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GEOSCIENCES

Comparison of stationary and nonstationary estimation of return period for sewer design in Antioquia (Colombia)

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Abstract: Estimating the probability of occurrence of extreme hydrologic events is a fundamental input in the design of hydraulic infrastructure. The classical approach to this problem has been to fit parametric probability functions to annual maxima streamflow data and use them to calculate the risk of failure. An underlying assumption of this approach is the stationarity of the time series. However, the stationarity of streamflows may not hold due to the effect of land cover change and climate change on rainfall runoff processes on watersheds. This study assesses the effect of considering non-stationarity in the estimation of design peak flows at 33 gauging stations in the state of Antioquia, Colombia. Particularly, the effect of non-stationarity in the mean of Gumbel-distributed peak flows is evaluated. This study focuses on the 5-yr and 10-yr return period annual flood flows, which are customary in the design of type sewerage systems. The results show similar behaviours for both return periods. All gauge stations show an asymptotically tendency in the risk of failure to 100% as the project lifetime tends to 30 years. In general, 71.4% of gauging stations show that the estimated risk of failure is larger when non-stationary conditions are assumed, relative to assuming stationary conditions, and that the magnitude of the difference increases for larger return periods. The rest of gauging stations shows the opposite behaviour. Our results support the use of a probability model that includes non-stationary in the mean, and they suggest that a model that also includes non-stationary in the variance could be important.

Key words: Reliability, return period, risk, sewer design, time series.

INTRODUCTION

Non-stationarity has been observed in hydrologic time series (Milly et al. 2008, Stedinger & Griffis 2008, Mondal & Mujumdar 2016) and Colombia in not the exception. For example, El Niño-Southern Oscillation (ENSO) has been identified as a strong driver of Colombia's hydro-climatology at the inter-annual scale (Bedoya et al. 2019, Navarro et al. 2019, Poveda et al. 2001). Long-term (multi-decadal) trends have been detected in monthly series of air temperature, precipitation and streamflows (Carmona & Poveda 2014, Ochoa & Poveda 2004, Pérez et al. 1998). These variability patterns challenge the validity of classical hydraulic engineering designs. The studies show strongest rainfall storms that cause floods more frequently and trigger landslides, thus sewer design is, therefore, a critical issue for social protection. In this study we assess the effect of non-stationarity on flooding risk estimation in Antioquia.

In this paper we evaluated a more complete methodology that includes trends in the mean for estimation of two flood quantiles (5 and 10 years), while the variance is assumed to be stationary. The geometric distribution is used to analyze how the return period evolves and therefore the risk of failure. Maximun annual floods are assumed to follow a Gumbel distribution. Two aspects need to be considered when interpreting the results of the methodology. First, the trend of the mean is linear, this behavior may not feasible over longer lifetimes (> 30 years) because it can introduce strong biases, especially when longer return periods are analizyd, therefore, exploring asyptotic models could be realistic. Second, introducing a model for non-stationarity in the variance into the study includes more uncertainty and can lead to overestimating or underestimating flood quantiles depending on the positive or negative trend of the variance. When data have a large variance the type log distributions helps to obtain results for low Tr feasibles.

DATA

The province of Antioquia in Colombia has a population of more than 6 million people distributed in 125 municipalities. Annual precipitation in Antioquia ranges between 1000 and 4000 mm approximately. The available data consists of annual maximum times series at 33 gauge stations distributed all over Antioquia (Figure 1), from which 31 belong to the national weather service of Colombia (Instituto de Hidrología, Meteorología y Estudios Ambientales, IDEAM), and 2 to the water en electricity supply company of Medellín (Empresas Públicas de Medellín, EPM). As shown in Table I, the period of records is from 1972 to 2013, all time series are longer than 15 yr and 24 of them are longer than 30 yr.

MATERIALS AND METHODS

Non-stationarity causes an increase or decrease in the frequency and magnitude of maximum flows, i.e. the return period changes with time, and so does risk. The occurrence of non-stationary in the time series was assessed by the Mann-Kendall (MK) test (Kendall 1955, Mann 1945, Cheng et al. 2014, Read & Vogel 2015, 2016) for a significance level a=5%. The null hypothesis (Ho) of the MK test is that no trend exists in the data. For those series that Ho was rejected, the magnitude of the mean (m) and standard deviation (s) trends were calculated as the slope of a linear regression over a 20 year period.

To assess the effect of non-stationarity on flood risk estimation we follow the method outlined by Salas & Obeysekera (2014), who extended the basic concepts of return period and risk into a non-stationary framework. The Salas & Obeysekera (2014) approach consists in allowing the parameters of the probability function to vary with time. Assuming the random variable zq follows a Type I General Extreme Value (GEV) or Gumbel probability distribution, its cumulative probability function (CDF) is given by Eq. (1).

$$F(z_q) = exp[-exp(-\alpha(z_q - \beta))] \tag{1}$$

where α=1.281/σ and β=μ-0.45 are parameters and μ and σ are the mean and standard deviation respectively. Let X be a random variable representing the time when the design flow z_{q0} is exceeded

Table I. General characteristics of discharge measurement stations in state of Antioquia-Colombia. Sites 1–31 belong to IDEAM and sites 32–33 to EPM.

