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Analysis of intense hydrological periods based on observed and estimated flow series at a reference station on the Paraná River, Argentina

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Abstract
The hydrological variability and especially extreme phenomena such as droughts and floods affect natural and human systems worldwide. The Paraná River sub-basin, belonging to the La Plata basin, is of great regional importance, and in recent years extreme events have been observed that have impacted socio-economic aspects of the community. This study compares the series of a relevant hydrological index, calculated from observed flows and unregulated contributions within Argentine territory, at the same reference station. Intense hydrological periods are analyzed in both cases, for droughts and excess water events, for subsequent comparison.

Keywords: extreme hydrological phenomena; SDI index; regulated and unregulated flows

Análisis de períodos hidrológicos intensos a partir de series de caudales observados y estimados en una estación de referencia del río Paraná, Argentina

Resumen
La variabilidad hidrológica y en especial los fenómenos extremos como las sequías e inundaciones afecta a los sistemas naturales y humanos en todo el mundo. La subcuenca del río Paraná perteneciente a la cuenca del Plata, es de gran importancia regional y en los últimos años se han observado eventos extremos que han afectado aspectos socioeconómicos de la comunidad. En este estudio se comparan las series de un índice hidrológico pertinente, calculadas a partir de caudales observados y de aportes sin regulación dentro del territorio argentino, en una misma estación de referencia. Se analizan los períodos hidrológicos intensos en ambos casos, tanto de sequías como de excesos hídricos, para su posterior comparación.

Palabras clave: fenómenos hidrológicos extremos; índice SDI; caudales regulados y no regulados

1 Introducción

Hydroclimate variability affects natural and human systems worldwide.

Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being [1].

Droughts and floods stand out as extreme hydrological phenomena.

Extreme events occurring in the La Plata basin can greatly affect the natural systems of the basin as well as the social and economic sectors. [2].

The Paraná-Plata basin is the second largest hydrological basin in South America and is of great importance for the countries of the region (Argentina, Bolivia, Brazil, Paraguay and Uruguay [3].

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Also, this basin is the most densely populated region in South America and is economically dependent on agriculture and hydroelectric power generation. Within this basin is the sub-basin of the Paraná River, whose main tributary is the Paraguay River, covering an area of approximately 2,700,000 km². In Argentina, the Paraná River valley stretches over a length of 900 km, starting at the confluence of the Paraguay and Alto Paraná rivers in Corrientes.

He absence of precipitation in a specific area over a certain period leads to a hydrological deficit known as "drought." Surface hydrological drought is characterized by reduced flow in river channels, lower water levels in lakes, reservoirs, and other water bodies. This climatic challenge has significant negative impacts on the socioeconomic aspects of a region [4].

Given the recent changes in the frequency, duration and intensity of droughts, a comprehensive understanding of water scarcity is needed at different temporal and spatial scales. This requirement is pressing given the marked increase in demand of water for agriculture, energy production, industry and human consumption [5]

Recently, a multi-year drought has affected the La Plata basin from mid-2019 until at least the first months of 2023. This prolonged and severe drought has severely impacted water availability for various socioeconomic activities and natural ecosystems [6].

Regarding water excesses, they form the opposite phase to deficit phenomena, causing floods in which case their harmful effects affect different sectors and aspects of human activity and their quality of life. In the 20th century, humidity has progressively increased in the Río de la Plata basin, and the probability of major flooding is also increasing [7].

The Paraná River (main channel of the Plata Basin) presents annual floods that, in irregular periods are more intense and with an approximate frequency of two per century, are extraordinary and catastrophic [8].

Nevertheless, it is necessary a joint view of the main hydroclimatic variables and their sectoral impacts at different timescales to provide accurate and integrated information that will facilitate decision-making processes [9].

