



DOI: <https://doi.org/10.29298/rmcf.v12i65.873>

Article

## Reconstrucción dendrohidrológica de escurrimientos en la subregión hidrológica Coahuayana, estado de Jalisco

### Dendrohydrological reconstruction of streamflow on the Coahuayana hydrological sub-basin, Jalisco State

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#### Resumen

Se desarrolló una red dendrocronológica de coníferas para la región hidrológica Armería-Coahuayana en el sur de Jalisco. El análisis de componentes principales determinó que las cronologías poseen una respuesta climática común y se integraron en una cronología regional de madera temprana, tardía y anillo total con una longitud de 215 años (1800-2014) y un periodo estadísticamente confiable de 1860 a 2014, con fines de reconstrucción hidroclimática. La cronología regional de madera temprana mostró una respuesta significativa con los registros del gasto acumulado enero-junio ( $r = 0.70$ ,  $p < 0.01$ , 1952-2005) de la estación hidrométrica Quito, subregión hidrológica Coahuayana, Jalisco. Esta se utilizó para desarrollar una reconstrucción de flujo, la cual presentó alta variabilidad interanual y multianual de escurrimientos, en la que la sequía más extrema (1869 a 1876) puede considerarse como un período de escurrimientos con posibilidad de ocurrir en el futuro e implementar acciones de mitigación. La precipitación invierno-primavera y por ende los escurrimientos en la cuenca Quito evidenciaron influencia del fenómeno del Niño Oscilación del Sur, como lo indica su asociación con el índice SOI enero-junio ( $r = -0.47$ ,  $p < 0.01$ ) y picos significativos de 3.21 años, con el análisis espectral en la frecuencia de este fenómeno. Otros eventos circulatorios, como la Oscilación Decadal del Pacífico registró un efecto significativo, pero menor ( $r = 0.38$ ,  $p < 0.01$ ); mientras que, la influencia de la Oscilación Multidecadal del Atlántico no fue significativa.

**Palabras clave:** Coníferas, dendrohidrología, El Niño Oscilación del Sur, madera temprana, Región Hidrológica 16, sequías.

#### Abstract

A dendrochronological network of conifers was developed for the *Armeria-Coahuayana* basin in southern *Jalisco*. A principal component analysis showed a common climatic response among the chronologies, therefore, they were integrated into regional representative chronologies of earlywood, latewood and total ring width with a length of 215 years (1800-2014), where the confident period for hydroclimate reconstruction extended from 1860 to 2014. The earlywood chronology had a significant association ( $r = 0.70$ ,  $p < 0.01$ , 1952-2005) with the seasonal January-June gauged records of the *Quito* gage station located in the *Coahuayana* sub-hydrological region, *Jalisco*, and a streamflow model was developed for reconstruction purposes. The streamflow reconstruction showed high- and low frequency variability, where the extreme 1869-1876 drought could occur in coming years in order to take mitigation actions. The winter-spring streamflow in the *Quito* watershed is significantly influenced by the *El Niño* Southern Oscillation as corroborated by its association with the January-June SOI index ( $r = -0.47$ ,  $p < 0.01$ , 1952-2014). Its influence is verified with the significant peak (3.21) detected in a power spectral analysis for the earlywood-chronology. Circulatory phenomena as the Pacific Decadal Oscillation showed a significant but comparatively lower association ( $r = 0.38$ ,  $p < 0.01$ ) and the Atlantic Multidecadal Oscillation was not significant.

**Key words:** Conifers, dendrohydrology, *El Niño* Southern Oscillation, earlywood, Hydrological Region 16, droughts.

Fecha de recepción/Reception date: 25 de septiembre de 2020

Fecha de aceptación/Acceptance date: 28 de enero de 2021

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## Introduction

The demand for water resources in Mexico increases annually according to population growth (Conagua, 2018). This demand is not coupled with the supply of these resources, due to modifications in the hydrological cycle derived from changes in land use and global warming problems, which, according to general circulation models, will produce significant reductions in precipitation by 2030 (Riva, 2015). The volume of water *per capita* in the country has decreased; in 67 years (1950-2017), availability fell 79 %, from 17 742 to 3 656 m<sup>3</sup> inhabitant<sup>-1</sup> year<sup>-1</sup> (Conagua, 2018).

The quantitative assessment of water resources is a difficult task to complete, particularly from the limited network of climatic and hydrometric stations and their short length and quality of data, which limits making inferences about their historical behavior and trends. In this regard, tree rings constitute a high-resolution “proxy” to analyze the interannual and multiannual climate variability (Woodhouse *et al.*, 2006; Martínez-Sifuentes *et al.*, 2020), since, in their bands of annual growth, the prevailing environmental conditions during its development are recorded (Schweingruber, 1996).

Dendroclimatic reconstructions, particularly hydrological reconstructions in western Mexico, are very limited (Villanueva *et al.*, 2012; Cerano *et al.*, 2013), but show the potential for the development of extensive series, which can contribute to understanding the variability interannual and multiannual of the climate and the influence of climatic forces, which impact the availability of water resources for productive purposes and for human consumption (Villanueva *et al.*, 2017).