Id	Site	Locality	River basin	Lat.	Lon.	Period	Length [yr]
1	Palmira Hda.	Cáceres	Man	7.47	75.23	1973-2013	40
2	Sonsón	Sonsón	Sonsón	5.41	75.18	1973-2013	40
3	Margento	Caucasia	Cauca	8.02	74.57	1975-2010	35
4	La Candelaria	Arboletes	San Juan de Urabá	8.39	76.26	1978-1994	16
5	Tascón	Dabeiba	Riosucio	7.05	76.25	1976-1995	19
6	Mutatá	Mutatá	Riosucio	7.13	76.26	1976-2013	37
7	Pte. Pescadero	Toledo	Cauca	7.05	75.41	1984-1999	15
8	La Bodega	Yondó	Regla	6.42	74.24	1976-2012	36
9	El Añil	Uramita	Riosucio	6.52	76.09	1972-2013	41
10	Campamento	Andes	San Juan	5.40	75.52	1972-2013	41
11	Yarumal	San Andrés	San Andrés	7.01	75.39	1982-1999	17
12	Caramanta	Yolombó	Nus	6.30	74.51	1974-2013	39
13	Pte. Anorí	Anorí	Nechí	7.12	75.18	1975-2011	36
14	Las Flores	Nechí	Cauca	8.06	74.46	1975-2013	38
15	Pte. Real	Rionegro	Negro	6.08	75.22	1973-2013	40
16	Brasilia	Bolívar	Bolívar	5.49	75.56	1972-2013	41
17	El Cedral	San José de la Montaña	San Andrés	6.52	75.40	1980-2013	33
18	Olaya	Olaya	Cauca	6.38	75.49	1984-1999	15
19	La Mascota	Yalí	San Bartolomé	6.38	74.52	1975-2013	38
20	El Remolino	Bolívar	San Juan	5.51	75.54	1972-2013	41
21	El Rodadero	Venecia	Sinifaná	6.00	75.48	1972-1990	18
22	Los Sirpes	Concepción	Qda. La Concepción	6.22	75.09	1972-2011	39
23	Apaví	Tarazá	Cauca	7.28	75.19	1972-2013	41
24	La Magdalena	Urrao	Penderisco	6.17	76.08	1974-2013	39
25	La Galera	Santafé de Antioquia	Tonusco	6.33	75.51	1972-2013	41
26	Pailania	Cocorná	Sto. Domingo	5.58	75.07	1973-2013	40
27	Brisas del Nechí	Yarumal	Nechí	6.56	75.22	1975-2013	38
28	Pte Ferrocarril	Pto Nare (La Magdalena)	Cocorná	6.02	74.38	1974-2006	32
29	El Cangrejo	Betulia	San Mateo	6.12	75.51	1974-2008	34
30	Coltepunto Rns 19	Rionegro	Qda La Cimarrona	6.10	75.21	1994-2013	19
31	Cañafisto	Santafé de Antioquia	Cauca	6.25	75.23	1979-2010	31
32	Piedras Blancas	Santa Elena	Río Medellín	6.29	75.49	1978-2003	25
33	Yarumito	Barbosa	Río Medellín	6.47	75.29	1981-2003	22

