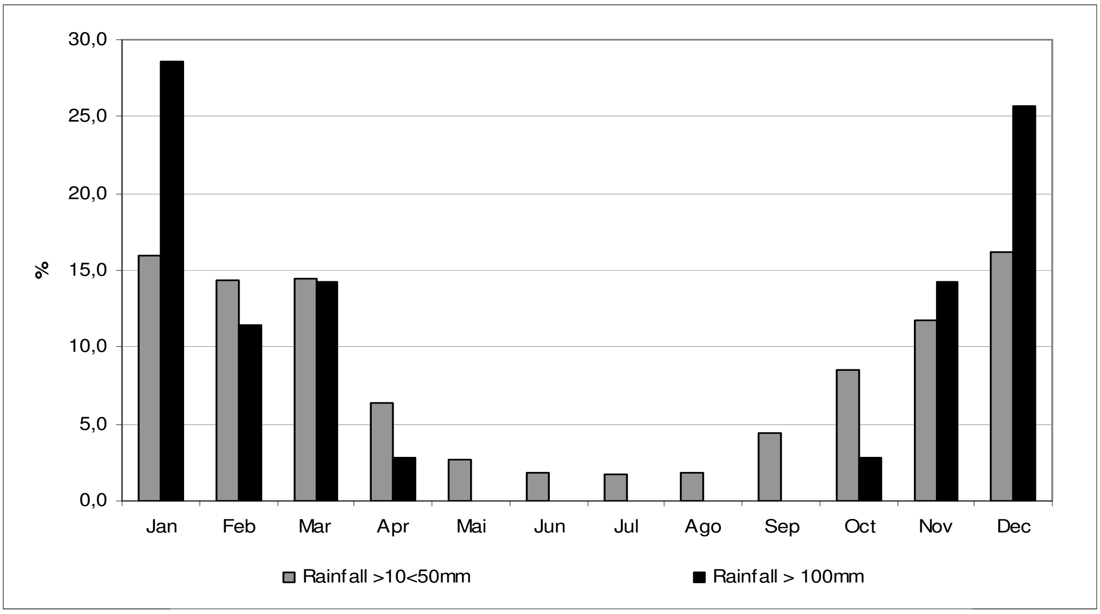


Figure 11. Percentage distribution of medium-intensity (>10<50mm) and high-intensity events (> 100mm) during the months of the year (average for the whole series).

5 Conclusions

The results found allow us to conclude that the pluviometric dynamics in the municipality of Resende tend to be more and more regulated by the action of regional mechanisms, thus allowing the generation of frontal rainfalls to determine the local pluviometric variability pace. This behavior reproduces the downward trend in annual precipitation (approximately 8% during the course of the researched period) that was previously detected for a historical 65-year series at the Resende Station (MEIS et al, 1981). This resultant is due to the fact that the rainfall events with intensity lower than 50mm has presented a decrease in frequency (R^2=0,0085) that is more significant than the increase in the number of events with intensity higher than 50mm (R^2=0,0051).

In the last decade, between 1990 and 2000, the monthly average regiment presented negative deviations in all the months of the year (most of them over 12% with the exception of March and September) reaching a negative rate of up to 44% in the average for the month of August. This results differ from those obtained for the first research decade (1938-1949), in which all the months varied positively in relation for the monthly average of the series, reaching an mean positive variation of up to 26% for the month of July.

The increase in the system's instability comes precisely from the fact that the higher frequency and lower intensity events (which are, therefore, the most regular in rainfall distribution) – reaching a total of 95,6% of all events in the researched period (classes 1 a 3) – point toward a downward trend as opposed to lower frequency and higher intensity events (4,4% of all events, distributed between classes 4 and 5), which have presented an upward trend. This trend however seems to be linked to important characteristics regarding instability of the environmental system, such as:

- Intensification of seasonality (which is already very high, since 74% of the annual pluviometric totals are distributed between November and March), with a PCI variation of 11,71 (in the beginning of the series) to 15,38 (in the end of the series);
- An increase in the frequency of extreme events (β_1= 0,0034 for events with intensity above 100mm) associated with instability lines and stationary fronts. A vast number of works have been dedicated to the social-economic impacts of this class of events both in the urban area and in agricultural production.

- Alteration in the refilling dynamics of reserves due to the reduction in the availability of water infiltration and finally a functional and structural alterations in geo-ecosystems since the vegetation is required to generate processes of adaptation to these dryer periods.

Considering these results, it is reasonable to suppose that the reduction trend in lower-intensity precipitations during the summer is being compensated (at least regarding pluviometric totals, though not regarding hydrological functionality) by an increase in higher-intensity precipitations associated to a larger movement of regional atmospheric systems. But in winter months, even though the downward trend in lower intensity rainfall events is significantly smaller, the absence of a compensation that would be provided by higher intensity events not only strengthens seasonality but also originates the annual pluviometric balance deficit pointed out in the beginning of this research.

These results undoubtedly point out tendencies rather than irreversible determinations in local rainfall distribution, and their interpretation should make based on the benchmark for global and regional alteration trends in atmospheric dynamics.

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