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Assessment the non stationary behavior in series of annual maximum flows by means of an econometric test

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ABSTRACT—In this paper we perform a mean analysis of variance time series for annual maximum flows in 20 gauged catchments of Mexico that do not satisfy tests of independence, homogeneity and trend. The unit root Augmented Dickey Fuller (ADF) test is a tool utilized in econometrics, and we applied here to find a relation between the transient behavior of the mean and variance of the time series against size for hydrological series samples. Only three of the 20 catchments are non-stationary, however, we can detect intercept start with an unexpected high value of the graph line mean against the series size. One of the conclusions of this paper is that among the largest series of data, for example, more than 30 years of records, it reduces the probability of non-stationarity also the magnitude of the slope of the trend line of the mean against the size of the time series does not allow to conclude on the non-stationarity of a given series, and the ADF test turned out of utility to define the transient behavior. Knowing the stationarity of time series in hydrology is important since it allows to define the type of statistical analysis that will be carried out.
Keywords—Annual maximum inflows, Augmented Dickey Fuller test, non-stationarity, homogeneity test.

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I. INTRODUCTION

The analysis of hydrological time series for annual maximum begins with the review of the independence of the series to verify that it is a random variable in time; in addition, homogeneity and trend tests are performed because the traditionally applied theories consider that data series are stationary in their mean and variance. Short-length records present conditions of significant variations in the mean and variance values over time, while some long records may present a clear tendency to increase or decrease the value of the historical mean in time, or well, in the first years it presents oscillations in the value of the average and then tends to a stable value when increasing the length of the record as the length of the record increases.

The collapse of the hypothesis of stationarity due to climate variability was addressed by Poveda and Alvarez 2012, López and Francés 2014. On the other hand, the possible effects of global warming on water resources have been the topic of many recent studies, thus, detecting the trend and stationarity in a hydrologic time series may help us to understand the possible links between hydrological processes and global environment changes.(W. Wang1,2005) Non-stationarity tests, such as unit root tests, based on hypothesis test, such as that of Dickey Fuller, Dickey Fuller Augmented (UAM 2004, Van Gelder et al. 2007, Rutkowska and Ptak 2012, Khalili et al. 2013), help to identify the type of annual time series and to decide if a traditional frequency analysis is sufficient or if distribution functions need to be considered with non-stationary parameters (López and Francés 2013, Tramblay et al. 2013, Alvarez and Escalante 2016). Non-stationarity studies applied to underground and surface hydrology data as well as climatic variables have been carried out in countries of the European Union, Asia (Graf, 2015, Graf, 2018, Chen et al.,

2018) but few studies have been conducted in American countries (Guevara et al., 2010, Díaz and Guevara, 2016, Ruiz and González, 2017) and there are few who give more details of the test used and the delay times considered; a case that does comment on some discrepancies in the results of non-stationarity with respect to what can be observed from the behavior of the data over time is that of Tadesse et al., 2017.

The aim of this study is to analyze the non-stationarity test of time series for annual maximum flows in 20 stations located in Northwest Mexico, we obtained correlograms and used unit root Dickey Fuller Augmented test, commonly applied in econometric studies, and of not extended use in hydrological time series in America, using EViews® software. The total series, although not all the series meet the homogeneity and trend tests, only four were non-stationary when the test was applied only to the constant (intercept) and when the test was applied to both the constant and the trend (trend and intercept) were only 3 non-stationary, according to the test applied. Mean behavior and time variance in analyzed series was drawn to look for behavior patterns of these statisticians in the non-stationary case.

II. METHODOLOGY

A. Non-stationary series

An autoregressive series of order one AR (1) has the form

$$y_t = \rho y_{t-1} + \mu + \epsilon_t \quad (1)$$

Where y_t and y_{t-1} are the values of the variable and at times t and t-1; ρ y μ are parameters to be estimated and ϵ_t is the supposed white noise. If $|\rho| \geq 1$ is a non-stationarity series and the variance of y_t increases with time and approaches an infinite value. If $|\rho| < 1$, it is a stationary series. Thus, the hypothesis of tendency to stationarity can be evaluated by testing whether the absolute value of ρ is strictly less than one (EViews 2017).

B. Dickey Fuller Test

Traditional Dickey Fuller test (Dickey and Fuller 1979) is performed using a modified version of equation 1 by subtracting the value y_{t-1} on both sides of the equation, defining the increase Δy_t:

$$\Delta y_t = \alpha y_{t-1} + \mu + \epsilon_t \quad (2)$$

Where $\alpha = \rho - 1$. The null and alternative hypotheses can be written as follows

$$H_1: \alpha = 0$$
$$(3)$$
$$H_0: \alpha < 0$$

and they are evaluated using the conventional parameter t_α for α:

$$t_\alpha = \hat{\alpha}/(se(\hat{\alpha})) \quad (4)$$

Where $\hat{\alpha}$ is the estimator of α, and $se(\hat{\alpha})$ is the standard error coefficient (estimate standard deviation)

More recently, (MacKinnon 1996) performed a larger set of simulations than those tabulated by Dickey and Fuller. Additionally, MacKinnon estimated the response surfaces for the simulation results, allowing the calculation of Dickey-Fuller critical values and ρ values for arbitrary sample sizes. The Simple Dickey-Fuller unit root test described is valid only if the series is an AR (1) process. If the series is correlated in larger lag orders, the assumption of white noise disturbances ϵ_t is violated.

C. Augmented Dickey Fuller (ADF) Test

Augmented Dickey-Fuller (ADF) test performs a parametric correction for high order correlations assuming that the series follows an AR (ρ) process and adding a lag ρ of the dependent variable and to the right side of the test regression:

$$\Delta y_t = \alpha y_{t-1} + \mu + \beta_1 \Delta y_{t-1} + \beta_2 \Delta y_{t-2} + \cdots + \beta_\rho \Delta y_{t-\rho} + \upsilon_t \quad (5)$$

Where: $\beta_1, \beta_2, ..., \beta_\rho$ are constant coefficients that affect the increments of the variable y_t until a lag ρ and υ_t it is the residual.