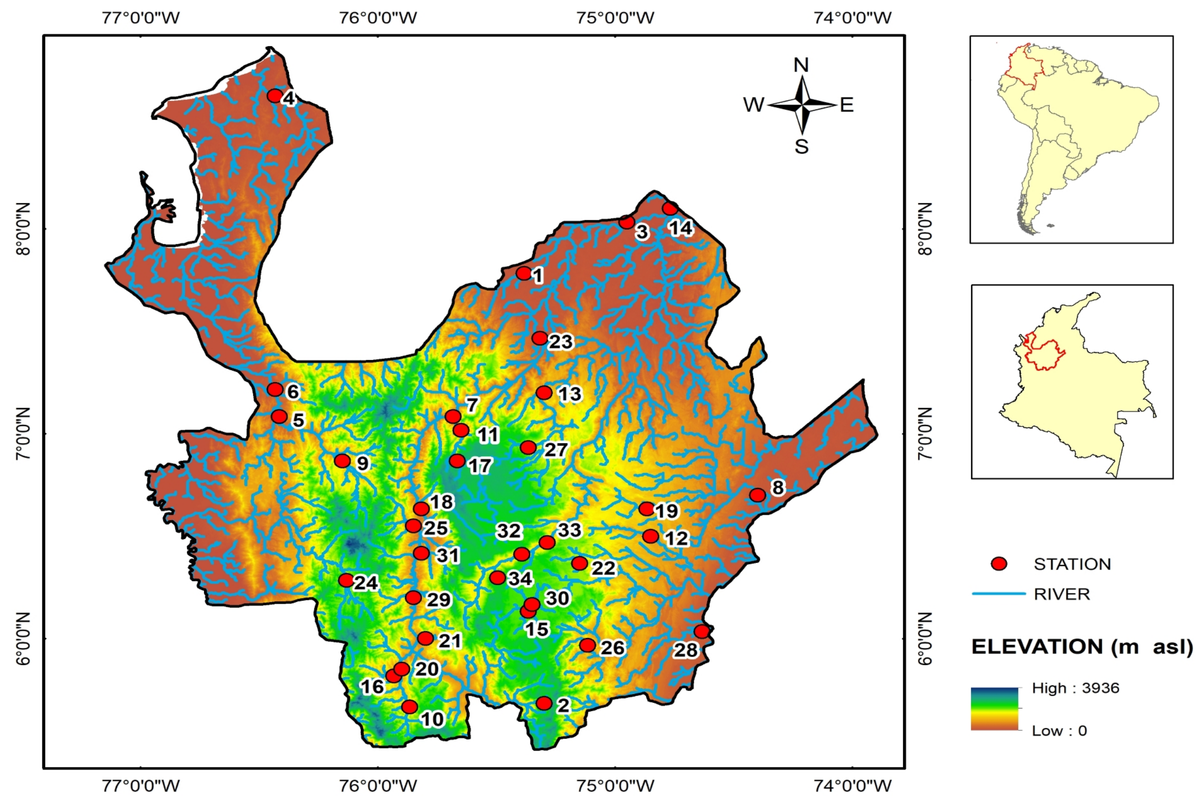

Figure 1. Geographical distribution of the streamflow gauging sites.

for the first time. Assuming that the events are independent, the probability that a flow will exceed z_{q0} for the first time at X=x is given by Eq. (2).

$$f(x) = \begin{cases} p1 & \text{if x=1} \\ \prod_{t=1}^{x-1}(1-p_t) & \text{for x=2,3,...,}x_{max} \end{cases} \tag{2}$$

where $p_1, p_2, ...p_t$ are the time-varying exceedance probabilities and x_{max} is the time when p_t=1. The expression in Eq. (2) is the generalization of the geometric distribution for non-stationary conditions series (Salas & Obeysekera 2014) and has parameters that vary over time. The cumulative distribution function for the geometric distribution is given by Eq. (3).

$$Fx = 1 - \prod_{t=1}^{x} 1 - p_t \qquad x = 1, 2, ..., x_{max} \tag{3}$$

where $F_x(1)=p_1$ and $F_x(x_{max})=1$. To incorporate the non-stationarity of p, we assumed a linear trend of the parameters m and s over time (Katz 2013). This is, $\mu_t=\mu_0+S_\mu t$ and $\sigma_t=\sigma_0+S_\sigma t$, where μ_0 and σ_0 are the stationary parameters and S_μ and S_σ are the long-term trend slopes of μ and σ (see Table II).

Table II. Long-term trends in the parameters of annual maximum discharge time series in Antioquia. Third column shows the MK test results. R: Ho rejected. NR: Ho not rejected.

Id	Site	MK	Trend	S_μ [m³/s/dec]	S_σ [m³/s/dec]	S_α [s/m³/dec]	S_β [m³/s/dec]
1	Palmira Hda.	R	Increasing	6,68	13,43	-0,007	0,641
2	Sonsón	R	Decreasing	-3,21	3,80	-0,003	-4,921
3	Margento	R	Increasing	253,03	36,01	0,000	236,820
4	La Candelaria	NR	No trend	0,00	0,00	0,000	0,000
5	Tascón	R	Decreasing	-148,95	-10,05	0,000	-144,420
6	Mutatá	A	No trend	0,00	0,00	0,000	0,000
7	Pte. Pescadero	R	Increasing	438,03	126,28	-0,001	381,200
8	La Bodega	NR	No trend	0,00	0,00	0,000	0,000
9	El Añil	R	Increasing	20,50	14,51	-0,005	13,975
10	Campamento	NR	No trend	0,00	0,00	0,000	0,000
11	Yarumal	NR	No trend	0,00	0,00	0,000	0,000
12	Caramanta	R	Increasing	1,65	-2,55	0,003	-4,908
13	Pte. Anorí	R	Decreasing	-13,40	-21,49	0,001	-3,731
14	Las Flores	R	Increasing	351,66	225,69	-0,001	250,100
15	Pte. Real	R	Increasing	4,73	4,41	-0,009	2,746
16	Brasilia	NR	No trend	0,00	0,00	0,000	0,000
17	El Cedral	R	Increasing	2,27	-4,41	0,037	4,255
18	Olaya	NR	No trend	0,00	0,00	0,000	0,000
19	La Mascota	NR	Notrend	0,00	0,00	0,000	0,000
20	El Remolino	NR	No trend	0,00	0,00	0,000	0,000
21	El Rodadero	R	Increasing	7,27	25,43	-0,047	-4,172
22	Los Sirpes	R	Decreasing	-3,83	6,16	-0,017	-6,602
23	Apaví	R	Increasing	143,21	41,47	0,000	124,540
24	La Magdalena	R	Increasing	23,01	16,40	-0,012	15,629
25	La Galera	NR	No trend	0,00	0,00	0,000	0,000
26	Pailania	R	Decreasing	-30,06	1,76	0,000	-30,850
27	Brisas del Nechí	R	Decreasing	-9,62	-3,74	0,005	-7,937
28	Pte. Ferrocarril	NR	No trend	0,00	0,00	0,000	0,000
29	El Cangrejo	NR	No trend	0,00	0,00	0,000	0,000
30	Coltepunto Rns 19	R	Increasing	6,51	1,48	-0,071	5,849
31	Cañafisto	R	Increasing	121,59	-16,32	0,000	128,940
32	Piedras Blancas	R	Increasing	0,76	1,87	-0,628	-0,085
33	Yarumito	R	Increasing	16,27	-6,73	0,002	19,293