The production of water in the south-southwest portion of the state of *Jalisco* impacts the well-being of human settlements located in the border area of the states of *Jalisco*, *Colima* and *Michoacán*, which depend on the water produced in hydrological regions such as *Armería-Coahuayana* (INEGI, 1995; INEGI, 2000). In this way, the objective of the present study was to generate a network of series of growth rings distributed in the *Armería-Coahuayana* hydrological region (RH16) and to develop a reconstruction of the runoff produced in the *Coahuayana* basin of the state of *Jalisco*, whose volumes of flow are recorded at the *Quito* and *San Gregorio* hydrometric

stations. The hypothesis of the research is that the dendrochronological series in RH16 show a common climatic signal and that, when integrated into a series of regional growth, they will allow the estimation of flow volumes that occurred in this hydrological region to be extended into the past.

## Materials and Methods

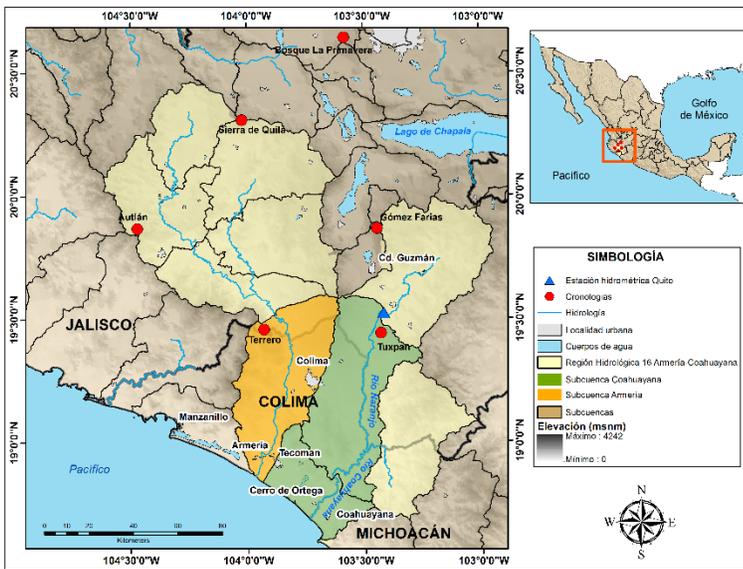
### Study area

The *Armería-Coahuayana* hydrological region is located in the south of the state of *Jalisco* in the *Eje Neovolcánico* and *Sierra Madre del Sur* provinces; in *Jalisco* it covers an area of 12 581.5 km<sup>2</sup>, which represents 15.70 % of the state's total. The region's climate is warm subhumid with subtypes AW<sub>0</sub> and AW<sub>1</sub> (w) summer rains (García de Miranda, 1989). Precipitation in the region varies from 800 to 1 200 mm per year, with an average temperature of 24 to 26 °C (INEGI, 2000). This hydrological region is made up of the *Coahuayana* and *Armería* rivers subregions, which drain into the Pacific Ocean.

The *Coahuayana* river subregion is made up of four hydrological basins, *Quito*, *Coahuayana-Jalisco*, *Coahuayana-Colima* and *Coahuayana-Michoacán* with a total area of 7 895 km<sup>2</sup>; it is located south of *Jalisco* and extends towards *Colima* and *Michoacán*. In the state of *Jalisco*, it covers an area of 4 487.6 km<sup>2</sup>, which is equivalent to 5.60 % of its surface. The precipitated volume in the *Coahuayana* basin is 3 383 million m<sup>3</sup> (Mm<sup>3</sup>), of which 281.0 Mm<sup>3</sup> drain (INEGI, 2000).

### Dendrochronological sampling and dendrohydrological reconstruction

For the generation of dendrochronological series, various sites were selected in coniferous forest communities, in the upper parts of the basins of the RH16, corresponding to the state of *Jalisco*; the selected sites were: *Autlán de Navarro* (AUT); *Gómez Farías* (GFA), *Sierra de Quila* (SQU), *Terrero* (TER), *Tuxpan* (TUX) and *Bosque La Primavera* (BLP) (Figure 1).



**Figure 1.** Distribution of sites sampled for the development of dendrochronological series in Hydrological Region 16 *Armería-Coahuayana* in the state of *Jalisco* (left) and site condition in a coniferous stand in *Bosque La Primavera* (right).

Sampling included several pine species, such as *Pinus douglasiana* Martínez (Pdou), *Pinus oocarpa* Schiede ex Schltdl. (Pooc), *Pinus devoniana* Lindl. (Pdev), *Pinus lumholtzii* B. L. Rob. & Fernald (Plum), *Pinus durangensis* Martínez (Pdur), *Pinus maximinoi* H. E. Moore (Pmax) and *Pinus pseudostrobus* Lindl. (Ppse), which makes it possible to capture more accurately the hydroclimatic variation that characterizes this area (Table 1).



**Table 1.** Geographic location of the collection sites and species sampled in the hydrological *Armería-Coahuayana* 16<sup>th</sup> region.

<b>Site</b>	<b>North latitude (degrees)</b>	<b>West longitude (degrees)</b>	<b>Altitude (m)</b>	<b>Species</b>
AUT	19.614	104.251	1 910	Pdou, Pooc, Pdev, Plum
GFA	19.869	103.395	2 202	Pdur, Pmax
SQU	20.300	104.064	2 029	Pdou
TER	19.457	103.929	2 401	Ppse
TUX	19.441	103.428	1 440	Pooc
BLP	20.645	103.586	1 821	Pooc

At each site, 30 to 50 trees were selected. The dendrochronological samples were obtained with a Pressler's bit and in each tree, two to three increment cores were extracted at breast height (1.35 to 1.40 cm). The number of total increment cores extracted per site was 90 for AUT, 87 for GFA, 130 for SQU, 90 for TER, 120 for TUX, and 150 for BLP.