Above equation is used to test equation (3) using the parameter t obtained with equation (4). An important result obtained by Fuller is that the asymptotic distribution parameter t for α is independent of the number of early lagged differences included at Augmented Dickey-Fuller regression (ADF). In addition, while the assumption that an autoregressive process (AR) may appear restrictive, Said and Dickey (1984) demonstrated that the ADF test is asymptotically valid in the presence of a moving average component (MA), preventing them from being included in the regression sufficient terms of lag differences (EViews, 2017).

When the parameter t of the ADF test results within the acceptance zone of the alternative hypothesis (e.g. at 5% level of significance) the non-stationary assumption is accepted, and the probability is commonly greater than 0.05. When the probability of the non-stationary hypothesis being accepted is zero and t is out of the confidence interval, then the series is stationary. It is important to verify that there is no autocorrelation in the series, for the verification this condition, Durbin-Watson test (Campos-Aranda 2011) is used, if this parameter is between the values of 1.85 and 2.15 there is no autocorrelation in the series and the lag times in the models proposed by the ADF test can be considered; otherwise, a lag time must be given manually to re-test and verify the non-stationarity of the series.

D. Homogeneity test

Helmert test: This test consists of analyzing the sign of the deviations of each event under study with respect to its mean. If a deviation of a certain sign is followed by another of the same sign is said to form a sequence, otherwise a change of sign is considered. The series is homogeneous if it satisfies the condition (Campos 1998):

$$-\sqrt{n-1} \leq (S-C) \leq \sqrt{n-1} \tag{6}$$

where n is the size of the series, C is the number of sign changes and S is the number of sequences.

Student's test: This test To verify if there are significant changes at series mean, the Student's t test is used.

If a series Q_i for i=1, 2…, n, is divided into two sets n_1 y n_2 both of size $n_1 = n_2 = n/2$, then statistic t_d for the homogeneity test is define by following expression:

$$t_d = \frac{\bar{x}_1 - \bar{x}_2}{\left[\dfrac{n_1 S_1^2 + n_2 S_2^2}{n_1 + n_2 - (\frac{1}{n_1} + \frac{1}{n_1})}\right]} \tag{7}$$

where $\bar{x}_1$ y S_1^2 are the mean and variance of the first part of the record, $\bar{x}_2$ y S_2^2 are mean and variance of the second half of the record.

The absolute value of t_d is compared against the two-tailed Student's t distribution, and with $v = n_1 + n_2 - 2$ degrees of freedom for a significance level of α = 0.05. If and only if the absolute value of t_d, greater than that of the Student t distribution, we conclude that the difference between the means shows inconsistencies and therefore the series Q_i is considered non-homogeneous.

Other hypotheses of homogeneity are those of Cramer, Pettitt, standard normal, Buishand, Von Neummann, Fisher, whose detail can be consulted in Pérez (2017), Pettitt (1979), Alexandersson (1986), Alexandersson and Moeberg (1997), Buishand (1982), García (2013).

E. Trend test

Spearman test

Spearman's rank correlation coefficient is a non-parametric measure of correlation – that is, it assesses how well an arbitrary monotonic function describes the relationship between two variables without making any other assumptions about the particular nature of the relationship between variables (Maritz 1981). The spearman's rank correlation coefficient is calculated by Equation 8 (Gao et al. 2010):

$$R_s = 1 - \frac{6\sum_{i=1}^{N} d_i^2}{n(n^2-1)} \tag{8}$$

where n is the original size of two data series x, y which are converted to N ranks x_i, y_i, and the differences $d_i = x_i - y_i$ between the ranks of each observation of the two variables are calculated. This test is typically used to determine whether the two measurement variables are correlated; i.e. whether, as one variable increases, the other variable tends to increase or decrease. It is a non-parametric alternative to correlation, and it is used when the data do not meet assumptions regarding normality, homogeneity and linearity. Spearman's rank correlation is also used when one or both of the variables consist of ranks.

Null hypothesis of the Spearman's rank test is (Gao et al. 2010):

Ho: The rank of one variable does not covary with the rank of the other variable; in other words, as the rank of one variable increases, the rank of the other variable is not more likely to increase (or decrease).

Mann-Kendall test. Kendall (1938) proposed a measure tau to measure the strength of the monotonic relationship between x and y. Mann (1945) suggested using the test for significance of Kendall's tau, 453 where one of the variables is time as a test for trend. Spearman and Mann-Kendall test can be used in order to verify the trend of a time series; the procedure of its application is described in detail by Kendall and Gibbons (1990), Dahmen and Hall (1990), García (2013), Martínez et al. (2009), Hamed (2016).

The homogeneity and trend tests help to identify the stationarity of time series.

F. Anderson's independence test

Event independence test verifies that each sample data is the product of a stochastic process (Pérez 2017). To verify that sample data are random variables, Anderson independence test is used. This test makes use of the serial correlation coefficient r_k for different lag times "k".

Serial correlation coefficient is calculated with following expression (Escalante and Reyes 2005):

$$r_k = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(x_{i+k}-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \qquad (9)$$

For k = 1, 2, ..., $n/3$

95% confidence limits of r_k are calculated with

$$r_k(95\%) = \frac{-1 \pm 1.96\sqrt{(n-k-1)}}{n-k} \qquad (10)$$

Estimated values for r_k against the lag times k along with their corresponding confidence limits are plotted, this graph is called sample correlogram.

If less than values 10% r_k exceed confidence limits, sample is said to be independent, therefore, data are the product of a stochastic process. A time series correlogram example is shown in Figure 1.

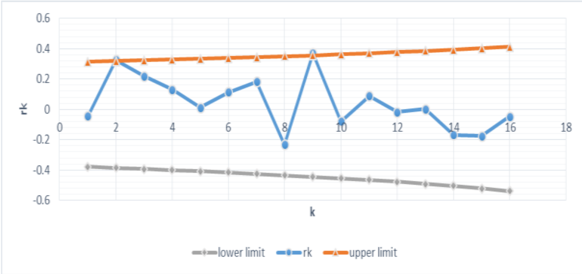


Figure 1. Time series correlogram example

III. RESULTS AND DISCUSSION

G. Mean and Variance

Twenty of fifty-four stations from the hydrological regions 9 to 13 located in northwestern Mexico (Figure 2) were selected from a regionalization study by Domínguez et al. (2017), which did not satisfy the tests of homogeneity, trend and independence (Table 1). The stations are characterized by having at least 20 years of records and are not affected by regulation caused by works upstream of them. When investigating which of those series are stationary or non-stationary, it helps for the frequency analysis to select between distribution functions commonly applied in hydrology or distribution functions with non-stationary parameters that depend on covariates.

