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Agricultural drought in the Claromecó river basin, Buenos Aires province, Argentina

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Abstract

The dry and wet periods affecting the Claromecó Creek Basin in the south of the Province of Buenos Aires were analysed applying Palmer's Model. Palmer's Drought Severity Index was calculated regionally for five towns for the 1904-1999 period. Both the rate corresponding to the drying of soil humidity and the regional climatic rates were taken into account. On analysing the conditions featured in each decade and during the period as a whole, it was found that whereas droughts prevailed 42.7% of the time, wet conditions predominated 35.5%, and during the remaining 21.8% of the time conditions were normal. Drought periods lasted longer than wet ones - an average of 16 to 19 months as opposed to a maximum of 11 months. The harshest droughts affecting regional farming were registered in 1962/63 (with an 80% loss of the wheat crop, the worst harvest ever), 1995/96 and 1998/99.

Key words: Drought, wet period, dry period, Palmer's Model, South of Buenos Aires.

Resumen

Se aplica el modelo de Palmer para analizar los episodios secos y húmedos de la cuenca hidrográfica del arroyo Claromecó, localizada al sur de la provincia de Buenos Aires, Argentina. El Índice de Severidad de Sequía de Palmer es calculado en cinco localidades y para el período 1904-1999, desarrollando explícitamente las rectas que representan la tasa del secado de la humedad del suelo y los coeficientes climáticos regionales. Se analizan los períodos secos y húmedos por décadas y para el periodo total. Durante el período analizado el 42,7 % se caracterizó por condiciones de sequía de distinta intensidad, el 32,7 % con condiciones húmedas y el resto con condiciones normales. Los episodios mas largos observados corresponden a las sequías, con máximos entre 16 y 19 meses mientras que los máximos periodos húmedos no superan los 11 meses. El impacto de las peores sequías en la economía agrícola regional se registró en los años 1962/63 (con la mayor pérdida en la cosecha de trigo, 80 %), 1995/96 y 1998/99.

Palabras clave: *Sequía, episodio húmedo, episodio seco, modelo de Palmer, Sur de Buenos Aires.*

1. Introduction

Droughts occur when there is water scarcity as a result of long months of insufficient rainfall. They should not be regarded as simple natural phenomena, since their impact on society derives from the relationship between the natural event and water demand. Generally speaking, a drought could be described as the water shortage affecting the biotic elements of a particular region for a long period of time. Water requirement will depend on the distribution of plants, animals and human beings as well as on their ways of life and land use (Servicio Meteorológico Nacional, 1988; FAO, 1990).

One must differentiate between the hydrological drought or sustained hydrologic shortage and the apparent or agricultural drought when rainfall does not coincide with the seasonal needs of crops. Agricultural droughts last a short period of time and affect the growth of pastures and crops, but they do not generally alter hydric balance to a large extent. They are characterised by a fall in the groundwater level, and they happen when the amount and distribution of precipitation, water reserves in the soil, and evapotranspiration combine to cause a considerable drop in crop and cattle yields (WMO, 1975). In short, they are distinguished by their intensity, frequency, magnitude and geographical distribution.

Droughts are a normal climatic feature of semi-arid regions and are, therefore, related to the high variability of rainfall. They are closely connected with the predominantly anticyclonic conditions which prevail for a certain length of time. Moreover, they depend on the conditioning imposed by the changes in atmospheric pressure which alter the general atmospheric circulation. Recurrent and extremely severe droughts are one of the principal adversities which affect the regions allotted to agriculture in Argentina.

The occurrence of a rainy or dry year in the centre of Argentina is related to both the anomalies of the dynamics of the atmospheric systems over the big oceanic basins (González and Barros, 1996; Grimm *et al.*, 2000), and the large scale anomalies connected with the atmospheric circulation, such as the phenomenon called El Niño (Pittock, 1980; Vargas, 1987; Grimm *et al.*, 2000). At the same time, water vapour is introduced from the Amazon and the Atlantic Ocean due to the increase in jet stream at low altitudes above the Chaco-Paraguayan plain located to the east of the Andes and the north of Argentina (Wang and Paegle, 1996). Water shortage, being a hydric extreme, is linked to anomalies or fluctuations in the circulation field of the troposphere. Therefore, droughts are the result of a climatic anomaly.

The identification and the intensity of droughts have been studied in several research papers, with precipitation information provided by meteorological surface stations (Ravelo and Rotondo, 1987; Lucero and Rodríguez, 1991). Some authors studied the droughts in the pampean region and their influence on the profit of the wheat crop (Scian and Donnari, 1997). Ravelo and Pascale (1997) identified and examined droughts in several localities of Córdoba and Buenos Aires using information from meteorological stations and satellite images. Ravelo (1999) characterised the droughts of the pampean meadows by means of drought indices and satellite information. Kogan (1991) used satellite images to examine the droughts on a global scale.

The identification and intensity of droughts must be considered as factors that should affect national or regional economic planning. Hence, the importance of tracking droughts in different locations over a period of time. Palmer's monthly Drought Index (PDSI) (Palmer, 1965) is one of the methods available for detecting and evaluating droughts. The objective of this study is to identify the periods of agricultural droughts and to characterise their intensity and duration in the south of Buenos Aires province, since droughts are related to regional economies and cereal yield.