S_μ, S_σ, S_α and S_β are the long-term slope of μ, σ, α and β.

The average expected time E(X) or return period (T) for the geometric distribution under a non-stationary framework can be calculated by Eq. (4) (Salas & Obeysekera 2014) or the simplified version in Eq. (5) (Cooley 2013, Salas & Obeysekera 2014):

$$T = E(x) = \sum_{x=1}^{x_{max}} xf(x) = \sum_{x=1}^{x_{max}} xp_x \prod_{t=1}^{x-1}(1-p_t) \tag{4}$$

$$T = 1 + \sum_{x=1}^{x_{max}} xp_x \prod_{t=1}^{x}(1-p_t) \tag{5}$$

Finally, the flood risk (R) during the project lifetime (n) can be calculated by the expression in Eq. (6) (Chow et al. 1988, Salas & Obeysekera 2014):

$$R = 1 - \prod_{t-1}^{n}(1-p_1) \tag{6}$$

In summary, this method is implemented by following these steps:

- Fit a Type I GEV probability distribution function to the annual maximum streamflows by the method of moments.
- Define a return period T_0 for the analysis. In this study the 5 and 10 years were used because these values commonly used values in sewer design.
- Set p_0=1/T_0 and q_0=1-p_0, then calculate the design flow z_{q0} by inverting q_0=$F_{Z(z,q0)}$.
- Calculate p_t=1-qt from pt=$F_{Z(z,qt)}$ for all years in the lifetime n. In this study n=30 years.
- Obtain the non-stationary return period (T) from Eq. (5) for a design lifetime n.
- Calculate the equivalent stationary return period and the flow value that must be used to guarantee the protection of 5 and 10 years during the structure lifetime.

In the analysis of the frequency of maximum extreme events, the fitting of the distributions or estimation of their parameters can be carried out by the method of moments or by the method of maximum likelihood (L-moments). In this case, the fit used was moments due to observation data length. The data length is between 15 and 40 years for the 34 stations. The literature shows that the fitting is more efficient by the L-moments method for a number of data greater than 25 (Agilan & Umamahesh 2017). This condition is not possible for all 34 stations, therefore the fitting was made by the method of moments.

RESULTS

Mann-Kendall test results give 12 stationary and 21 non-stationary time series (see Table II). From the 21 non-stationary series, 15 of them show a positive and 6 a negative trend. Table III shows the variation of the return period for 5 and 10 years in a non-stationary context for non-stationary series analysed. The magnitudes of the trends observed in the series are also listed in order to verify the coherence of the results obtained. Figure 2 shows graphs of the risk of failure during a 30-yr lifetime