The samples were processed according to conventional dendrochronological techniques (Stokes and Smiley, 1968) and with a Velmex measurement system, 0.001 mm precision (Robinson and Evans, 1980), measurements of both the total ring width were obtained. The dating quality was performed by using the COFECHA program (Holmes, 1983) and the total ring width, was standardized with the ARSTAN program, a negative exponential curve, positive, straight lines with negative or positive slope, and a spline that conserves 50 % of the variance (Cook, 1987), which produced three versions of the chronology, standard, residual and arstan.

In order to analyze the common variance between the dendrochronological series, a Principal Component Analysis (PCA) was run and based on the first principal component; the sites to be integrated into a measurement database were defined and a regional chronology was generated, where the useful length of the chronology for reconstruction purposes was determined based on the Expressed Population Signal (EPS) with a value  $\geq 0.85$  (Wigley *et al.*, 1984).

From the National Bank of Surface Water Data of the National Water Commission (Bandas), the records of the hydrometric stations present in the RH16 were downloaded with the following codes: 16041 *Quito* (18.525° N, 103.417° W), 6020 *El Nogal* (19.892° N, 103.8° W), 16021 *San Gregorio* (19.834° N, 103.35° W), 16031 *Canoas* (19.525° N, 103.884° W) and 16033 *El Rosario* (19.667° N, 103.992° W). The runoff volumes produced in the *Coahuayana* basin are recorded at the *Quito* and *San Gregorio* hydrometric stations; while the volumes of the *Armerías* river in the *Canoas*, *El Nogal* and *El Rosario* hydrometric stations.

The hydrometric records at the monthly and seasonal level were normalized by transforming them to base 10 logarithms and, later, they were compared with the regional dendrochronological series of earlywood, latewood, and total ring width in their standard and residual versions; this generated a model for an individual or combined hydrological station for the reconstruction of runoff volumes.

The available hydrometric records were calibrated both in the total length of the period and in two sub-periods, corresponding to half of the records; the verification was carried out in half of them, through the Library of Dendrochronological Programs of the University of Arizona (DPL), with the "Verify" subroutine.

The statistically calibrated and verified regression equation was used to reconstruct the seasonal runoff volumes, to which a flexible decadal spline was fitted to highlight low-frequency events (Cook and Peters, 1981).

The presence of years or periods with low or high seasonal runoff present in the reconstruction was determined based on the value of the median  $\pm 0.5$  of the

standard deviation, in which the values above this parameter are classified as wet events and underneath, as dry events.

The significant frequencies in the regional dendrochronological series and, therefore, in the runoffs, were calculated by means of a Power Spectral Analysis (Wilks, 1995), carried out with the Library of Dendrochronological Programs in "R", version 1.6.7 (Bunn *et al.*, 2018).

The interannual and multiannual variation of the climate in Mexico is influenced by various ocean-atmosphere phenomena. In this study, to determine the best relationship between the regional chronology of earlywood, latewood, and total ring width and ocean-atmosphere phenomena, the best association of these chronologies with indices of *El Niño* Southern Oscillation (ENSO, for its acronym in English) through the Southern Oscillation Index (SOI) reconstructed in the period from previous November to February of the current growth year (Stahle *et al.*, 1998) and the Multivariate Index (MEI) (Wolter and Timlin, 2011); as well as with indices of the Pacific Decadal Oscillation (PDO, for its acronym in English) (Mantua *et al.*, 1997) and the Atlantic Multidecadal Oscillation (AMO, for its acronym in English) (Enfield *et al.*, 2001).

The presence of wet and dry events in the reconstruction was verified with documented historical data of droughts, wet periods, food production and existing dendroclimatic reconstructions (Cerano *et al.*, 2013; Domínguez, 2016; Ortega-Gaucín, 2018; Villanueva *et al.*, 2018).

## Results

The extension of the dendrochronological series was different between sites, the most extensive of which was that of *Autlán de Navarro* (1800-2014) and the shortest that of *Terrero* (1935-2015). The intercorrelation between series exceeded the critical value of 0.328 ( $p < 0.01$ ) for an adequate dating and the average sensitivity indicates that the series have potential for hydroclimatic reconstructions (Table 2).