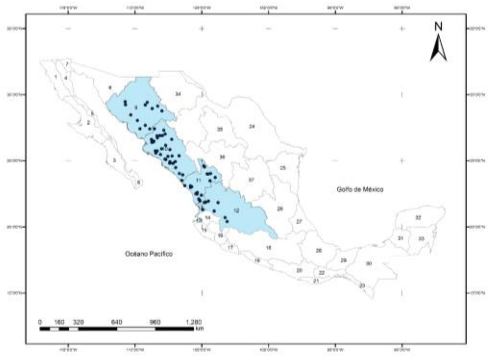


Figure 2. hydrological Location regions 9 to 13 in the Mexican Republic (National Water Commission)

TABLE I HOMOGENEITY, TREND AND INDEPENDENCE TESTS RESULTS. STATIONS FROM HR 9 TO 13, REGIONS AT MEXICO

Region	Station	Name	Number of years	Homogeneity tests								Trend tests		Independence	Final Criterion
				Helmert	t de Student	Cramer	Pettit	Standard normal	Buishand	Von Neumman	Fisher	Spearman	Mann Kendall	Anderson	
	9008	Tecori	23	X	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	9011	La Junta	65	X	X	X	X	✓	X	X	✓	✓	✓	✓	X
	9017	El Oregano	61	X	✓	✓	X	X	X	✓	✓	✓	✓	✓	X
	9067	San Bernardo	50	X	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓
	9068	Tezocoma	33	X	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
9	9080	Guapoca	45	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	9082	El Cubil	39	✓	X	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	9083	La Guadalupe	30	X	✓	✓	✓	✓	✓	X	X	✓	✓	✓	X
	9084	Paso De Nacori	46	✓	X	X	X	✓	✓	X	X	✓	✓	✓	✓
	9089	Cocoraque	20	X	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	9090	El Cajon	28	X	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	9093	Punta De Agua Ii	22	X	✓	✓	X	X	✓	X	✓	✓	✓	✓	X
	10027	El Bledal	57	X	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	10036	Jaina	62	X	X	✓	X	X	X	X	X	✓	✓	✓	✓
	10037	Huites	52	X	✓	✓	✓	✓	✓	X	X	✓	✓	✓	X
	10053	Alamos	18	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	10063	Batopilas	29	X	✓	✓	X	✓	✓	X	X	✓	✓	✓	X
	10064	Chinipas	33	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	10066	Choix	43	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	10070	Acatitan	46	X	✓	✓	X	X	✓	X	✓	✓	✓	✓	X
10	10079	Badiraguato	39	X	✓	✓	X	✓	✓	X	✓	X	X	✓	X
	10083	El Quelite	36	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	10086	Pericos	30	✓	X	X	X	X	X	✓	✓	X	X	X	X
	10087	Tamazula	34	X	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	10100	Urique Ii	30	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	10110	Toahayana	29	✓	X	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	10111	Piaxtla	52	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	10112	Guatenipa Ii	42	✓	X	X	X	X	X	X	X	✓	✓	✓	✓
	10113	La Huerta	30	✓	✓	✓	X	X	✓	X	✓	✓	✓	✓	✓
	10120	Guasave Puente Carretera	22	X	X	X	X	X	X	✓	X	✓	✓	X	X

TABLE II CONTINUATION

Region	Station	Name	Number of years	Homogeneity tests								Trend tests		Independence	Final Criterion
				Helmert	t de Student	Cramer	Pettit	Standard normal	Buishand	Von Neumman	Fisher	Spearman	Mann Kendall	Anderson	
11	11008	San Felipe	48	X	X	✓	X	X	X	X	✓	X	X	X	X
	11010	Refugio Salcido	54	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	11012	San Pedro	63	X	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	11014	Acaponeta	64	X	✓	✓	X	✓	✓	X	X	✓	✓	✓	X
	11016	Baluarte Ii	52	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	11023	Caboraca	38	X	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	11027	El Saltito	35	X	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	11030	El Bejuco	26	X	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	11035	La Ballona	47	X	X	X	X	X	X	✓	X	✓	✓	X	X
	11040	Vicente Guerrero	42	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	11042	El Pino	26	X	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
	11046	Rosa Morada	28	X	X	X	X	X	X	X	X	✓	✓	X	X
	11058	Siqueros	50	✓	✓	✓	X	✓	✓	X	X	✓	✓	✓	X
	11070	Las Tortugas	33	X	X	X	X	X	X	✓	✓	✓	✓	X	X
	11074	La Estancia	30	✓	✓	✓	X	X	✓	X	X	✓	✓	✓	X
	11075	Pajaritos	25	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	11080	Mezquital	20	✓	✓	✓	X	✓	✓	X	✓	✓	✓	✓	✓
12	12428	Bolaños	64	X	✓	X	✓	X	X	X	✓	✓	✓	✓	X
	12438	La Yesca	58	X	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	12514	El Caiman	54	X	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	12520	Huaynamota Ii	33	✓	✓	✓	✓	X	✓	X	✓	X	X	✓	X
	12693	El Carrizal	28	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓
	12733	Chapalagana	30	✓	✓	X	✓	✓	✓	X	✓	✓	✓	✓	✓
13	13002	El Refilion	32	✓	X	X	X	X	X	X	✓	✓	✓	X	X

Notes: ✓ Satisfies x Does not satisfy

To the selected series of Table 1 the mean and variance were calculated from two years of registration to the size of the sample, to observe tendencies to grow or to decrease by their statistics. (Figures 3 to 6); a summary of the slopes, intercept and the coefficients of determination were obtained in each case (Table 2).