2. Methodology

Palmer's Drought Index was used in this research on the Claromecó creek basin located in the south of the Province of Buenos Aires, for the 1904-1999 period. PDSI was used due to the fact that it is an index which takes into account the precipitation variable, radiation, the physical properties of the soil, and its humidity condition. In addition, this index has been preferred for the Pampean region because the existence of former studies from other farming areas of Argentina allow the comparison between PDSI results and their correlation with crop yields.

The Palmer Model was used according to the methodology presented by Ravelo (1990). The hydrological balance and the humidity anomaly index were obtained. The hydrological balance model considers two ground levels: the higher level which contains 25 mm (1 inch) of useful water and the lower level which contains a certain quantity of useful water depending on the considered depth and the intrinsic ground characteristics. The method defines a series of variabilities that the potential values assume, namely the recharge and loss of water and the potential run-off. The difference between the actual precipitation (p) and the rainfall necessary to maintain the average climatic or normal humidity ($\hat{p}$) is defined by Palmer as humidity divergence (d):

$$d = p - \hat{p} \tag{1}$$

These divergences are positive during wet periods and negative during dry ones. Palmer also obtained an anomaly index for humidity (z) by multiplying the d values by a constant k corresponding to a particular place and period ($z-dk$). It was considered as the demand-supply of humidity ratio and was represented as a function of evapotranspiration (ET), soil water recharge (R), precipitation (P) and water loss from the soil (L):

$$k = \frac{\overline{ET}+\overline{R}}{\overline{P}+\overline{L}} \tag{2}$$

The hydric balance was calculated according to the monthly pluviometric registers from 1904 to 1999 collected by the weather stations located in the area of the Claromecó river basin. This information was completed with the data gathered by the Benito Juárez weather station for the 1974-1999 period (figure 1). As regards the amount of usable water in this region, the storage capacity presented the following values: 90 mm, 101 mm, 103 mm and 106 mm (Echagüe *et al.*, 1991). The evapotranspiration resulting from the combined processes of the evaporation of the soil and the transpiration of plants was estimated according to Penmann (1948).

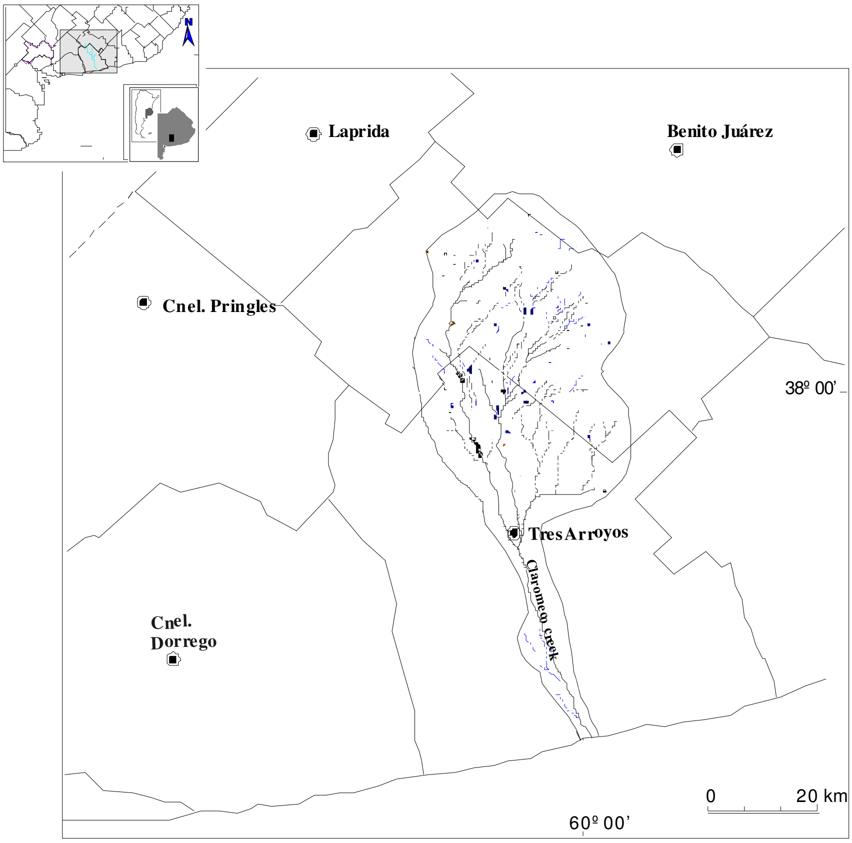

Fig. 1: Location of the weather stations in the study region.

The negative indices in terms of the duration of dry periods are shown on the straight line graphed in figure 2. The straight line which joins the maximum amount of dry extremes was allotted a value of -4 and identified with the extreme drought category. The a and b rates corresponding to the straight line were calculated, where $a = 15.16$ and $b = 24.93$, for the whole region studied.