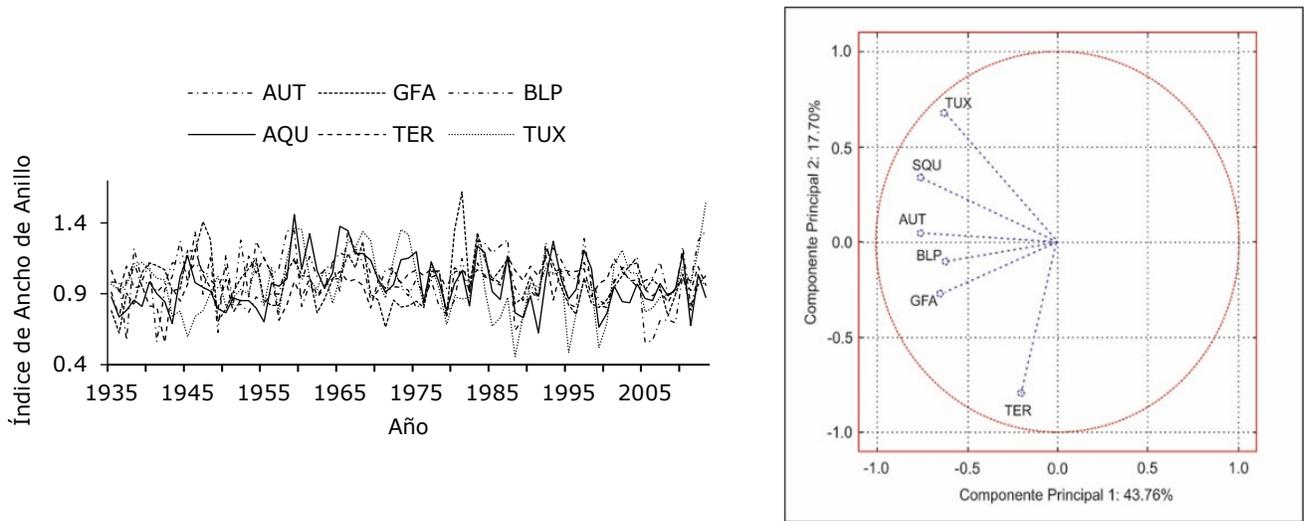
**Table 2.** Dendrochronological parameters and extension of the generated chronologies.

<b>Site</b>	<b>Species</b>	<b>Intercorrelation between series</b>	<b>Mean sensitivity</b>	<b>Extent</b>
AUT	Pdou, Pooc, Pdev, Plum	0.544	0.379	1800-2014
GFA	Pdur, Pmax	0.495	0.219	1880-2014
SQU	Pdou	0.420	0.305	1850-2013
TER	Ppse	0.537	0.342	1935-2015
TUX	Pooc	0.523	0.349	1867-2014
BLP	Pooc	0.506	0.401	1850-2014

The dendrochronological series show a similar behavior in the common period (1935-2013), when the greatest association was determined between the AUT and SQU sites (0.67,  $p < 0.01$ ) and was lower (0.35, 0.45) but significant ( $p < 0.01$ ) with the other chronologies.

The first component of the PCA explained 43.76 % of the total variance, with the AUT, GFA, SQU, TUX and BPL chronologies; while the chronology of the TER site showed greater variance in the second component (17.7 %) (Figure 2).



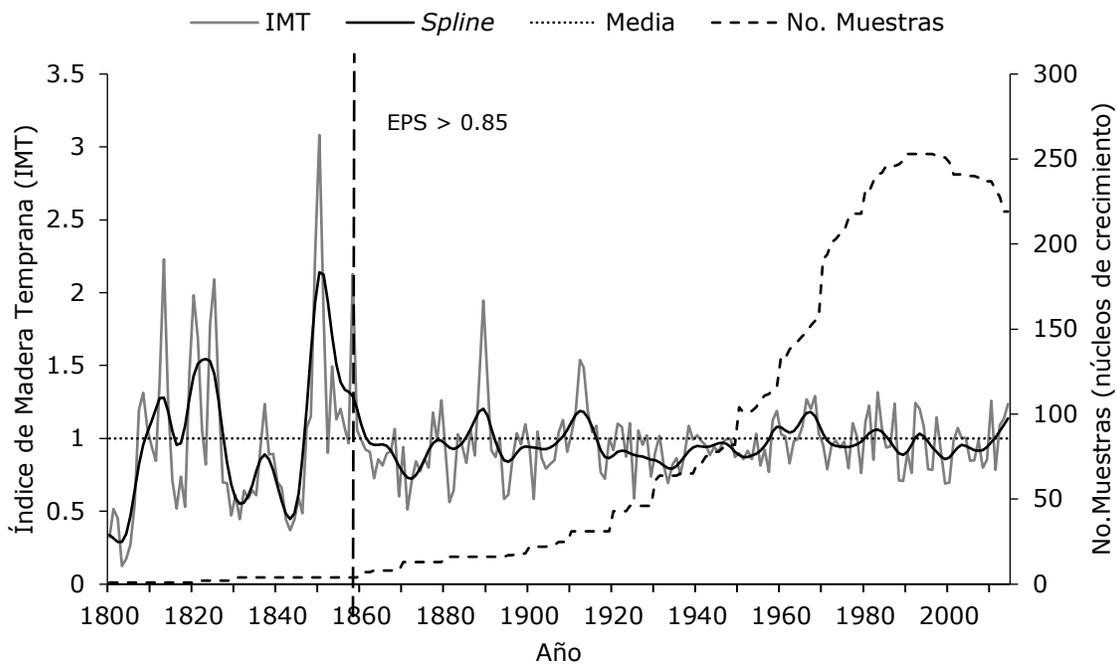


*Índice de Ancho de Anillo* = Ring Width Index; *Año* = Year; *Componente Principal* = Principal Component.

**Figure 2.** Interannual behavior of the growth indices of the total ring series for the common period (1935-2013) (left) and behavior of the series when analyzed using Principal Components (right).

The integration of the original measurement bases of these sites, excluding the chronology of the TER site, resulted in a time series of 215 years (1800-2014), in which the period with a significant Expressed Population Signal ( $EPS \geq 0.85$ ) was from 1860 to 2014 (155 years) with more than seven radii, so for runoff reconstruction purposes it was the period considered in the analysis (Figure 3).