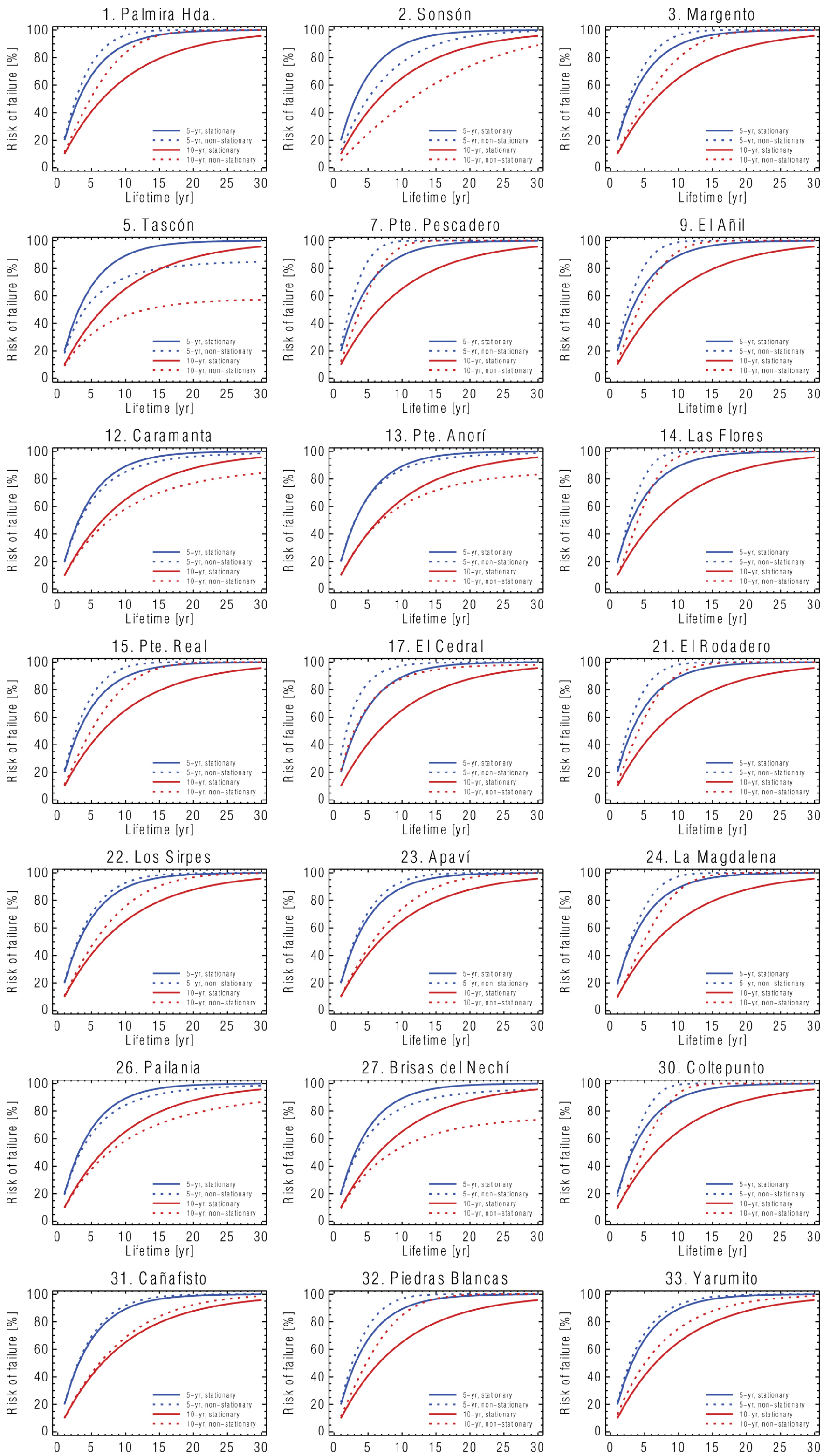

Figure 2. Risk of failure under stationary and non-stationary scenarios for 5-yr and 10-yr return period design for all the non-stationary series of the data set.

Table III. Variation of the return period in a non-stationary context.

ID	Site	Trend	T_0=5 yr	T_0=10 yr
1	Palmira Hda.	Increasing	3,96	6,23
2	Sonsón	Decreasing	7,3	14,84
3	Margento	Increasing	4,01	6,7
5	Tascón	Decreasing	3,95	4,66
7	Pte. Pescadero	Increasing	3,23	4,82
9	El Añil	Increasing	3,46	5,18
12	Caramanta	Increasing	4,95	9,39
13	Pte. Anorí	Decreasing	5,04	18,35
14	Las Flores	Increasing	3,54	4,89
15	Pte. Real	Decreasing	3,97	6,35
17	Cedral	Decreasing	3,18	5,47
21	El Rodadero	Increasing	3,59	5,28
22	Los Sirpes	Increasing	4,48	7,36
23	Apaví	Decreasing	4,36	7,6
24	La Magdalena	Increasing	3,99	5,99
26	Pailania	Decreasing	6,19	14,38
27	Brisas del Nechí	Decreasing	8,75	28,9
30	Coltepunto Rns 19	Increasing	3,8	5,49
31	Cañafisto	Decreasing	4,61	8,68
32	Piedras Blancas	Increasing	3,88	6,1
33	Yarumito	Decreasing	4,45	7,65

for the 21 non-stationary series in the data set. To highlight the effect caused by the non-stationarity, Figure 3 shows the geographical location of the stations in the department of Antioquia. For each season it is indicated if the trend is increasing (white circle) or decreasing (pink circle). In addition, each of gauge station has the realtive variation (+) or (-) to 5 and 10 of nonstationary return period with respect to stationary condition.

Figure 4 shows the Table IV in a graphic to visualize the results of maximum discharges and increase (+) or decrease (-) percentages for 5-yr and 10-yr of return period.