Considering that the monthly index is influenced by the state of humidity of the previous month, the c rate was calculated in the following equation (Donnari and Scian, 1993):

$$x_i - x_{i-1} = (z_i/40.09) + c\, x_{i-1} \tag{3}$$

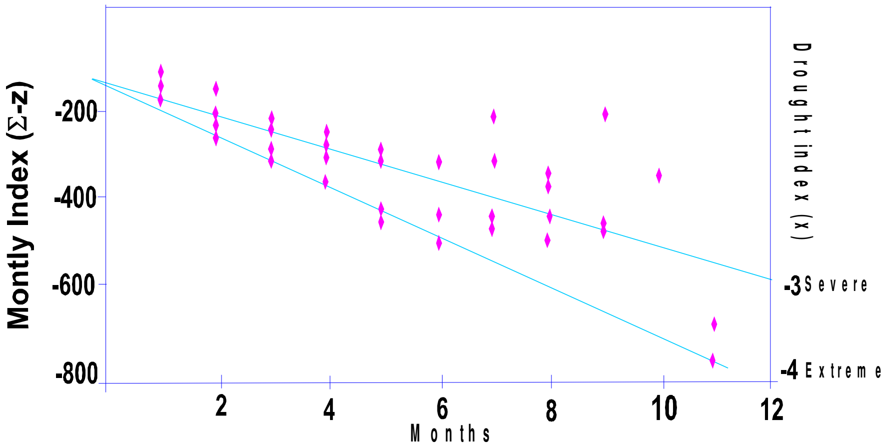

Fig. 2: Duration of dry periods. Negative indices.

The extreme values considered were those registered by the towns studied, regarding -4 as an indicator of the extreme drought category. The straight line equation was calculated by applying the following formula:

$$X_I = \sum_{i=1}^{I} z_i/(a\,t+b) \tag{4}$$

The values corresponding to humidity anomalies measured in millimetres ($Z_i = k_j d$) were converted into monthly drought indices and standardised to determine the regional climatic weight factor by means of the following equation:

$$\hat{k}_j = 1.5\ \log_{10}(T_j + 2.8)/\overline{D_j} + 0.50 \tag{5}$$

Thus, the drought severity index (PDSI) was calculated with this formula:

$$\Delta x_i = z_i/(a\,t+b) + c\,x_{i-1} \tag{6}$$

The straight line which joins the maximum amount of dry extremes was allotted a value of -4 and identified with the extreme drought category. The a and b rates corresponding to the straight line were calculated using equation (1) where $a = 15.16$ and $b = 24.93$, for the whole region studied. Considering that the monthly index is influenced by the state of humidity of the previous month, the c rate was calculated in the following equation (Donnari and Scian, 1993):

$$x_i - x_{i-1} = z_i/40.09 + c\,x_{i-1} \tag{7}$$

The c rate value obtained for this region (-0.378) was then replaced in equation 7 to obtain the DSI using the following equation:

$$x_i = z_i/40.09 + 0.622\,x_{i-1} \tag{8}$$

A drought is thought to begin when the DSI features a negative value below -0.5 and to finish when it changes its sign or if its values are over -0.5. It is not interrupted if there are intercalary months with values ranging from 0 to -0.5.

Although PDSI and its well-known methodology are widely used, the present work has placed special emphasis on the regional drying rate; employing for the final expression, the climatic ratios standardised for the south of the Province of Buenos Aires. The PDSI results were compared to the bread wheat yields in the area studied, and the impact of negative indices on regional economy was analysed. The harvest data were obtained from the Farming Statistics (INTA, 1999).

3. Results

One of the most questionable steps taken to obtain the PDSI is the calculus of the climatic weight factor by means of equation (5) (Alley, 1984). Figure 3 shows the monthly progress of such a factor for the southern slope as well as the rates corresponding to the Southern wheat belts II, IV and V after standardisation (Scian and Donnari, 1997). Whereas the maximum k values presented by the Southern Slope are those of August (1.34), June and January (1.33), the minimum values were registered in March and April, 0.96 and 0.97 respectively (figure 4). The annual variation of k is related to the rates of region IV which lies in the south of the Province of Buenos Aires, and is at the same time among the values that characterise the semi-arid region (Southern-V) and the humid pampean region (Southern-II).

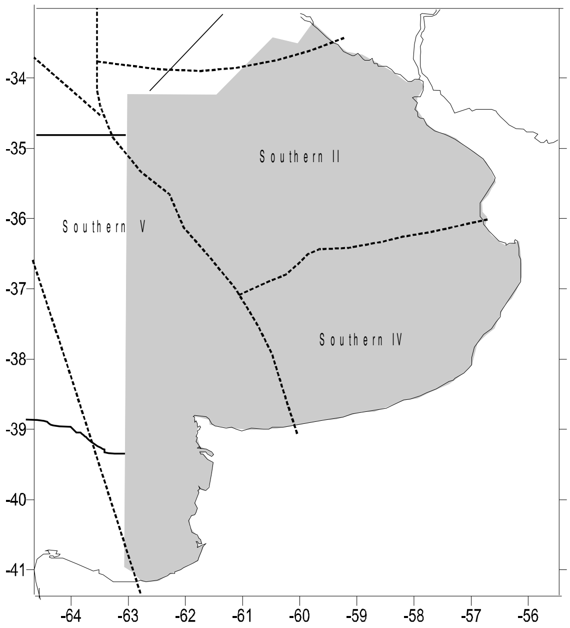

Fig. 3: Ecologics wheat belts in the Buenos Aires province.