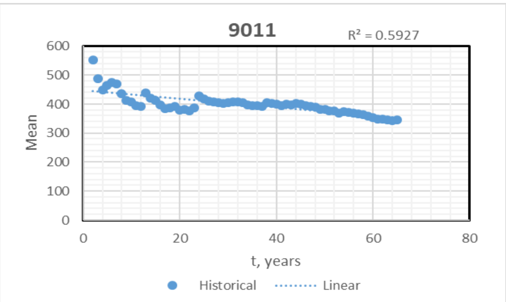
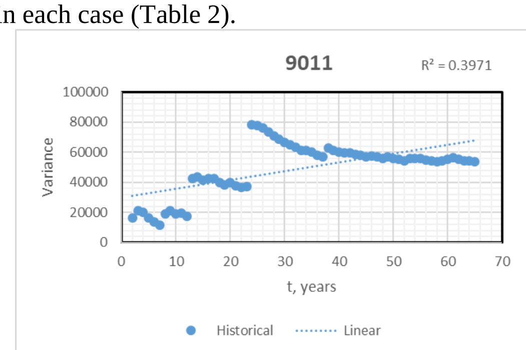


Figure 3. Mean behavior and variance according to the size of the series. HR 9.



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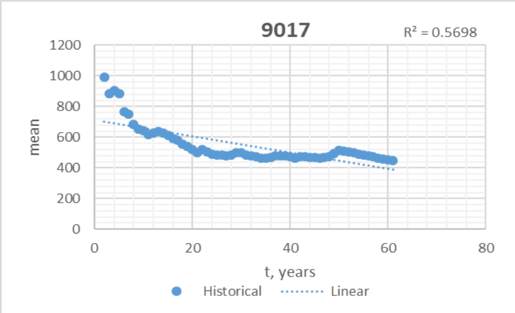

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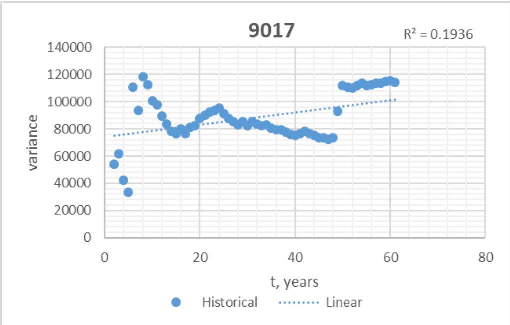

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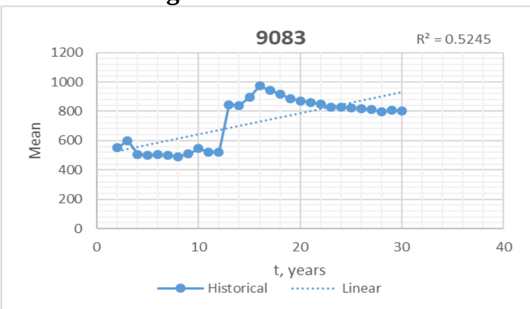

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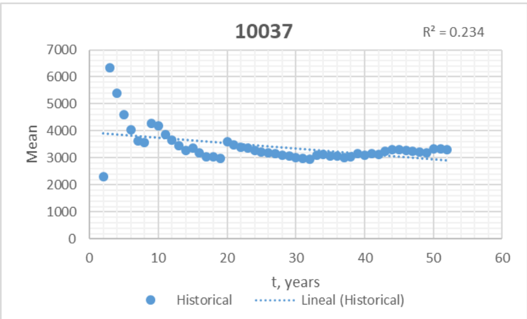
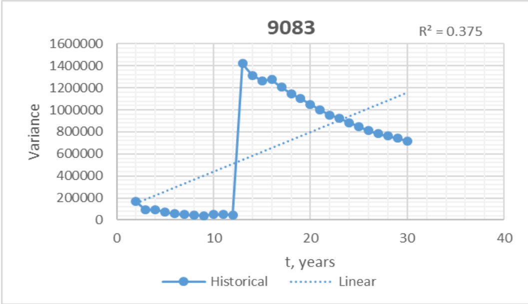


Figure 4. Mean behavior and the variance according to the size of the series. HR 10



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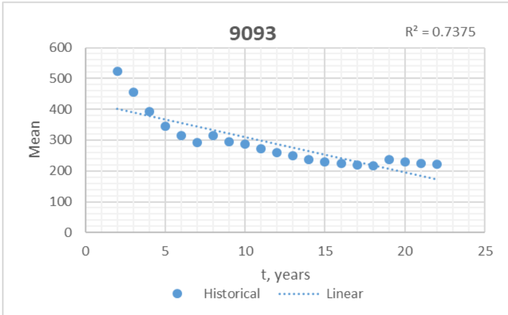

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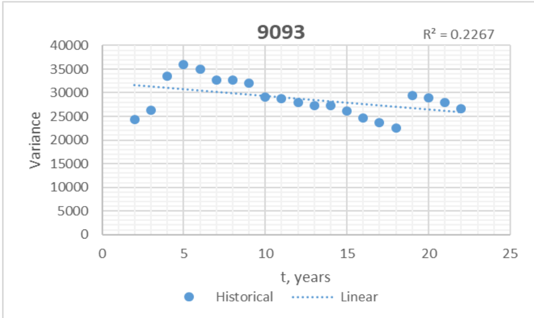

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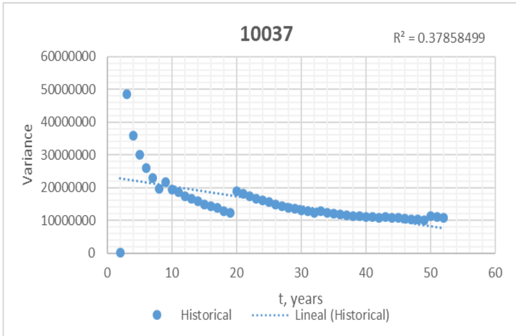

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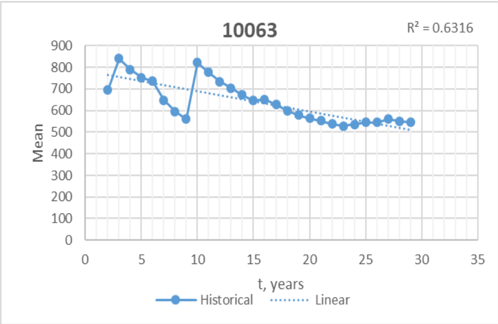

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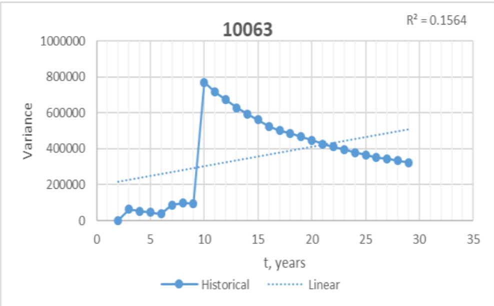