DISCUSSION

The study tested the stationary of stationarity 33 annual maximum streamflow series in Antioquia. Results show that in 21 gauging stations the assumption of stationary in the mean is rejected, while

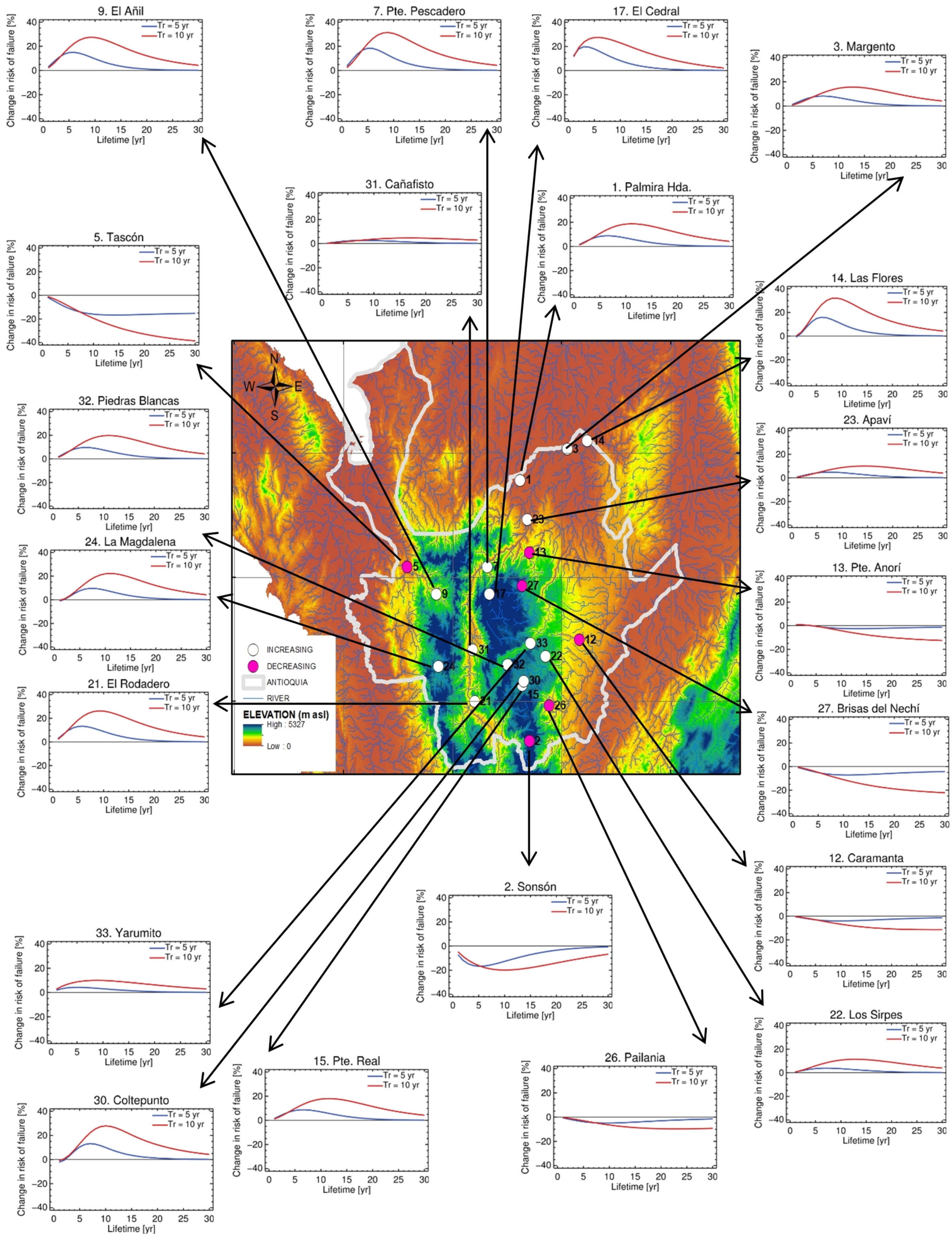

Figure 3. Geographical distribution of trends (+) and (-) and change in the risk of failure when including the effect of non-stationary for 5-yr and 10-yr return period design for all the non-stationary series of the data set.