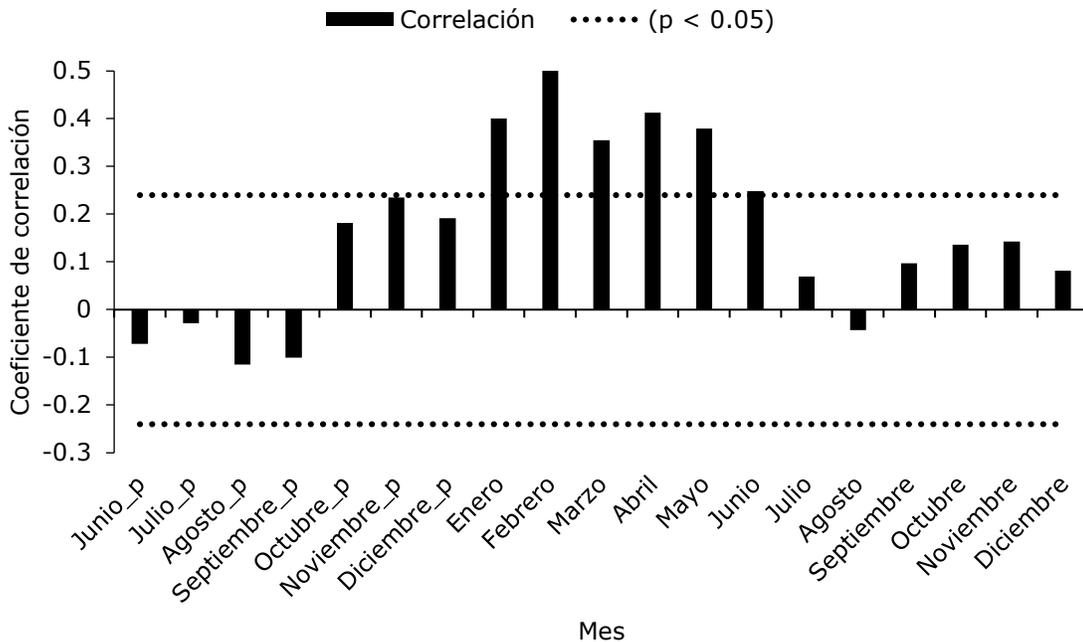


*Índice de Madera Temprana* = Early Wood Index; *No. Muestras (núcleos de crecimiento)* = No. Samples (growth nuclei); *Media* = Mean.

**Figure 3.** Regional early wood chronology, representative of the *Coahuayana* hydrological subregion.

The best response between the regional series of earlywood, latewood, and total ring width and the hydrometric data was between the early wood chronology and the gauged records of the *Quito* hydrometric station ( $r = 0.62$ ,  $p < 0.01$ ,  $n = 54$ ); Therefore, the dendrohydrological analysis was limited to this basin, whose hydrometric station registers 90 % of the annual runoff produced in the *Coahuayana* hydrological subregion of the state of *Jalisco*.

A more detailed analysis between the early wood series and the records from the *Quito* hydrometric station in the previous months from June to December and during the growing year (January-December), indicated that the monthly volumes from January to June had a significant association ( $p < 0.05$ ) with the early wood indices both, monthly and seasonally (Figure 4).



*Coeficiente de correlación* = Correlation coefficient; *Mes* = Month; *Junio* = June; *Julio* = July; *Agosto* = August; *Septiembre* = September; *Octubre* = October; *Noviembre* = November; *Diciembre* = December; *Enero* = January; *Febrero* = February; *Marzo* = March; *Abril* = April; *Mayo* = May.

Values above or below the dotted lines are significant ( $p < 0.05$ ).

**Figure 4.** Correlations between regional early wood chronology and monthly hydrometric records from the *Quito* hydrometric station.

When considering the accumulated January-June flow of the 1952-2005 period, the association increased to 0.62 ( $p < 0.01$ ) and when normalizing the accumulated flow with  $\log_{10}$ , the correlation reached 0.70 ( $p < 0.01$ ).

The results of the model calibration process were significant ( $p < 0.01$ ), both in the total period of records (1946-2005,  $r = 0.70$ ,  $p < 0.01$ ,  $n = 54$ ) that explains 50 % of the variation in runoff, as in the sub-periods 1946-1974 ( $r = 0.64$ ,  $p < 0.01$ ) and 1975-2005 ( $r = 0.74$ ,  $p < 0.01$ ). The verification process in both subperiods was significant for various statistical tests such as

correlation, sign test, "t" test and first significant difference. The subperiod from 1975 to 2005 was used to generate the reconstruction model, which was the following:

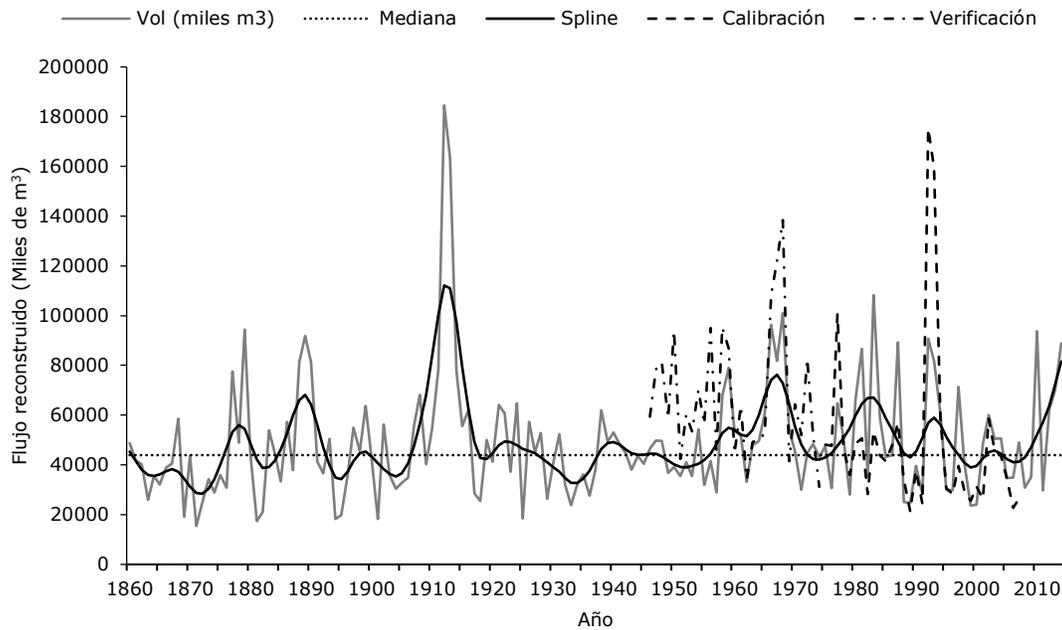
$$Y_i = 3.6489021 + 1.0514014X_i$$

Where:

$Y_i$  = Seasonal January-June volume reconstructed in  $\log_{10}$

$X_i$  = Index of regional early wood chronology standard version

The annual values in  $\log_{10}$  were transformed to metric units to obtain volumes in thousands of  $m^3$  (Figure 5).



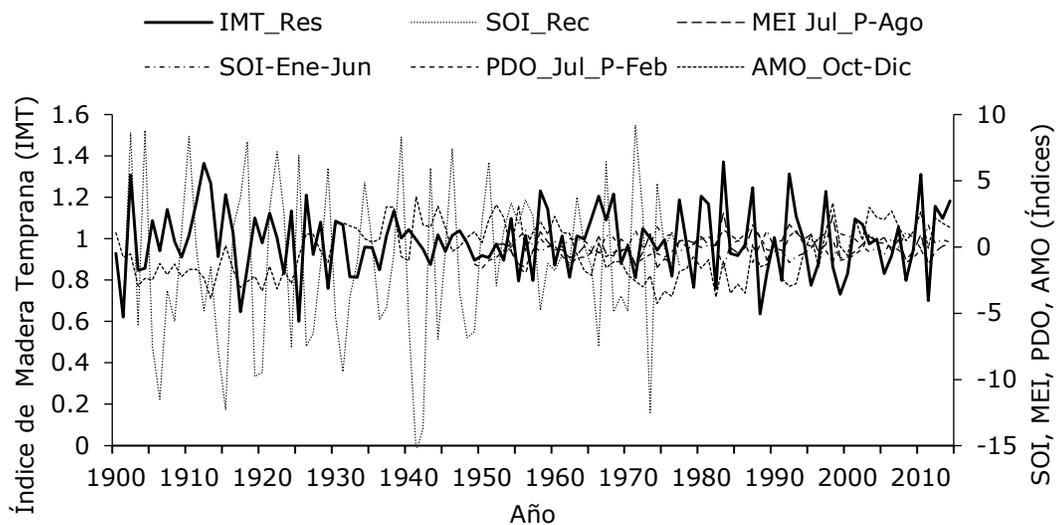
*Flujo reconstruido (Miles de  $m^3$ )* = Reconstructed flow; *Año* =Year.

The dashed lines represent the hydrometric records used for the calibration test (1975-2005) and verification (1946-1974) of the reconstruction model.

**Figure 5.** Reconstructed seasonal volume January-June for the Quito basin in the *Coahuayana* hydrological subregion, *Jalisco* state.

Based on the reconstructed median and considering as wet events the median  $\pm 0.5$  of the standard deviation (24039.4) for wet and dry events, respectively; the dominance of humid periods is observed. The longest droughts correspond to the periods 1861-1867, 1869-1876, 1903-1906, 1932-1937, 1949-1953 and 1988-1991, where the most severe drought occurred from 1869 to 1876; while some of the wettest events took place in the periods 1888-1890, 1910-1916, 1980-1981, 1983-1984, 1992-1994 and 2012-2014.