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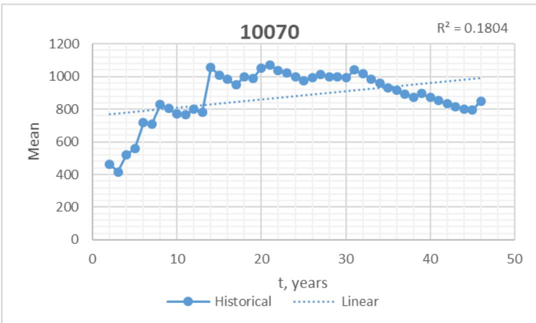


Figure 4. Continuation

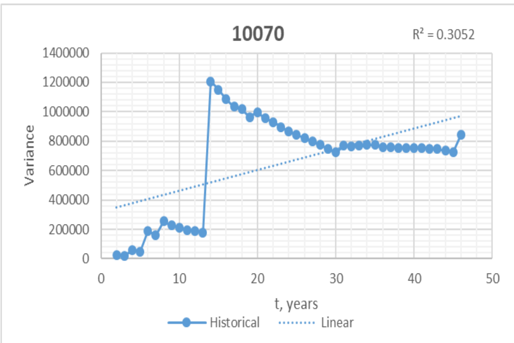
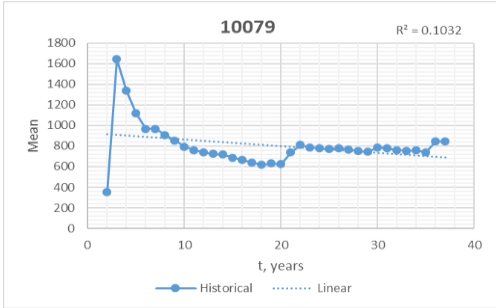


Figure 4. Continuation



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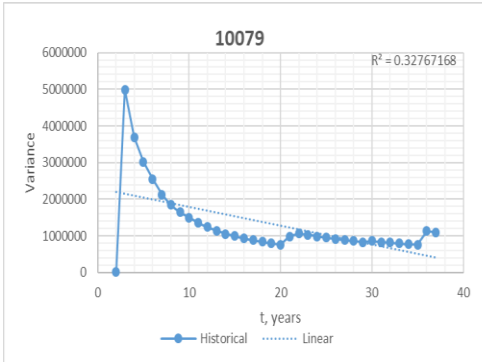

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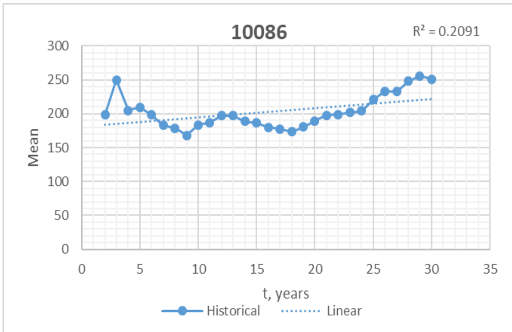
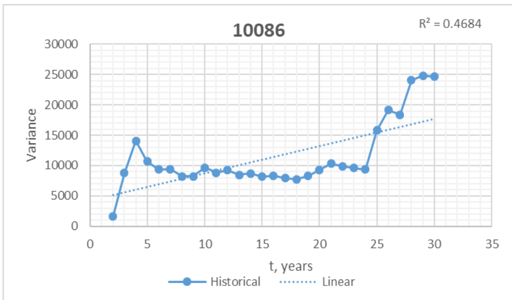


Figure 4. Continuation



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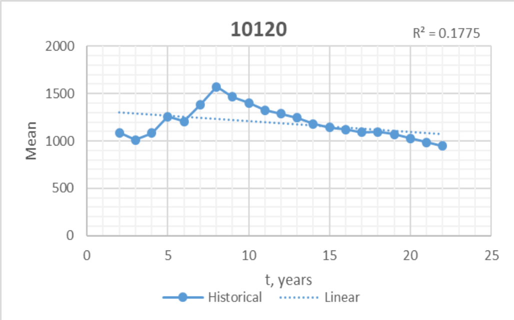


Figure 4. Continuation

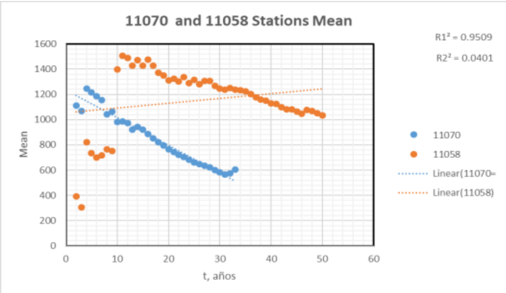
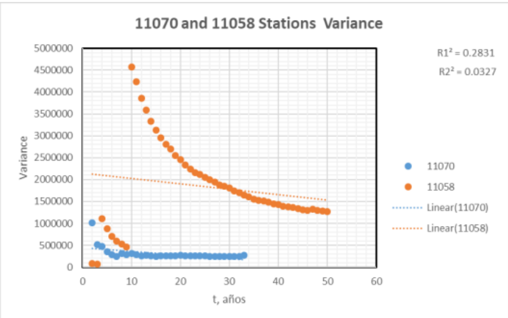


Figure 5. Mean behavior and variance according to the size of the series. HR 11



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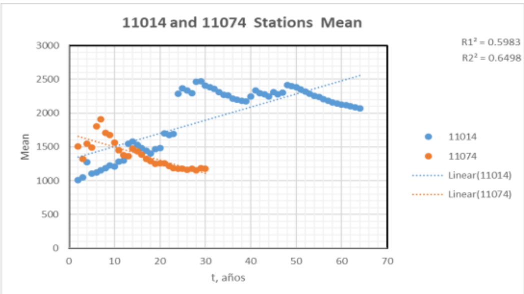