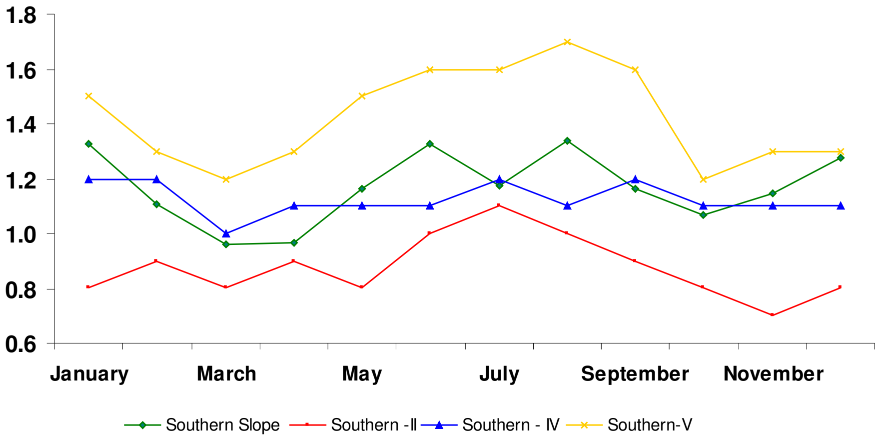

Fig. 4: Climatic weight factor for the different regions.

A simultaneous analysis of the frequency and percentage of the wet and dry indices was carried out for all five towns. Figure 5 shows that 42.7% of the 4788 months considered presented droughts of diverse intensity. The highest frequencies fall into the incipient and weak drought categories (35.3%), while 24.3% correspond to the normal category and 7.20% to the moderate and severe drought category. Only 0.14% correspond to the extreme drought classification.

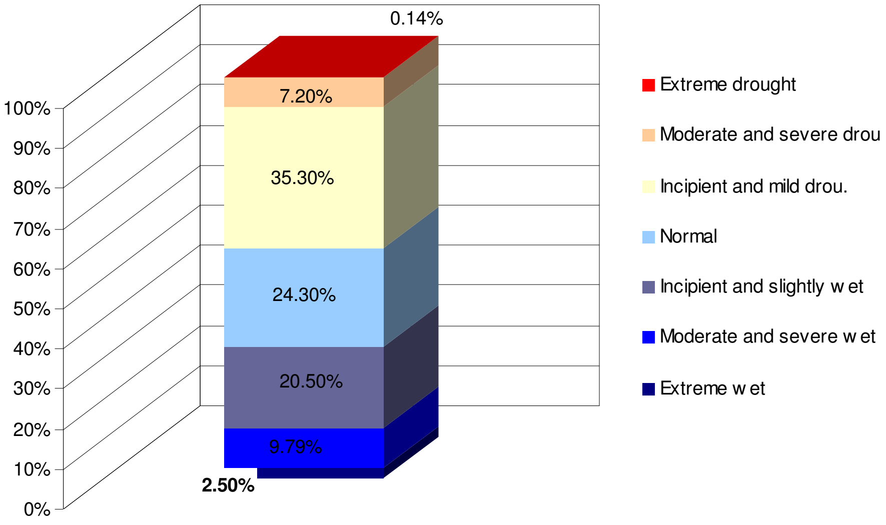

Fig. 5: Frequency of wet and dry indices.

The cases analysed show that 33% of the months were wet, 2.5% were extremely wet and 9.79% were either moderately or severely dry. Thus for the period studied the percentage of dry periods was higher than of wet ones. Figure 6 graphs the monthly percentage of droughts, revealing that the incipient and weak category is the predominant rank; June being the driest month and December the least dry (only 165 months out of the total considered were droughty).

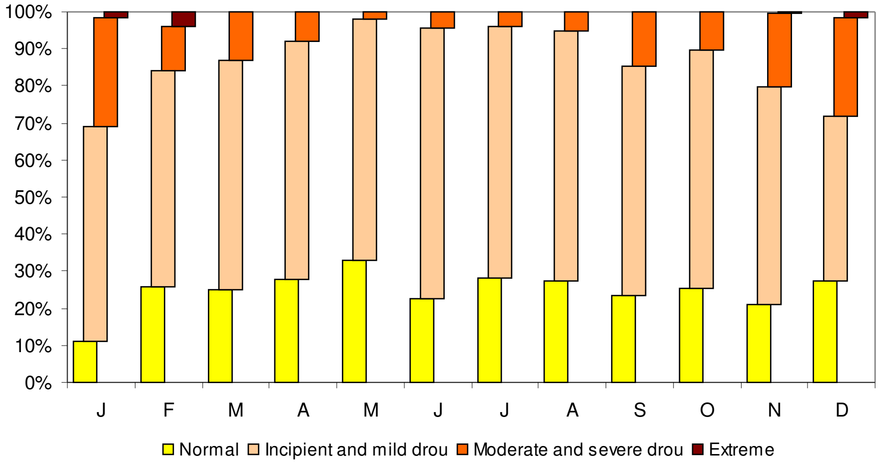

Fig. 6: Percentage of droughts in the region.

Moderate and severe droughts predominated in late spring and summer (November, December and January) with a total of 161 cases, while extreme droughts occurred in December, January and February. Every month presented normal category droughts, May having the highest value (33%).

May showed a predominance of negative (or dry) indices until the 70s when an extremely humid period began. Although there has been no recurrence of dry periods as prolonged as those of the 60s, later droughts have caused great impact. The duration and intensity of both the dry and wet periods registered from 1904 to 1999 were analysed for the five towns. In order to study the dry periods, extreme intervals were defined as shown in table 1.