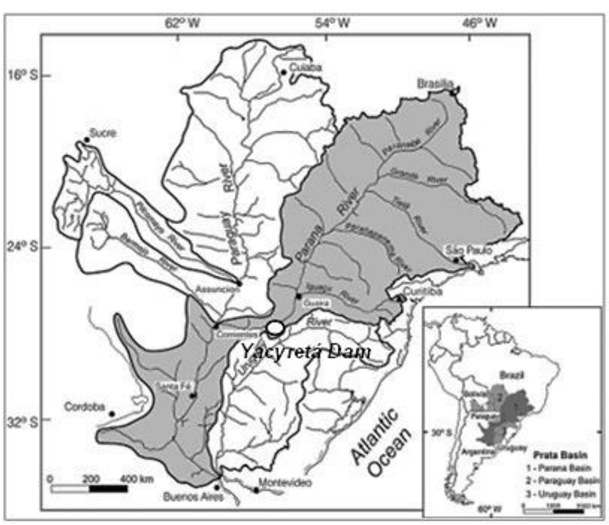

Figure 1. The La Plata Basin is formed by the Paraná–Paraguay and Uruguay Rivers. The Paraná River receives the Paraguay River near Corrientes, Argentina.
Source: Stevaux, J. and Meurer, M., 2009 [10]

Table 1.
Selected stations

River	Name	Country	Period
Paraná	Corrientes (Observed series)	Argentina	1904-2022
Paraguay	Puerto Bermejo	Argentina	1956-2022
Iguazú	Baixo Iguaçu	Brazil	1956-2022
Paraná	Itaipú	Brazil	1931-2022

Source: Own elaboration

In such a way that the tasks carried out in order to evaluate these extreme hydrological events are of great importance in the national territory and in this case in the sub-basin of the Paraná River, belonging to the Plata Basin.

From this and due to the hydrological variations that have been observed in recent years in the Paraná River, it is considered necessary to analyze the dry and wet historical periods, based on a basic quantitative evaluation in fluvial sections of the Paraná, Iguazú River (both still in Brazilian territory) and Paraguay, with the purpose of estimating the series of monthly flows upstream of the Corrientes station (Paraná River in Argentine territory) and its subsequent comparison with the data series observed in the latter (Fig. 1), to analyze the occurrence of historical extreme hydrological events, dry and humid, and the possible influence of regulation, within the national territory, in a reference station of the Paraná River.

2 Methodological procedure

2.1 Preprocessing

First, the sum of flows from the two stations in Brazil is carried out: Itaipú on the Paraná River and Baixo Iguaçu on the Iguazú River (upstream of the binational Yacyretá Dam) and from the Puerto Bermejo station on the Paraguay River (previously completed by statistical processing with a nearby series upstream, called Puerto Bermejo) [11]

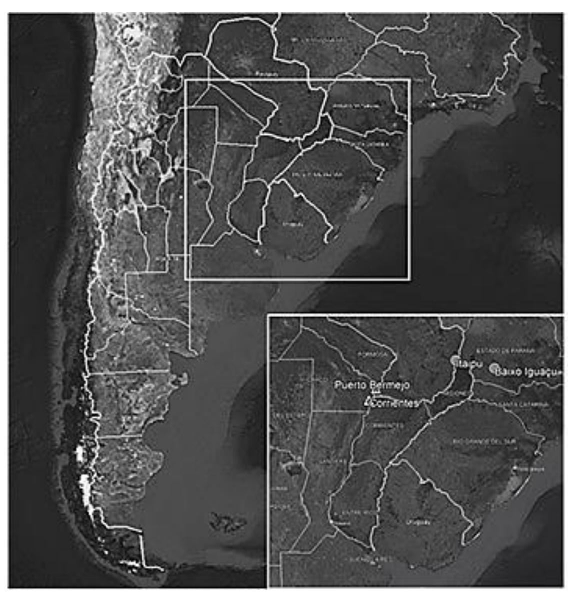

Figure 2. Relative location of the study area and the selected stations.
Source: Own elaboration from Google Earth images. Data SIO, NOAA, U.S Navy, NGA, GEBCO. Image Landsat / Copernicus