Figure 5. Continuation

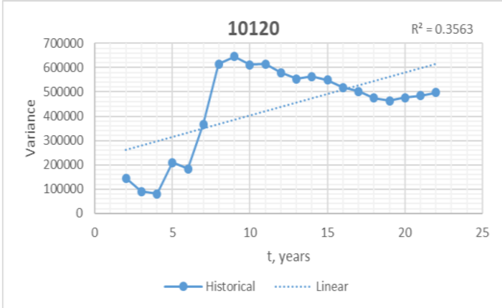

Figure 4. Continuation

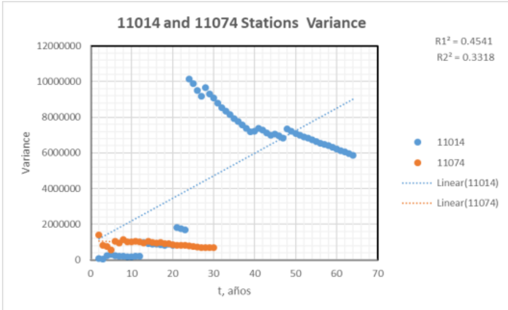

Figure 5. Continuation

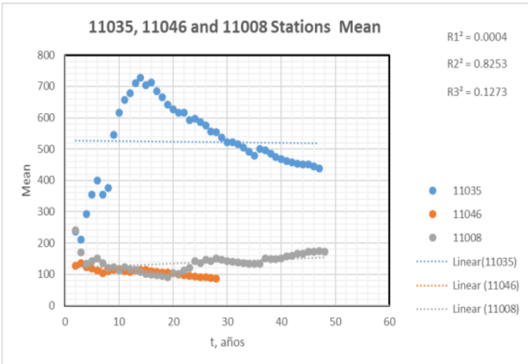

Figure 5. Continuation

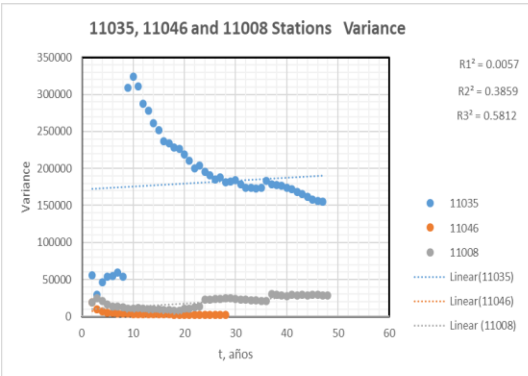

Figure 5. Continuation

From the observation of mean and the variance of the time series analyzed in general, it can be observed that as the number of records years increase, a tendency to constant mean values is noted in almost all the stations; however, the mean values seems to be non-stationary in stations 9093, 10063, 11035, 11058, 11070, 12428. For the variance we see more fluctuations in time and we found non-stationarity trends in almost all stations except for station 11070.

H. Augmented Dickey Fuller test (applied to the constant (intercept))

The Dickey Fuller unit root test was applied to 20 stations, which did not fulfill the tests of independence, trend and homogeneity, the EViews ® software was used for this purpose. A summary of probability results reported by this test is shown in Table 2. The detail of the Dickey Fuller test parameter for the non-stationary series (station 11046) is shown in Appendix 1.

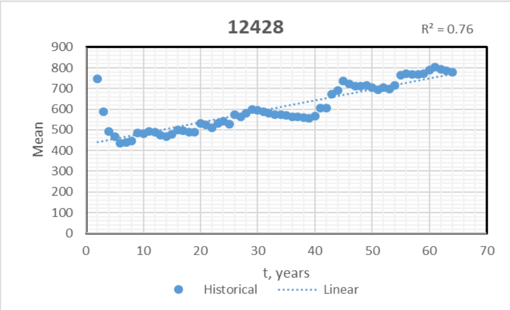

Figure 6. Mean behavior and the variance according to the size of the series. HR 12 y 13

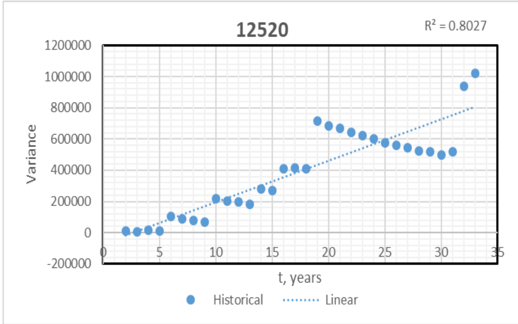

Figure 6. continuation

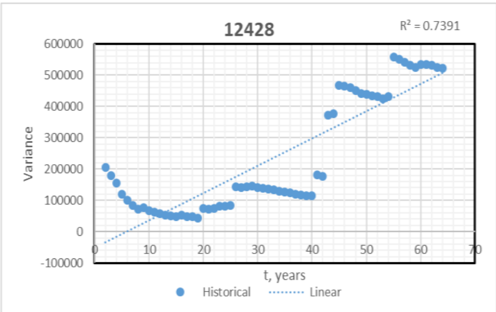

Figure 6. continuation

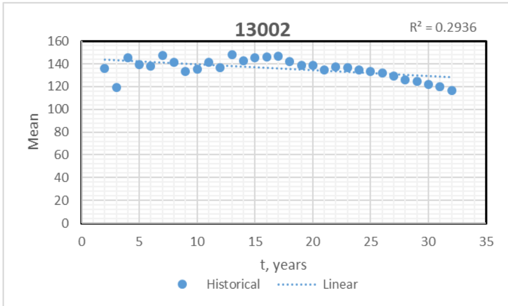

Figure 6. continuation

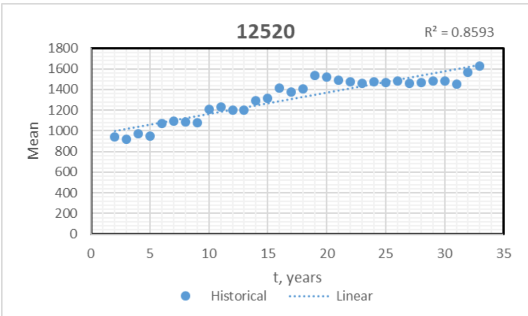

Figure 6. continuation

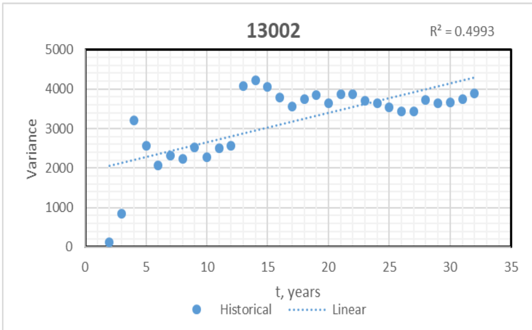

Figure 6. continuation

TABLE IIII RESULTS OF THE DICKEY FULLER TEST, SLOPE, INTERCEPT AND DETERMINATION COEFFICIENT TREND LINES FOR MEAN AND THE VARIANCE IN TIME. STATIONS HR 9 TO 13