Table 1: Dry extremes intervals.

Period	Number of Months	$\sum(-z)$
Nov. 1952-Dec. 1952	2	-245.89
Nov. 1954-Jan. 1955	3	-313.08
Nov. 1998-Feb. 1999	4	-364.22
Oct. 1955-Feb. 1956	5	-447.60
Dec. 1967-Jul. 1968	8	-500.54
Jul. 1959-Feb. 1960	8	-463.38
May. 1924-Jan. 1925	8	-490.60
May. 1995-Jan. 1996	8	-467.98
Feb. 1921–Dec. 1921	11	-347.90
Apr. 1917-Feb. 1918	11	-767.09

Extreme droughts affected this region from the beginning of the XX century to the 30's with values of up to -3.93. They lasted a maximum of 15 months and presented a PDSI of -3.04, being all of them severe in nature. However, there was a moderately dry period which spanned 24 months towards the end of the 30's (figure 7).

No important droughts were registered until the 50's. From March 1961 to May 1963 there occurred one of the lengthiest dry periods ever with a marked negative impact on regional economy. Its minimum PDSI was - 2.98 and it lasted 16 uninterrumpted months. Towards the end of the 70's, there was a moderate drought with a -2.72 PDSI which extended for 14 months.

Even though the following two decades featured only moderate droughts, studies on precipitation variability in Argentina show that there have been episodes of severe and extreme drought since the end of the 90's. The most outstanding dry periods are a moderate drought with a -2.08 PDSI which extended from May 1995 to January 1996, and a severe one with a -3.29 PDSI from November 1998 to February 1999).

4. Discussion

There exist several small and large scale factors which affect atmospheric circulation and generate droughts in the area studied. Among the large scale phenomena, there is El NIÑO which leads to a drop in summer rainfall in most of northwestern Argentina. Such a fall is also experienced by a large portion of South America, which begins its dry season in winter as well.

Regionally, the typical atmospheric disturbances from the west are heightened by the positive anomalies of sea temperatures in the vicinity of Chile. As a result, there are snowfalls in the Andes and intense phenomena like the Zonda, a wind which extends the drying of the air over the centre of Argentina in the winter.

Meanwhile, the predominance of cold anomalies over the Malvinas Current, and of hot anomalies over the Brazil Current, contribute to the development of cyclones in the Atlantic. These are accompanied by southwesterly winds (Pamperos) in the centre of the country. Except in eastern Mesopotamia, dry and cold water transport is poor when the northerly wind blows due to the scarcity of available humidity in the centre of South America.

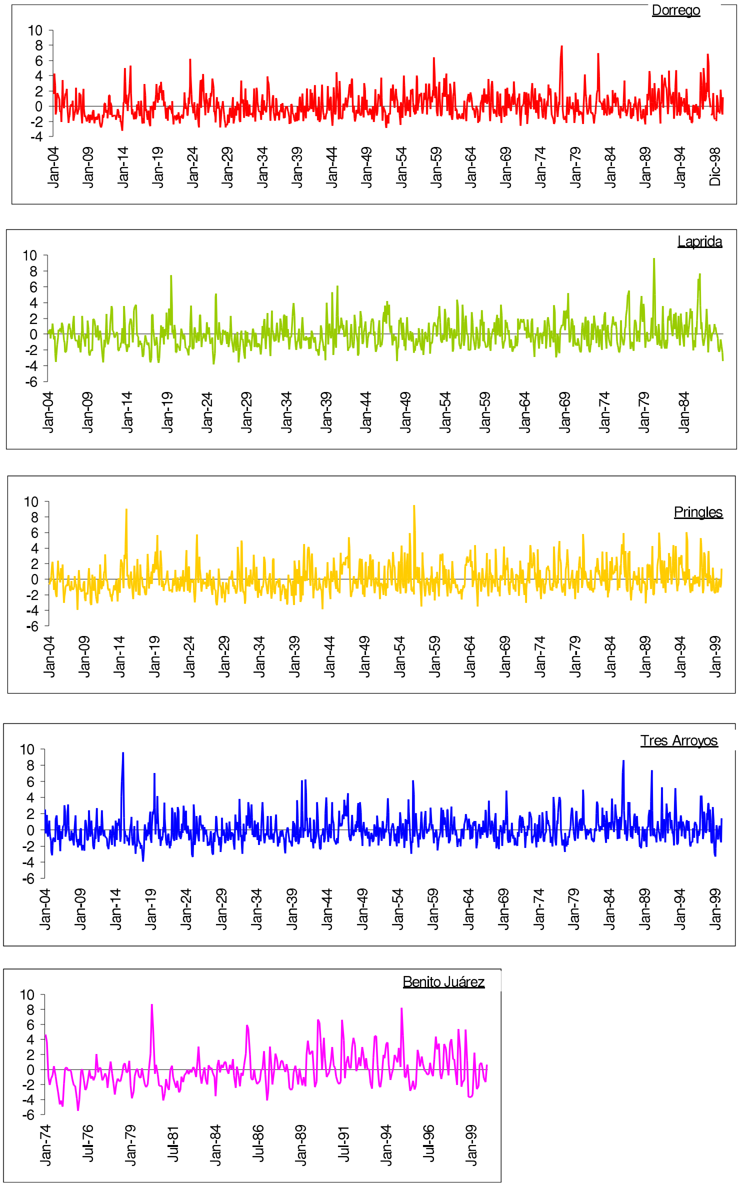

Fig. 7: Temporal progress of the PDSI in the study area.