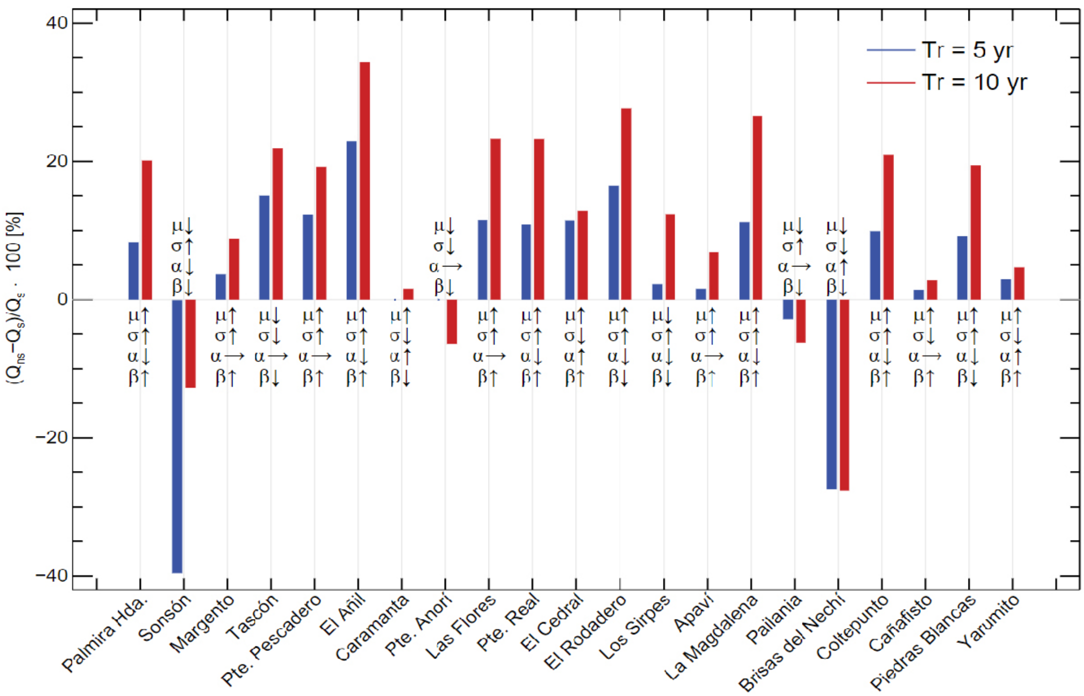

Figure 4. Effect of the non-stationarity approach in the design flood for 5-yr and 10-yr return period. Qs and Qns are the stationary and non-stationary flow estimations.

Table IV. Maximum discharges and increase (+) or decrease (-) percentages of stationary maximum discharge for quantile variations.

Id	Site	LYUT	St Q_{max} [m³/s]	T_{0eq} [yr]	Non St Q_{max} [m³/s]	Rel. var. [%]	St Q_{max} [m³/s]	T_0eq [yr]	Non St Q_{max} [m³/s]	Rel.var. [%]
1	Palmira Hda.	2043	216,42	7	234,43	8,32	252,98	27,5	303,89	20,13
2	Sonsón	2043	93,14	2	56,25	-39,61	117,56	6,5	102,56	-12,76
3	Margento	2040	3098,55	6,5	3210,61	3,62	3389,11	21	3687,16	8,79
5	Tascón	2025	918,44	12,5	1056,17	15	1023,44	47,5	1247,26	21,87
7	Pte. Pescadero	2029	2712,74	12,5	3047,76	12,35	2968,15	51	3537,05	19,17
9	El Añil	2043	190,16	11	233,74	22,92	228,61	44,5	307,18	34,37
12	Caramanta	2043	178,15	5	178,14	No sig.	201,64	11	204,78	1,56
13	Pte. Anori	2041	575,35	5	575,34	No sig.	659,39	7	616,76	-6,46
14	Las Flores	2043	4469,26	12,5	4983,77	11,51	4861,51	83	5991,78	23,25
15	Pte. Real	2043	66,14	7	73,3	10,82	80,66	25,5	99,39	23,22
17	Cedral	2043	52,9	8,5	58,96	11,46	60,77	20,5	68,58	12,85
21	El Rodadero	2020	134,88	10,5	157,03	16,42	155,61	45,5	198,62	27,64
22	Los Sirpes	2041	87,61	5,5	89,52	2,18	101,18	19,5	113,72	12,4
23	Apaví	2043	3493,97	5,5	3548,32	1,56	3878,47	16,5	4145,84	6,89
24	La Magdalena	2043	153,11	7,5	170,32	11,24	182,19	33,5	230,48	26,51
26	Pailania	2043	270,39	4,5	262,73	-2,83	318,69	7,5	298,98	-6,19
27	Brisas del Nechí	2043	110,17	2	79,97	-27,41	130,17	3	94,26	-27,59
30	Coltepunto Rns 19	2043	24,4	9	26,82	9,9	27,24	43,5	32,96	21
31	Cañafisto	2040	2833,48	5,5	2873,32	1,41	3115,29	12,5	3203,12	2,82
32	Piedras Blancas	2033	11,71	7,5	12,78	9,17	13,53	28,5	16,15	19,35
33	Yarumito	2033	375,83	6	386,96	2.96	414.18	14	436.57	4.65

LYUT: Last year of lifetime; St: Stationary.

for the other 12 gauging stations the assumption of stationary can not be rejected. Increasing trends are predominant in the analysed streamflow time series (15 increasing and 6 decreasing). Mainly the gauge stations with increasing trend are in the central zone of the study area, while the stations with decreasing trend have no a clear tendency (Figure 4). This result is in accordance with the dominant positive rainfall trends over Antioquia observed by Cantor & Ochoa (2011), deserves attention and justifies the non-stationarity approach in flood frequency estimation and sewer design.