No	key	Name	Number of years	Eviews ADF unit root probability	Stationarity	Mean vs number of years equation slope	intercept	R^2	Variance vs number of years equation slope	intercept	R^2
1	9011	La Junta	65	0	✓	-1.4847	448.64	0.5927	582.81	29811	0.3971
2	9017	El Orégano	61	0.0005	✓	-5.3611	714.93	0.5698	458.44	73883	0.1936
3	9083	La Guadalupe	30	0.0002	✓	14.467	497.99	0.5245	35727	82669	0.375
4	9093	Punta de Agua II	22	0.0015	✓	-11.445	425.19	0.7375	-286.54	32156	0.2267

5	10037	Huites	52	0	✓	-20.521	3961.3	0.234	-302964	23472651.94	0.3786
6	10063	Batopilas	29	0.0002	✓	-9.4103	785.17	0.6316	10878	195060	0.1564
7	10070	Acatitan	46	0	✓	5.126	756.84	0.18094	14137	322210	0.3052
8	10079	Badiraguato	39	0	✓	-6.4405	929.89	0.1032	50806.41	2294784.30	0.3277
9	10086	Pericos	30	0.0138	✓	1.3483	181	0.2091	450.93	4194.8	0.4684
10	**10120**	**Guasave PuenteCarretera**	**22**	**0.1092**	**x**	**-11.363**	**1325.7**	**0.1775**	**17657**	**227612**	**0.3563**
11	11035	La Ballona	47	0.0408	✓	-0.1873	527.26	0.0004	395.94	171624	0.0057
12	11014	Acaponeta	64	0	✓	19.508	1308.8	0.5983	126051	939105	0.4541
13	**11008**	**San Felipe**	**48**	**0.3431**	**x**	**0.722**	**119.83**	**0.1273**	**426.21**	**8985.2**	**0.5812**
14	**11046**	**Rosa Morada**	**28**	**0.9463**	**x**	**-1.3821**	**128.23**	**0.8253**	**-276.03**	**8264.5**	**0.3859**
15	11058	Siqueros	50	0.0016	✓	3.7549	1056.2	0.0401	-12437.02	2156653.38	0.0327
16	11070	Las Tortugas	33	0.0238	✓	-21.935	1236.1	0.9509	-8144.2	445500	0.2831
17	11074	La Estancia	30	0.006	✓	-19.484	1690.6	0.6498	-11834.14	1076268.67	0.3318
18	12428	Bolaños	64	0.0038	✓	5.3108	431.15	0.76	8722.9	-51739	0.7391
19	12520	Huaynamota II	33	0.0252	✓	20.661	958.16	0.8593	26590	-72006	0.8027
20	**13002**	**El Refilión**	**32**	**0.196**	**x**	**-0.5167**	**144.56**	**0.2936**	**74.5**	**1904**	**0.4993**

Results in Table 2 report that of the 20 stations, four are non-stationary (based on the ADF test); for these cases, the slopes of the lines drawn as trend line for the mean vs time are predominantly negative, except for station 11008, that resulted positive, single coefficient of determination R2 was high (0.8253 in the station 11046), the other coefficients are between 0.1 and 0.3. As far as variances were concerned, slopes were positive, except for station 11046 and coefficients of determination ranged between 0.4 and 0.6. These results do not correspond to the visual impression of behavior of means and variances, likewise in station 11046 a decrease in the maximum annual flow is observed in time and the analysis of the means with respect to the size of the sample (it was anticipated that there would probably be about six non-stationary stations but none of them is non-stationary, according to the ADF test).

For case of station 10120 it is observed that the Durbin-Watson statistic takes a value of 1.9942 which is in range of acceptance for not having autocorrelation in time series series[1.85,2.15] (University of Valladolid 2013), so the ADF test statistic is observed, which for the proposed model with a lag of one unit is -2.6969, which is greater than critical value with a confidence level of 5% (-3.01236) enters the acceptance range of the non-stationarity hypothesis, we also see that the probability of accepting the non-stationarity hypothesis is 0.1960 which is greater than 0.05, therefore, the series is non-stationary.

For the station 11008, the Durbin-Watson parameter indicates that there is no autocorrelation in the data for models with a lag up to three, the ADF parameter is in the acceptance zone of the non-stationarity hypothesis and the probability is higher than 0.05, so the series is not stationary.

For the station 11046, it is noted that test automatically considered models with a lag of six, it is also observed that there would be no autocorrelation with Durbin-Watson and the ADF parameter falls in the acceptance zone, in addition to having a high probability of acceptance for the alternative hypothesis, that is, not stationarity.

For the station 13002, the ADF test tested models with one-unit lag and the Durbin-Watson test gives 2.1671, i.e., it would indicate that there is autocorrelation in the data, reason why it is suggested to increase the lag to two, to verify if the series is or not stationary with that step. Similarly, at the station 13002 we can observe the same trend as at station 11046; this new test result is shown in Appendix 1. With this new test it is obtained that 13002-station series is non-stationary.

I. Correlograms

The correlograms of the original data of the 20 stations were obtained. As an example the correlogram for the station 11046 that resulted non-stationary is presented in Appendix 1.

Time series for stations that were non-stationary are shown in Figure 7.

