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N J Cely-Calixto[1], G A Carrillo Soto[1], and D Becerra-Moreno[2]
[1] Grupo de Investigación en Hidrología y Recursos Hídricos, Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia
[2] Grupo de Investigación Ambiente y Vida, Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia

E-mail: nelsonjaviercc@ufps.edu.co

Abstract. Physics includes the study and investigation of the phases that make up the hydrological cycle, including the estimation of flow rates in river basins, most of which are not instrumented, *i.e.*, they lack historical records of circulating flows. For this situation, the application of hydrological models can allow flow estimates to be made. In the Department of Norte de Santander, Colombia, some watersheds do not have instrumentation for flow measurement or hydrological modeling methodologies appropriate to the site. Therefore, methods such as the modified rational model of Teméz are used, even without knowing the relevance of its applicability to the site conditions. Consequently, for the present research, the Teméz model was validated in watersheds of the Norte de Santander Department to estimate the values of extreme flows with a return period of 100 years. In this sense, 11 watersheds were selected, which contained historical rainfall data greater than 20 years and a drainage network of fewer than 1000 Km^2. It was found that the Teméz model overestimates the real flows of the 11 hydrological basins, where the climatological parameters used in the application of the Fhrüling factor and its statistical verification using multivariate regression did not achieve an acceptable correlation.

1. Introduction

Physics includes the study and investigation of the phases that make up the hydrological cycle, including the estimation of flow rates in river basins. Flow records of a river basin are fundamental for planning the use of water resources, in terms of agricultural, industrial, and urban supply activities, as well as for the sizing of physical infrastructure works, such as hydraulic structures [1]. No instrumented watersheds can measure flows allowing them to contain records over time. However, watersheds generally do not have the instruments for flow monitoring, so estimates of these values must be made [2].

The circulating flows of river basins can be estimated by applying indirect methods, one of which is the hydrological model proposed in 1991 by Teméz J, called the modified rational model [3]. This model is widely used for flow estimation in Spain, allowing to obtain the values, even when data on the distribution of rainfall over time are not available [4].

The modified rational model is suitable for estimations in small basins and can be extrapolated for basins with an area of up to 3000 Km^2. It is based on an ideal event, with constant rainfall intensity and indefinite duration. Therefore, to obtain the maximum discharge it is sufficient that the duration of rainfall is equal to the time of concentration. Teméz introduced a series of modifications that reduce the simplicity of the rational method by considering a concentration period between 0.25 hours and

24 hours, a rainfall uniformity coefficient, based on the concentration-time, and a reducing factor according to the basin area [5].

Currently, the Department of Norte de Santander (DNdS), Colombia, has no instrumented watersheds, a situation that makes it necessary to resort to the application of hydrological models to obtain the values of extreme flows [6]. Therefore, the objective of this research is to validate the modified rational model of Teméz in watersheds of the DNdS, Colombia, to estimate the values of extreme flows with a return period of 100 years.

2. Methodology

Historical rainfall data provided by the hydrological stations (HS), property of the "Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)", located in DNdS, were used as the base information for this study. Eleven watersheds were selected from those located under the 40 HS of DNdS. For this purpose, two selection criteria were used among the HS. The first criterion was based on the content of historical data greater than 20 years, and the second criterion consisted of analyzing the drainage area of the monitored watersheds, considering those with a drainage area of less than $1000\ \mathrm{Km}^2$, according to the applicability of the Teméz model.

Figure 1 shows the delimitations made using ArcGIS® software of the selected watersheds areas. Figure 1 shows the names of each of the 11 watersheds, which are monitored by different precipitation stations. The Campo Seis, La Cabaña, Los Pomarrosos, Cornejo, and Las Vegas watersheds are each provided with two precipitation stations; La Donjuana, Pte. San Miguel and Pte. Abrego watersheds have three stations each; and Pte. Sardinata and Pte. López have four stations per watershed.

To characterize the watersheds, primary characteristics and morphometric indices were determined using ArcGIS® software: watershed area, A (Km^2); watershed perimeter, P (Km); Gravelius index, K_c; shape factor, K_f; mean watershed elevation, Z (masl); mean watershed slope, Y (%); main river channel length, L (m); mean channel slope, S (m/m); total channel slope, S_o (m/m) [4].

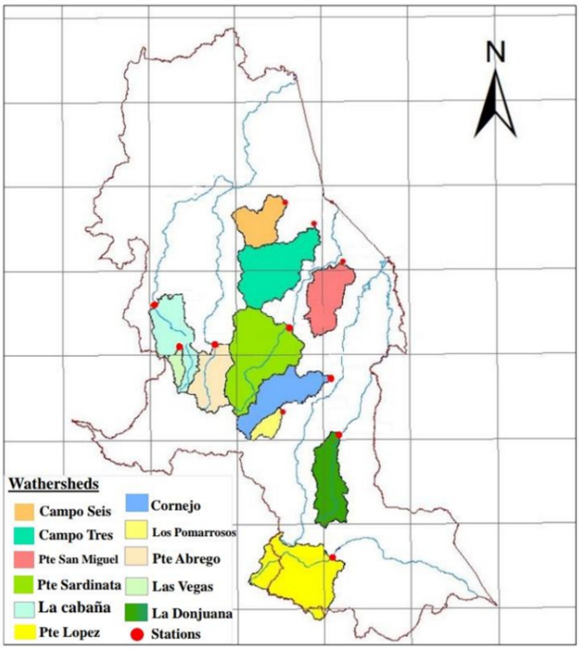

Figure 1. Delimitation of DNdS watersheds.