The results obtained for the period of return in non-stationary conditions are consistent with the trends detected in the series of maxima (Figure 3). An increase in magnitude causes an increase in the frequency of events and therefore in the probability of exceedance, as indicated in the hydrological literature.

According to Figure 3 the stations with an increasing trend (increase in magnitude), the periods of return obtained in a non-stationary context are lower than those used in the stationary scenario. When the trend is decreasing, the periods of return obtained in the non-stationary analyses are greater than those used in the stationary condition. Only Station 5 presents atypical behaviour, where although the observed trend of the series of maximums is decreasing, the methodology showed periods of return in a non-stationary scenario of less than 5 and 10 years.

The return periods for stations with increasing trend obtained using assumptions of non-stationarity are lower than those estimated using the stationary scenario. These records may be subject to more intense flood events than those for which they were designed under the stationary scenario, making the structure more vulnerable over time. As an example, if for Station 9 (El Añil), a hydraulic structure is designed for T^0=5 and 10 years and the records of maximum values available until 2012, the return period under non-stationary conditions at the end of the useful life would be of 3.46 and 5.18 years, respectively (see Table III). If the same exercise is carried out for 25 years, a return period is obtained in a non-stationary context of 7.96 years. Note that the reduction of T in stationary conditions is more significant as the stationary return period (T_0) increases. It is noted that Station 9 is one of the stations that presents a very marked and critical growing trend as the return period increases, resulting in extreme variations with respect to the stationary condition. This situation is directly related to the significant increases in the series of maximums that can be observed in the records of the last eight-year period.

The results show that when the series of maximum flows exhibit some type of non-stationarity, particularly with an increasing trend, the design return period should not be calculated according to a single value. Rather, it should be defined according to the characteristics of each current or river and intended work. However, these definitions should be made with caution because even if the trend tests are statistically significant, the inhomogeneity of the historical series could actually be due to the low-frequency components of the atmospheric and oceanic system; thus, the attribution of changes in the flow data is not an easy task. An unjustified increase in the design period of a structure can induce over-sizing and increases in construction costs.

On the other hand, for the stations studied with decreasing trends, it was found that using the traditional return period yields results that are more conservative than working with the estimates in the non-stationary context. In this order of ideas, it can be said that for practical purposes of designing works, traditional return periods with a certain degree of reliability can be continued, however, from the economic point of view, analytical tools can be developed to optimize the structure's costs.

The relative change in the design flows between the stationary and the non-stationary approaches range between -40% and +25% for the 5-yr return period and between -27% and +35% for the 10-yr return period (Figure 4). These differences are noteworthy because they could put the population at risk and could have also an important economic impact on hydraulic engineering projects.

Regarding the hydrological risk of failure, which increases as the useful life of the structure increases, for stations with an increasing trend and any value of n, the risk under non-stationary conditions is greater than for stationary conditions (Table IV and Figure 4). In this particular case, it can be observed from Station 9 (Figure 3) that for the non-stationary condition when a T_0=5 years is used, the risk of failure of 100% is presented for a smaller n than when designed with T_0=10 years. This depends on the initial level of protection or T_0, which associates the risk of 100% failure to a shorter useful life.

Likewise, it was found that as n increases, the risk becomes very high, even reaching 100% for the non-stationary condition. For stationary analysis, this value is not reached for high values of n.

CONCLUSIONS

Although, this study does not pretend to be definiteve about the existence of non-stationarity and its effect in the study area because the limited number of gauges in the area and the limited record lengths, however, it points out the importance of considering the effect of non-stationarity in the behavior of maximum events and the associated implications on the planning, design, operation and maintenance of infrastructure for water supply, transport and drainage of water in cities with high rates of population density and lack of adequate infrastructure.

Of the 33 streamflow gauging station records analysed, stationarity is rejected for 64% of them. The annual maximum series with increasing trends exhibit lower return periods in a non-stationary context than the initial level of protection of 5 and 10 years. The magnitude of the maximum flows associated with the design in a non-stationary context is greater than in the stationary condition. Thus, if the traditional hydrological analysis is used with a return period of 5 and 10 years, the flooding events may be more intense than events in a stationary condition. This causes the drainage system to become more vulnerable over time. The return period of reference is the stipulated for urban drainage design in Colombia. However, this conclusion can be generalized for periods of higher return. The study carried out by Carvajal Gómez & Poveda 2014 for Colombia supports this conclusion with period of return of 100 years.

The local climatic conditions have a strong influence on the obtained results (Wilches 2001). State of Antioquia is an area with a high climatic variability. This is determined by its proximity to the Pacific and Atlantic oceans, the characteristics of its tropical climate, the presence of two of the three branches of the Andes mountain range and the variability of the hydrological surface processes. This climatic variability does not allow any generalization about the optimal return periods for the design. Thus the calculation of the period of return must be exhaustive in the assessment of the flow and, above all, it must be conservative in its estimation.

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