The Severity Drought Index shows the geographical distribution of droughts during a specific harvest. For instance, in 1995/1996 and 1998/1999 extensive farming areas of Buenos Aires, Santa Fe, Chaco and Formosa experienced extreme droughts and considerable crop losses. A comparison between the PDSI average and the yield benefits from 1950 to 1999 is shown in figure 8.

There is a direct relationship between a negative PDSI and a decrease in yields. Negative PDSI values indicate drought periods. It can be clearly seen that wheat production was much below the average for the agricultural yields of 1951/52; 1962/63; 1974/75; 1982/83; 1988/89; 1990/91, 1995/96; 1998/99.

The cereal yield from 1980 on has shown a significant increase because new technologies were added: nutrients, fertilizers, plague-resistant seeds, etc. From 1950 to 1980, the average yield reached 1,694 kg/ha, while from 1980 to 1999, the average value increased to 2,597 kg/ha.

An important correlation was established between the monthly PDSI obtained at critical times for crops (June to December) and the drop in yields. The r^2 ratio recorded was 0.89, but when compared with the PDSI for November and December it dropped to 0.53.

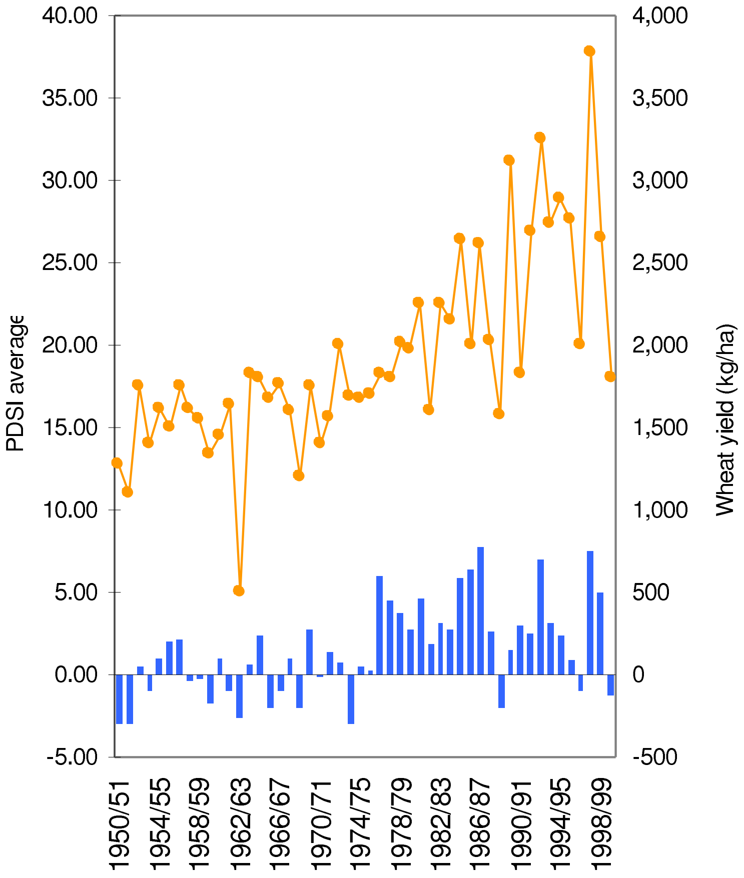

Fig. 8: Relation of PDSI average and the yield benefits from 1950 to 1999.

Nevertheless, other authors have found that the mean monthly PDSI index has a good correlation with wheat yield (Akinremi and McGinn, 1995). In other farming areas, particularly Córdoba, the analysis of the connection of negative PDSIs and the decline in yields has revealed a good relationship between these variables.

Next, the advance of the drought nucleus is shown to classify periods as very severe according to their impact. The first period corresponds to the drought that took place from May to October 1995 with a PDSI of -3.10, and the second from November 1998 to February 1999, which was more extreme than the previous one, lasted 4 months and presented a PDSI value of -3.50. Figure 9 graphs the space distribution of droughts corresponding to the Pampean sector studied (May and October 1995). A remarkably severe drought (PDSI -3.10) that subsided westwards occurred in May 1995, the epicentre being in northern Benito Juárez. Hydric conditions were very favourable for sowing summer crops. Dry conditions (which expanded towards the west) were slightly less favourable in the Tres Arroyos and Benito Juárez areas during July 1995 (PDSI -3.00).

The centre of this area presented weak to moderate droughts. The drought index shows the same distributional pattern, diminishing towards the west of the Pampean region, with indices above 2.0 in certain areas. September 1995 presented two extreme minimum nuclei, one to the NE and the other to the SW with PDSI values below -3.00. In October the severe drought was tempered and gave way to moderate and even weak droughts, such as the one located in Tres Arroyos. The situation was reversed in November 1995 when the PDSI registered values corresponding to incipient or weak humidity. Dorrego, Pringles, Tres Arroyos and Benito Juárez registered precipitations of 106 mm, 113 mm, 104 mm and 98 mm, respectively.