The outliers test was applied to each historical series of monthly peak flows and precipitation of the watersheds. The outliers test consists of identifying, using hydrological and mathematical criteria, data points that deviate from the trend of the remaining data [7]. This test consists of identifying, through hydrological and mathematical criteria, data points that deviate from the trend of the remaining data [7].

The method was used to identify which flows and precipitations significantly deviate from the trend, thus avoiding affecting the magnitude of the calculated statistical parameters. For this, Equation (1) was applied to detect major uncertain data, and Equation (2) was applied to detect minor uncertain data, as explained in [7], Flows and precipitation within the range were selected, and then the probability distribution methods were applied.

$$YH = \bar{y} + K_n Sy, \tag{1}$$

$$YL = \bar{y} + K_n Sy, \tag{2}$$

where, YH is the high outliers' threshold in logarithmic units, YL the low outliers threshold in logarithmic units, $\bar{y}$ the mean of the logarithmic values, Sy the standard deviation and K_n is the 10% significance level value.

The probability distribution functions normal, Gumbel probability distribution, and Log-Pearson were used, based on the maximum rainfall in 24 hours for each of the watersheds [8-10]. From these functions, rainfall and flow rates with a return period of 100 years were estimated to obtain a value similar to the real value of the flow in the channel.

In addition, the Thiessen polygon method [11] was used to determine average precipitation for each watershed, thus obtaining single precipitation for each hydrological station, since each basin analyzed had more than one precipitation station.

For the application of the modified rational method [3], the concentration time (Equation (3)), uniformity coefficient (Equation (4)), rainfall intensity (Equation (5)), runoff coefficient (Equation (6)), and extreme flow (Equation (7)) were estimated.

$$T_c = 0.3\left(\frac{L}{S^{0.25}}\right)^{0.76}, \tag{3}$$

$$K = 1 + \frac{{T_c}^{1.25}}{{T_c}^{1.25}+14}, \tag{4}$$

$$I_{T_c} = \left(\frac{I_t}{I_d}\right)^{\frac{28^{0.1}-{T_c}^{0.1}}{28^{0.1}-1}} \cdot \frac{Pd^*}{24}, \tag{5}$$

$$C = \frac{(Pd^*-P_o)(Pd^*+23\cdot P_o)}{(Pd^*+11P_o)^2}, \tag{6}$$

$$Q = \frac{C \times I \times A}{3.6} \cdot K, \tag{7}$$

where T_c is the time of concentration (hours), L is the length of the longest watercourse (Km), S is the average slope of the main channel (m/m), K is the uniformity coefficient, I is the rainfall intensity (mm/h), I_{T_c} is the average intensity corresponding to the time interval t (mm/h), Pd^* is the modified maximum daily rainfall (mm) corresponding to a return period T (mm), $\frac{I_t}{I_d}$ is the quotient between hourly and daily intensity, t is the time interval duration of I_t (hours), C is the runoff coefficient, P_o is the runoff threshold and A is watershed area (Km^2).

Additionally, a torrentiality factor was obtained, which is the quotient between the hourly and daily intensity, using as input the actual intensity-duration-frequency (IDF) curves and the precipitation of each watershed of the IDEAM institute. For this, it was necessary to locate the actual IDF curve stations and the closest hydrographic stations to allow a more accurate relationship at the time of interpolation.

The results of the flows calculated by the modified rational method, for the different probability distribution methods, were compared with the actual flows calculated from the maximum monthly flows of the hydrological stations. This made it possible to validate the Témez method concerning the conditions of the basin studied, and to try to calibrate the method to check the uniformity of the data, using Equation (8).

$$f(a) = A^{0.25}(1 - 0.0054), \tag{8}$$

where f(a) is the Fhrüling factor used in the calibration of the parameters of the modified rational method for to reduce rainfall by watershed spatiality and A is watershed area (Km^2).

3. Results

The characteristics of the 11 selected watersheds are presented in Table 1. In general, according to the results of the ArcGIS® software and the morphometric characteristics of the 11 watersheds (Table 1), it is observed that the basins reveal an oblong oval to almost rectangular shape, which indicates that there is less probability of instantaneous floods due to their elongated shape. In addition, the average slope in all cases is greater than 5%, which is natural for mountain rivers [12].

Table 1. Morphometric characteristics of the river basins.