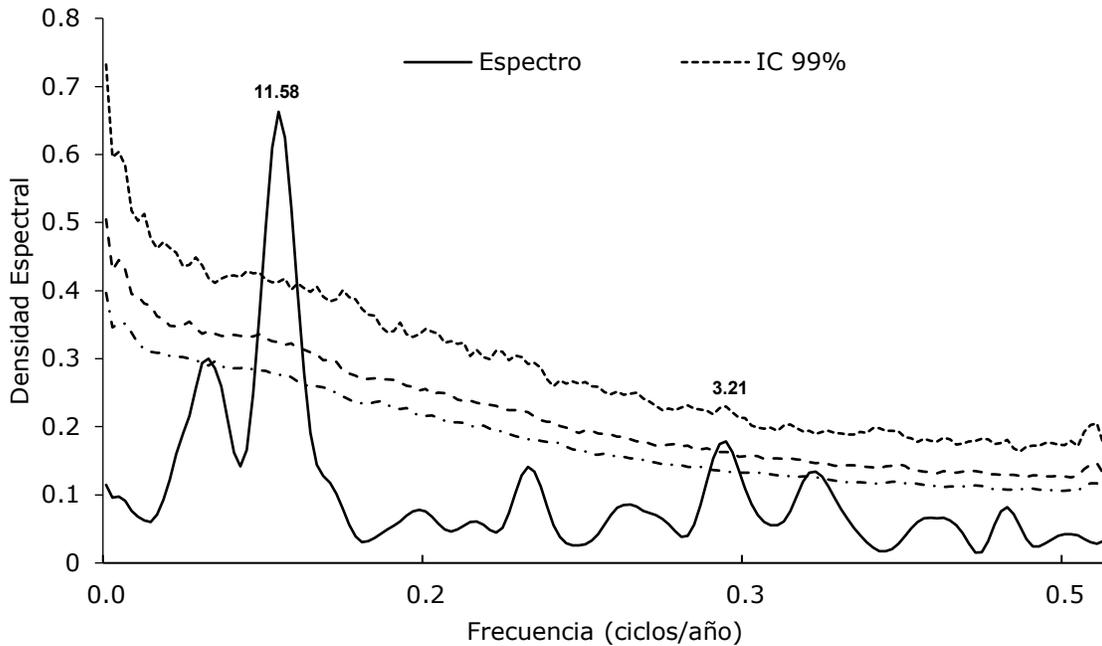
The greatest influence of atmospheric phenomena in the regional growth series on the variability of the climate of this region is attributed to the ENSO phenomenon during the winter-spring and early summer period, when the regional early wood chronology registered a correlation of  $-0.47$  ( $p < 0.01$ , 1952-2014) and  $0.43$  ( $p < 0.01$ , 1953-2014) with the SOI and with the MEI in the January-June and November-July periods, respectively; A significant association was also observed with PDO in the seasonal July-February period ( $0.38$ ,  $p < 0.01$ , 1949-2011), but the correlation with AMO indices was not significant ( $p > 0.05$ ) (Figure 6).



*Índice de Madera Temprana* = Early Wood Index; *Año* = Year.

**Figure 6.** Behavior of the circulatory phenomena indices (ENSO, AMO, PDO) in regard to the early wood index (dark solid line), representative of the *Quito* hydrological basin, *Coahuayana* hydrological subregion.

The power spectral analysis in the early wood regional growth series showed the presence of significant periodicities every 11.58 and 3.21 years (Figure 7).



*Densidad Espectral* = Spectral density; *Frecuencia* (ciclos/año) = Frequency (cycles/year).

**Figure 7.** Power spectral analysis for the regional earlywood series.

## Discussion

The individual chronologies of the total ring width were satisfactorily dated according to the intercorrelation between series (0.42 to 0.544), which exceeded the reference value (0.328,  $p < 0.01$ ); while the medium sensitivity (0.219 to 0.401) is considered adequate for hydroclimatic reconstruction purposes (Speer, 2010). Values similar to those of this study have been reported with *Abies guatemalensis* Rehder, *Abies Religiosa* (Kunth) Schldl. et Cham. and *Pinus strobiformis* Engelm. in *Michoacán* and *Oaxaca* (Carlón-Allende et al., 2018; Aquino et al., 2019).

Although the dendrochronological series were made up of various coniferous species, the association between chronologies was significant, with correlation values between 0.35 and 0.67, which implies the influence of climatic variables of regional impact and a similar response of the coniferous species in this region. The foregoing was corroborated with the Principal Component Analysis that integrated all the chronologies in the first component, except for the *Terrero* site, which despite correct dating, its interannual variability shows a different climatic signal, probably influenced by changes in the use of the soil (INEGI, 2000).

The integration of a network of dendrochronological series made up of various species has made it possible to analyze in various geographic regions of the continent, the reconstruction of drought indices (Cook *et al.*, 2010; Stahle *et al.*, 2016), ENSO indices (Stahle *et al.*, 1998) and flows in wide regions of North America (Woodhouse *et al.*, 2006; Anderson *et al.*, 2019) and Mexico (Villanueva *et al.*, 2017; Martínez-Sifuentes *et al.*, 2020).

The regional chronology of early wood registered a significant association with the accumulated volumes of the January-June period; this means that the precipitation that occurs in the winter, spring and early summer seasons, on which the drained volumes depend, defines the growth of early wood in western Mexico. Some studies have pointed out the effect of winter-spring precipitation conditions in explaining the growth of early wood and the total ring width in some conifer species from temperate forests of Mexico, such as *Pinus douglasiana*, *Abies religiosa* and *Pinus pseudotrobus* of Mexico (Cerano *et al.*, 2013; Carlón *et al.*, 2016).