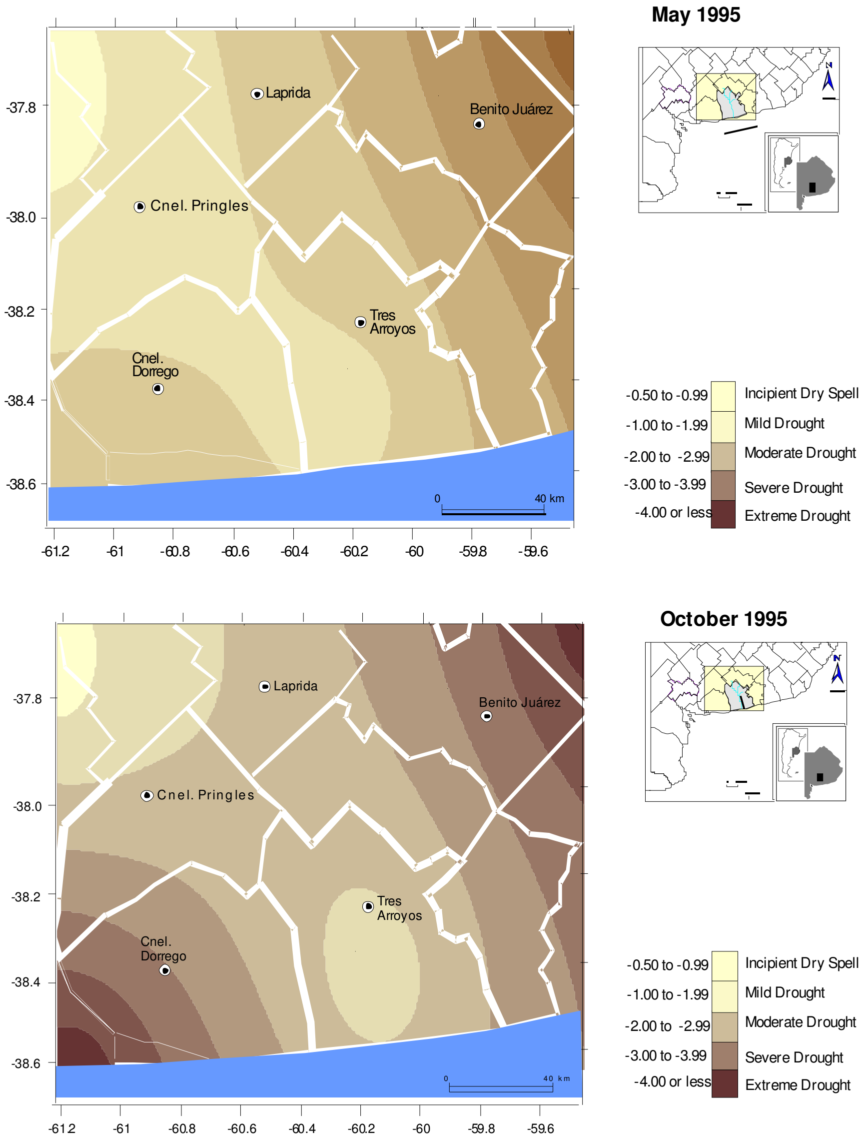

Fig. 9: Space distribution of droughts in the study region in May (top) and October (bottom) 1995.

Another droughty period extended from November 1998 to February 1999 (figure 10). The east and centre of the region experienced a weak incipient drought during the first month, while the NE presented a moderate to severe drought. By December 1998 it had advanced into the west and become moderate (PDSI values of up to -2.99 in the district of Tres Arroyos). Finally, in January it went beyond the districts of Tres Arroyos, Laprida and Coronel Pringles.

During February 1999, the drought intensified in the east with values of up to -3.25 for Benito Juárez. It is worth pointing out that it presented its minimum extremes in the north-eastern towns of Benito Juárez, González Chávez, and Tres Arroyos. The minimum extreme being -3.67 and the maximum -1.71 in the NW of the sector studied. By March 1999 the PDSI had already registered positive values of up to 2.21. The March 1999 rainfall was over 90 mm in the region.

To determine the impact of those droughts on the crops, the agricultural yields corresponding to 1995/96 and 1998/99 have been analysed. Droughts in that region are attributed to the La Niña phenomenon in the pampean region (Piccolo *et al.*, 2002). They started in spring and completed their cycle in March with strong autumn rains. In order to relate the impact of the drought periods with the crop yields of the region, one of the most productive crops, bread wheat in the Tres Arroyos county was analysed.