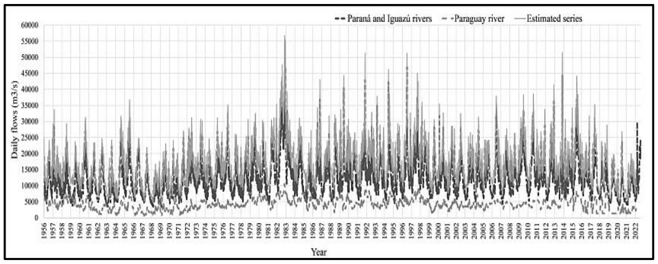

Figure 3. Observed daily data series: sum of the Paraná and Iguazú rivers (Brazil); the Paraguay river and estimated total daily series at the confluence.
Source: Own elaboration

After preprocessing and statistical analysis, the series detailed in Table 1 were obtained. Their relative location is shown in Fig. 2.

The estimated series with contributions (not regulated in Argentine territory) in the stretch upstream of the Corrientes station is compared with the observed values at that site, and through a relevant index, the different hydrological periods are analyzed.

2.2 Hydrological drought index

Streamflow Drought Index (SDI) developed by Nalbantis (2008) was used to analyze hydrological droughts. The SDI index allows the determination and classification of droughts in a basin. However, sufficiently long series of data is required data to estimate the frequency of drought events. Nalbantis (2008) indicated that SDI index is based in the analyze of the accumulated values of flows, volumes or runoff in three, six, nine or twelve months within for each hydrological year, called k1, k2, k3 and k4 respectively. These intervals allow to analyze the evolution of droughts in the annual period considered [12]. The SDI index function eq. (1):

$$V_{i,k} = \sum_{j=1}^{3k} Q_{ij} \quad (1)$$

$$i = 1,2,\dots,n;\ j = 1,2,\dots,12;\ k = 1,2,3,4$$

Where $Q_{i,j}$ are streamflow volume values, i is the hydrological year, j month within a hydrological year and $V_{i,k}$ cumulative of streamflow volume for the i year and k reference period. Then the SDI function is eq. (2):

$$SDI_{i,k} = \frac{V_{i,k} - V_k}{s_k} \quad (2)$$

$SDI_{i,k}$ is a hydrological drought index for the i year and k reference period. V_k and s_k are, respectively, the mean and standard deviation of volume data for k interval considered. The definition of the hydrological drought levels according to the SDI index is shown in Table 2.

From this classification, it is defined for this work that opposite periods of equal magnitude are defined as wet with the same level denomination (mild, moderate, severe and extreme).

Table 2.
Definition of states of hydrological drought with the aid of SDI

Description	Criterion	Probability
No drought	SDII,k=> 0	50
Mild drought	-1 <= SDII,k <0	34.1
Moderate drought	-1.5 <= SDII,k <-1	9.2
Severe drought	-2 <= SDII,k <-1.5	4.4
Extreme drought	SDII,k <-2	2.3

Source: Nalbatis, 2008 [13]

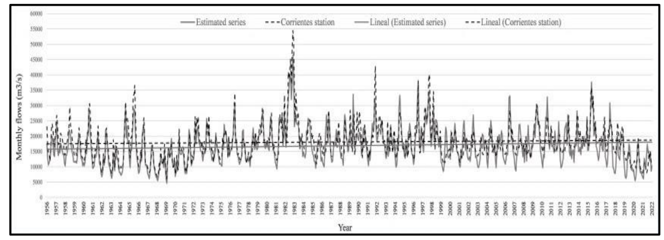

Figure 4. Flow series estimated at the upstream confluence and observed data series at the Corrientes station (1956-2022).
Source: Own elaboration

The present study focuses on the occurrence of intense periods (severe and extreme), that is, starting from the values (-1.5) and 1.5 of the SDI to evaluate this index at the Corrientes station for the observed data series and the estimated series, in order to observe the characteristics and evolution of dry cycles in years with historical records of monthly flows and then make an analogy with opposite values to characterize wet periods.