The reconstruction of January-June runoff in the *Quito* basin, characterized by the dominance of wet periods derived from the presence of large-scale climatic phenomena (Stahle *et al.*, 2020), also suggests the presence of prolonged droughts in the XIX<sup>th</sup> and XX<sup>th</sup> centuries; thus, the drought from 1869 to 1876 affected the recovery of *Chapala* Lake (Villanueva *et al.*, 2012) and in 1866 and 1876, there was little clastic contribution (indicative of drought); as supported by a sediment study carried out in a lake in western *Jalisco* (Sosa-Nájera *et al.*, 2010); the same thing

was also detected in winter-spring precipitation reconstructions (January-May) for the *Sierra de Manantlán* and *Bosque La Primavera, Guadalajara, Jalisco* (Cerano *et al.*, 2013; Villanueva *et al.*, 2018). The droughts in this region of the country resulted in food shortages for the population of *Jalisco* and *Michoacán* (Escobar, 1997).

In the XX<sup>th</sup> century, the droughts from 1932 to 1937, 1949 to 1953 and 1988 to 1991 have been well documented in climatic, hydrological and dendroclimatic reconstruction records, both for their impact on food production and for their social and economic effect (Domínguez, 2016). The 1949-1953 drought was the most severe of the XX<sup>th</sup> century in northern Mexico and southwestern United States of America (Seager *et al.*, 2009), which is reflected in reduced runoff in the *Conchos* basin (Martínez-Sifuentes *et al.*, 2020) and its effect is also corroborated in southern *Jalisco*.

The drought from 1869 to 1876, present in other precipitation reconstructions (Cerano *et al.*, 2013), has no precedent in the hydrological records of the *Quito* hydrometric station, and although the water availability in this basin does not seem to be limiting for productive purposes, a low availability of water can affect ecological processes of the forest and riparian ecosystems of this region, as well as for irrigation purposes; therefore, it is important to consider these events and design water management plans to mitigate their effects. Among them we can mention the modernization of irrigation in irrigated areas, use of species with less water requirement, sustainable management of the forest that favors hydrological stability, among other conservation actions.

The wet periods detected in the reconstruction are similar to those registered for the *Sierra de Manantlán* (Cerano *et al.*, 2013) and implied greater runoff entries to *Chapala* Lake, such as the periods 1877-1879, 1938-1942, 1963- 1970 and 1992-1994 (Villanueva *et al.*, 2012).

Phenomena of general circulation that show an impact on the climate of Mexico are ENSO, AMO and PDO, but the degree of influence is different in each of the regions of the country (Stahle *et al.*, 2011). ENSO, through its tele-connections, is the phenomenon that most impacts the climate of Mexico (Magaña *et al.*, 1999; Stahle *et al.*, 2016). In the northern region of the country, the warm phase of this

phenomenon (*Niño*) increases precipitation in the cold season of the year, but inhibits it during the cold phase (*Niña*), which produces drought conditions and its effect is opposite in the central and southern Mexico (Méndez and Magaña, 2010).

In this study, the early wood series showed a correlation of -0.47 ( $p < 0.01$ ) with the January-June SOI and 0.43 with MEI, which corroborates that ENSO exerts a positive influence on precipitation and, therefore, favors the winter-spring runoff in the *Coahuayana* hydrological subregion of the state of *Jalisco*. The influence of ENSO in this region defined significant peaks of 2.21 and 11.58 years, in which the 2.21 years is included in the dominant frequencies of ENSO (Bruun *et al.*, 2017), while the 11.58 years may be associated with dominant frequencies of the PDO (Mantua and Hare, 2002).

In regard to the PDO, the positive association between the previous July to February of the current growth years assumes that this phenomenon affects runoff in the study region, although its effect is more noticeable in northern Mexico in the winter and in the summer (Méndez *et al.*, 2010), when it behaves in phase with ENSO (Méndez and Magaña, 2010). The influence of AMO was not significant as described for other regions of Mexico (Stahle *et al.* 2020). The positive influence of ENSO and PDO has not been studied for this region of the country and the physical process that may originate this behavior is unknown; ENSO-AMO interaction studies have been referred to the *Yucatán* peninsula, where droughts coincide with the cold AMO phase in periodicities of 10 years (Mendoza *et al.*, 2007).

## Conclusions

The development of a dendrochronological network and integrated into a representative chronology of the *Armería-Coahuayana* hydrological subregion, made up of several conifer species, showed a common climatic response, which provides an option to extend the understanding of interannual hydroclimatic variability over time and over the years.

Of the dendrochronological series of early, late and total ring width, early wood responds with the greatest significance to the runoff accumulated in the winter-spring and early summer seasonal period, which implies that the precipitation of this period and its direct relationship with runoff has the greatest influence upon the annual increment of early wood from conifers in this hydrological subregion.

Of the ENSO, PDO, AMO (ocean-atmosphere phenomena), ENSO is the one that best explains the interannual and multiannual hydrological variability of the *Coahuayana* hydrological subregion.

### **Acknowledgements**

This study received funding from the projects Conacyt CB-2016-01-283134, "Mexican dendrochronological network: hydroclimatic and ecological applications"

### **Conflict of interest**

The authors of this article state that they have no conflict of interest of any kind with the institutions that financially supported the research.

### **Contribution by author**

José Villanueva Díaz: collection of dendrochronological material, data analysis and writing of the document; Aldo R. Martínez Sifuentes: analysis of results and design of figures; Ernesto A. Rubio Camacho: site selection and sampling; Álvaro Chávez Durán: definition of sampling sites and material collection; Juan de Dios Benavides Solorio: definition of study sites and collection of dendrochronological material; Julián Cerano Paredes: collection and dating of samples; Juan Estrada Ávalos: collection and analysis of hydrometric data.

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