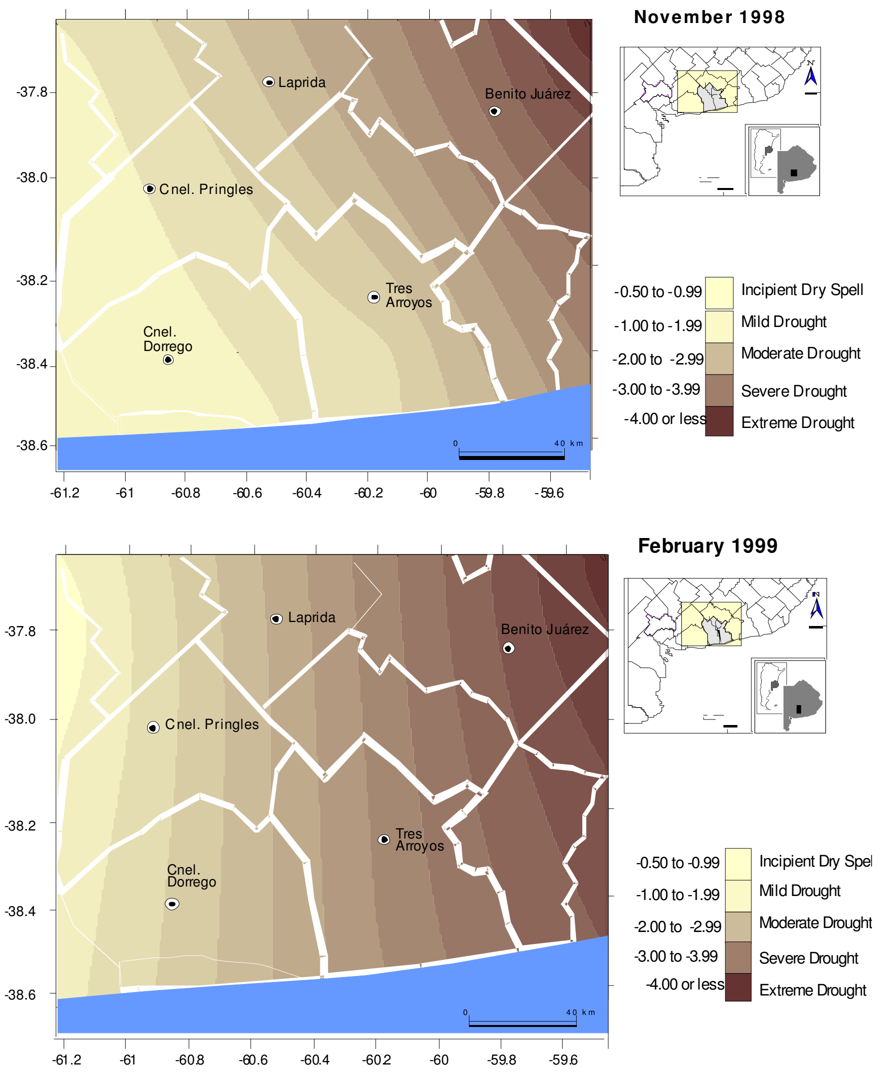

Fig. 10: Space distribution of droughts in the study region in November 1998 (top) and February 1999 (bottom).

The agricultural cereal yields corresponding to the years 1995/96 and 1998/99 showed a decrease in profit between 23 and 13%. Whereas at present the average yield is 2,597 kg/ha, those periods registered values as low as 2,010 kg/ha and 2,270 kg/ha, respectively. The big drought that occurred from November 1998 to February 1999 affected the Southeast of Buenos Aires and the wheat, sunflower, corn and soy yields decreased notoriously. The low yield of the pastures made it necessary to complete the feeding with hay, thus increasing production costs. Another setback was caused by livestock trampling on 600,000 registered hectares sowed with sunflower, corn and soy which were consequently lost. Sunflower the size of thistle, and corn without grains were observed. This is one notable evidence of the combination of hydric deficit during the critical period of the crops, and late frosts.

The fall of the yields marked the first negative impact of this drought. The wheat bread decreased from a yield of 2.93 ton/ha to 2.6. Corn fell from 4.29 tn/ha to 4, sunflower from 1.98 tn/ha to 1.4 and soy from 1.84 tn/ha to 1 tn/ha. The most affected counties of Southeastern Buenos Aires (figure 1) were San Cayetano, Tres Arroyos, Benito Juárez , Balcarce, Tandil, Necochea y Adolfo González Chávez. In some counties of Tres Arroyos and González Chaves watering equipment was installed in zones where the aquifers had good enough river flow, but it was not enough to try to diminish the damage caused by the hydric deficiency.

5. Conclusions

The application of Palmer's Drought Severity Index enabled the characterisation of the droughts affecting the south of the Province of Buenos Aires from 1904 to 1999. It was determined that the longest drought corresponds to the 1936-1939 period, extending over twenty-four months and ranking in the extreme drought category with maximum values of 510 mm and 499 mm for 1937 and 1938, respectively.

The PDSI allowed the simultaneous assessment of both the intensity and duration presented by the dry and wet periods corresponding to five different towns in the south of the Province of Buenos Aires. Taking into account the fact that the area studied is Argentina's agricultural region par excellence, the comparison of the average PDSI and the crop yields from 1950 onwards made an evaluation of the impact of droughts on regional economy possible.

The data considered spanned ninety-five years. 42.3% of the 4788 months studied presented negative indices of varied intensity, 35.7% of which correspond to incipient and weak droughts, and 10.5% to the moderate and severe categories.

The longest and most extreme dry conditions occurred until 1976; the longest, lasting nineteen and sixteen uninterrupted months with PDSI values of up to -4.03. The former belong to the severe category and happened in the 1962-1963 period. They had an extremely negative impact on crops, leading to a loss of 80% and a yield of just 512 kg/ha, the worst ever.

The data analysed for each of the regions spanned over a period of ninety-five years, presenting negative PDSI of varied intensity in 42.7% of the cases. While, 35.5% corresponded to wet conditions the rest were normal.

Apart from the detection of long droughts, it was possible to observe the coincidence of the intensity featured by the index and the severest dry conditions registered in the area. This methodology helps determine the zone where the dry and wet conditions occur as well as to identify the alternation of such variables in a specific study.

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