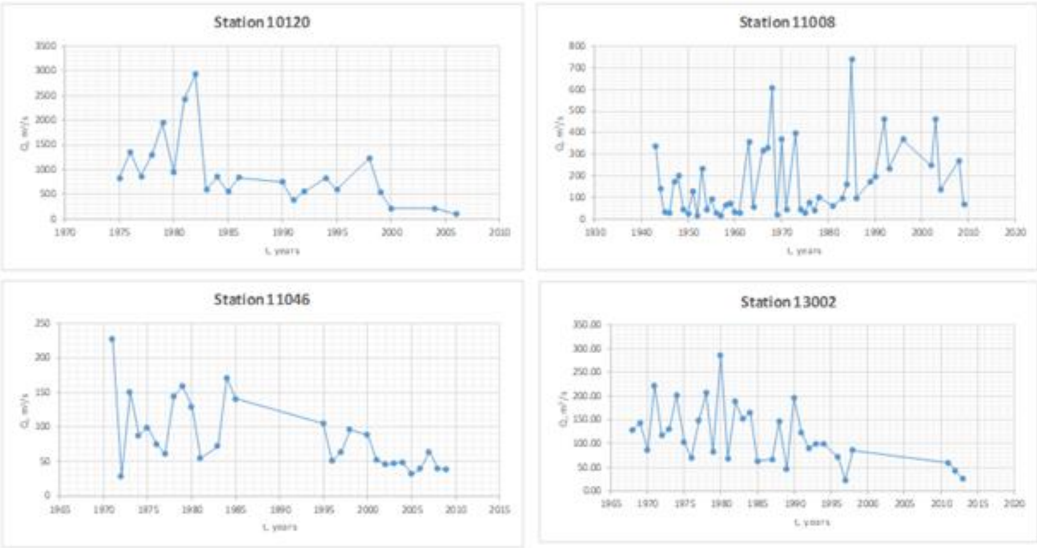

Figure 7. Non-stationary Series HR 10 a 13

Figure 7 shows more decreasing tendencies for annual maximum flows, but we have doubts of these tendencies are correct in stations 11046 and 13002. In these stations, a decrease in annual maximum flows can be seen from the nineties of the last century; this can be attributed to a change in water use in sites surrounding the rivers or to signs of climate change. The box plots of this two last stations are shown in Figure 8.

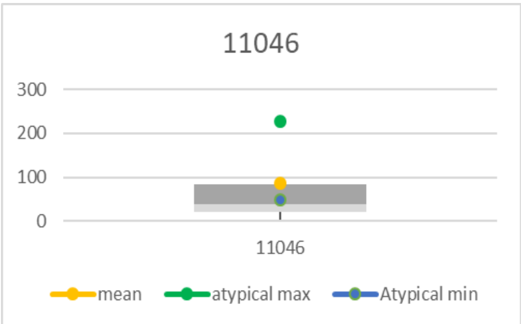

Figure 8. Box Plots. Stations 11046 and 13002

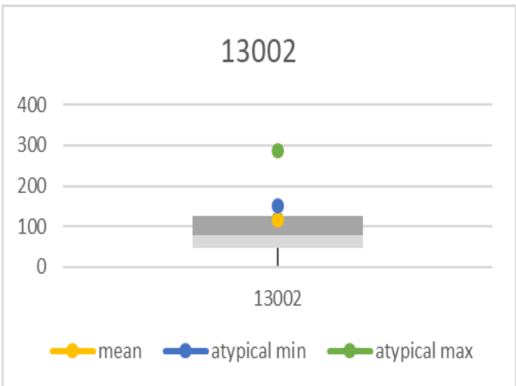

Figure 8. Continuation

In Figure 8 were added the values of the mean and of maximum and minimum atypical values that have historically been presented in stations 11046 and 13002, but there is no tendency for these outliers to have happened in recent years, that is, there are not enough elements to identify them as a result of climate change.

J. The Augmented Dickey Fuller test applied to the trend and constant (intercept)

University of Valladolid, 2013, recommends to perform the Dickey-Fuller test on both the constant and trend (when performing test again to four stations, but now considering the trend and constant, new results were obtained (in Appendix 1 is given the example for station 11046).

With this new test for the station 10120,it is observed that the Durbin-Watson statistic takes the value of 1.010 , is out of the region for autocorrelation approval[1.85,2.15] that is there is not autocorrelation in the data of series (University of Valladolid 2013), but the ADF test statistic is observed, which for the proposed model with a lag of one unit is -3.7199 that is lower than the critical value with a confidence level of 5% (-3.6445) of the range of acceptance of the non-stationarity hypothesis, and we see that the probability of accepting the non-stationarity hypothesis is 0.0434, is less than 0.05, therefore the time series is stationary. For station 11008, it is also observed that there is no autocorrelation by the value taken by the Durbin-Watson statistic, the program suggests models with lag up to nine units. Observing the value of the Dickey Fuller statistic of -3.2211, it is observed that it remains in the acceptance range of the unit root hypothesis (the critical value to accept the test at 5% is -3.5331) and the probability of 0.0956 that exceeds 0.05, therefore the series is non-stationary.

For station 11046, it is possible to have no autocorrelation with lag a lag of six, and Dickey Fuller statistic is in acceptance range of the unit root hypothesis (-2.519165) against critical value of -3.6450 and the probability is 0.3164 that exceeds 0.05 therefore the time series is non-stationary. Finally, for station 13002 it was found that there is no autocorrelation in the data, for lags of one unit, but the Dickey-Fuller statistic falls in the rejection range of the unit root hypothesis (-7.4975 versus the critical value at 5%, which is -3.5629), the unit root probability gives zero, so the null hypothesis is rejected and the time series is stationary. From the above results the conclusion is that only the stations 10120 and 13002 are stationary but according to Table 1 they do not satisfy the independence test then they are not considered as random variables.

IV. CONCLUSIONS

If we observed series behavior of annual maximum flows over time, as well as mean variation and variance statistics in time, it gives us a first impression of their tendencies, but they are not sufficient to obtain conclusions about the series stationarity. The ADF test (commonly applied in econometrics studies) it based on a method of hypothesis testing, turned out to be a useful tool to validate whether or not a given hydrological time series is stationary. By knowing the nature of the series, decisions can be made as to whether to make a frequency analysis using distribution functions with stationary parameters or to use distribution functions with parameters that depend on covariates. We can conclude that for the largest series of data, for example, more than 30 years of records, the probability of non-stationarity of the time series is reduced, also the magnitude of the slope of the trend line of the mean against the size of the series does not allow to conclude on the non-stationarity of a given series and ADF test turned out of utility to define the transient behavior of the time series.

The identification of the transient behavior of annual maximum runoff time series is useful information in studies that associate this pattern with the alterations that have been occurring in the climate, over time, both by natural mechanisms or human induced

Disclosure statement

The authors do not have any conflicts of interest.

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