3 Results

Fig. 3 shows the series of the contributing rivers and the total estimated at the confluence of these. It is possible to observe that the contribution of the Paraguay river is notably less than the total contribution of the rivers coming from Brazil

Then, the estimated monthly flow series upstream of the Corrientes station and the data series observed at this station are obtained (Fig. 4).

In general, the estimated series tends to underestimate the important peaks until the mid-90s and this can even be observed in the phase shift of the trend lines. From that time on, the peaks are slightly overestimated in several cases and the minimum values (valleys of the curves) are more intense with respect to the observed series.

It should be noted that the Yacyretá dam (Fig. 1) began to be built in 1983 and was put into operation at the end of 1994. Which would cause modifications in the behavior of the natural flow regime in the analyzed site. This change better shown in Fig. 5 (period 1956-1994) and Fig. 6 (period 1994-2022) where the trend changes from positive to negative. Also, in both cases the trend of the estimated series is slightly lower than the trend of the observed series.

This would indicate that natural flows present lower values than those regulated, marking the greatest probability of presenting dry cycles in the Corrientes station of the Paraná River.

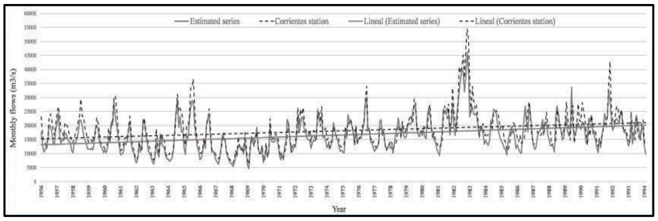

Figure 5. Flow series estimated at the upstream confluence and observed data series at the Corrientes station (1956-1994).
Source: Own elaboration

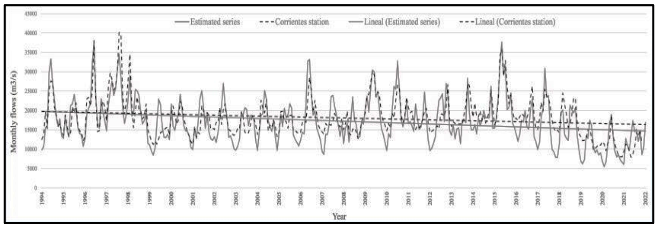

Figure 6. Flow series estimated at the upstream confluence and observed data series at the Corrientes station (1994-2022).
Source: Own elaboration

From this, the SDI indices are calculated with the estimated and observed data series for the analysis of dry and wet hydrological cycles (Fig.7). In addition, their 12-month moving averages are graphed and the lines of SDI 1.5 and (-1.5) are highlighted to facilitate the identification of severe or extreme events in wet and dry hydrological periods, respectively.

In the case of the characterization of the dry and wet periods with the SDI index, it is observed that both series present a similar behavior in their evolution over time, however, the estimated series would present more intense periods of drought, such as the years 1963-1964, 1967-1968 and 2019-2021.

In the case of excess water, the opposite happens. The maximum peaks of the estimated series present lower values than the observed series peaks, such as in the years 1982-1983, 1997-1998 and 2015-2016.

It should be noted that since the beginning of the 1980s the trend remained at normal to humid values until 2019. Then, it began to decrease noticeably.

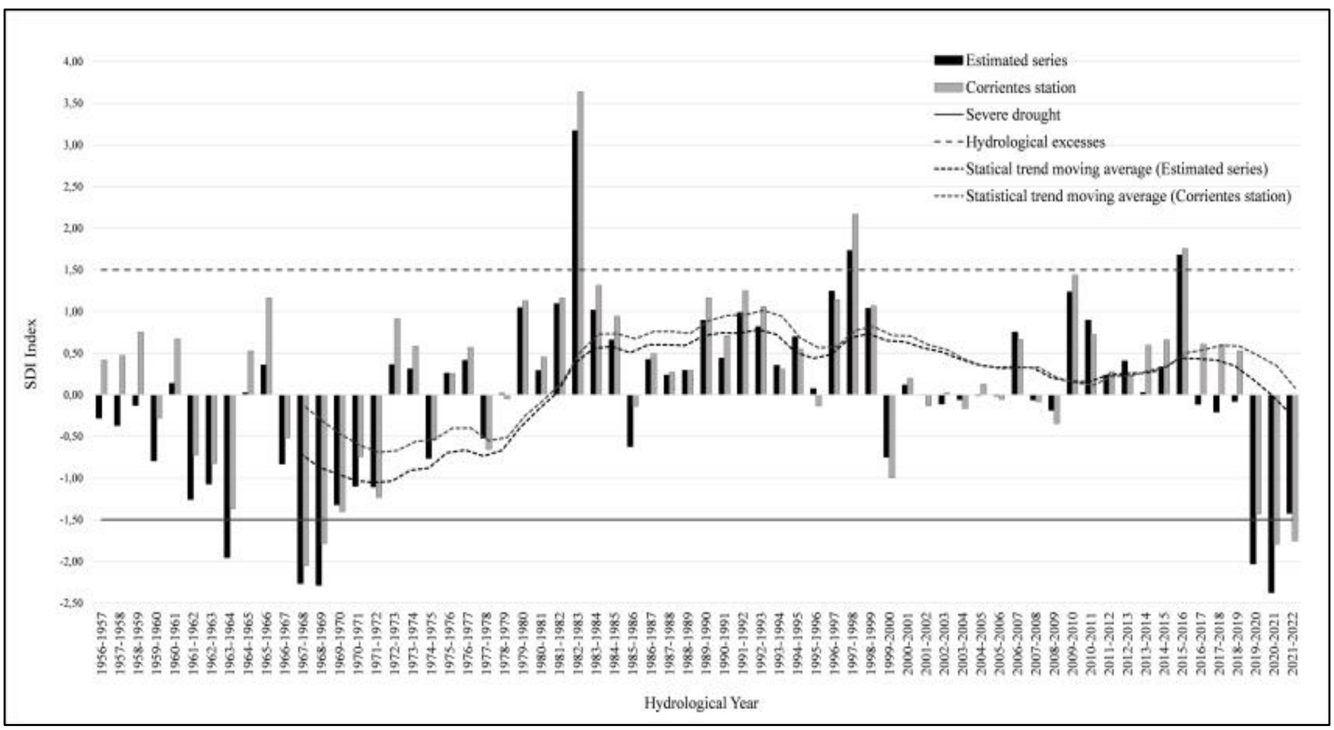

Figure 7. SDI indices of the estimated flow series at the upstream confluence and the observed flow series at the Corrientes station (1956-2022); their respective moving averages (12 months) and the lines of the indices representing excesses and severe droughts: 1.5 and (-1.5), respectively.
Source: Own elaboration

1 Conclusiones

It was possible to collect records in sections of the Paraná and Iguazú rivers (Brazil) and the Paraguay River in order to obtain a series of total flows at the confluence, upstream of the Corrientes station, which is adopted as a reference for subsequent comparison with the observed data series. This was done to analyze extreme hydrological events and periods and evaluate the possible influence of flow regulation and management during intense droughts and floods.

It was also observed that, in the absence of regulation, dry periods would likely be more intense, while periods of excesses would be less severe.

Years of extreme hydrological values were identified throughout the analyzed period.

It is worth noting that it is considered necessary to continue and expand this study from an integrated perspective of Water Resources; as well as to update it as the necessary records are obtained, allowing to advance in the understanding of extreme hydrological phenomena in the Paraná River basin, due to its regional importance.

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