Watershed	A (Km^2)	P (Km)	K_c (-)	K_F (-)	Z (masl)	Y (%)	L (Km)	S (m/m)	S_o (m/m)
Campo Seis	314.6	95.9	1.51	0.48	517.0	36.0	25.7	0.1241	0.0067
La Cabaña	530.8	136.6	1.66	0.34	1712.4	31.1	39.4	0.0637	0.0092
Los Pomarrosos	101.0	50.4	1.40	0.32	2149.4	67.2	17.8	0.1951	0.0834
Cornejo	460.8	142.1	1.85	0.17	1614.2	45.8	51.5	0.1171	0.0363
Pte Sardinata	909.9	161.5	1.50	0.27	1871.7	50.6	58.2	0.1270	0.0401
Campo Tres	706.2	156.4	1.65	0.22	637.7	34.8	56.5	0.0839	0.0089
Las Vegas	69.8	46.9	1.57	0.25	2083.6	36.1	16.8	0.1367	0.0545
Pte López	834.1	163.9	1.59	0.46	3287.5	38.1	42.6	0.1527	0.0341
La Donjuana	422.7	126.7	1.73	0.28	2000.2	45.3	38.8	0.0933	0.0322
Pte San Miguel	410.5	112.0	1.55	0.28	347.2	19.9	38.6	0.0455	0.0044
Pte Ábrego	367.4	109.3	1.60	0.44	2200.8	40.7	28.9	0.0816	0.0198

3.1. Application of statistical data adjustment

As an example, the maximum monthly flows were calculated in logarithmic units for the Campo Seis hydrology station, and the values of the outliers application are shown in Table 2. Based on Table 2, the outliers' thresholds are obtained: $YH = 3070\ m^3/s$, $YL = 43.7\ m^3/s$, flow greater than $1532\ m^3/s$, and flow less than $61.3\ m^3/s$, therefore, for this station, there are no doubtful data.

Table 2. Application values of questionable data from the Campo Seis station.

Average	n	K_n	Desviation
2.56	39	2.671	0.345

3.2. Probability distribution

For the application of the Normal, Gumbel, and Log-Pearson distribution methods in the example of the Campo Seis basin, on the Tibú precipitation station, the following was obtained: mean of the precipitation (P) of 113.8 mm; mean of the logarithms of the precipitation (Log P) of 2.0457; standard deviation of precipitation (S_P) of 25.14; standard deviation of logarithms of precipitation ($S_{Log\ P)}$)of 0.0983; coefficient of asymmetry (C_S) of -0.3204; and K of -0.0534.

Since each watershed had more than one precipitation station, the Thiessen Method was applied to determine for each watershed single average precipitation for the distribution functions at a 100-year return period [13], the uniformity coefficient (K) and simultaneity coefficient (K_A) was determined, as presented in Table 3. The modified maximum daily precipitation (Pd*) was determined using the distribution methods, as presented in Table 4.

Table 3. Time of concentration, coefficient of uniformity and simultaneity.

Watershed	T_c (hours)	K	K_A
Campo Seis	5.26	1.36	0.83
La Cabaña	8.26	1.50	0.82
Los Pomarrosos	3.64	1.26	0.87
Cornejo	9.02	1.53	0.82
Pte Sardinata	9.74	1.55	0.80
Campo Tres	10.31	1.57	0.81
Las Vegas	3.74	1.27	0.88
Pte López	7.42	1.47	0.81
La Donjuana	7.60	1.47	0.83
Pte San Miguel	8.66	1.51	0.83
Pte Ábrego	6.23	1.41	0.83

Table 4. Modified maximum daily precipitation.

Watershed	Maximum rainfall in 24 hours (mm) for T=100 yr.		
	Normal	Gumbel	Log-Pearson
Campo Seis	189.50	214.10	204.00
La Cabaña	88.00	100.60	96.60
Los Pomarrosos	157.00	176.60	165.20
Cornejo	130.50	150.00	142.30
Pte Sardinata	116.50	135.80	135.70
Campo Tres	150.00	167.50	129.20
Las Vegas	111.70	128.00	122.10
Pte López	58.90	69.20	67.00
La Donjuana	85.10	97.10	90.90
Pte San Miguel	144.60	162.30	140.20
Pte Ábrego	113.30	133.60	122.80

3.3. Validation of the modified rational method

The maximum flow (Q_{100}) was determined by the Teméz model for the distribution functions, and a comparison was made between the flows calculated and the actual flows calculated from the maximum monthly flows of the hydrological stations, as shown in Table 5.

Table 5. Comparison of peak flows (m^3/s) between the Teméz model and actual flows.

Watershed	Q_{100} (Teméz Model)			Q_{100} (Frequency analysis)		
	Normal	Gumbel	Log-Pearson	Normal	Gumbel	Log-Pearson
Campo Seis	3358	3642	3586	1199	1452	1469
La Cabaña	1916	2174	2145	538	673	802
Los Pomarrosos	1225	1310	1264	196	246	534
Cornejo	2525	2872	2777	598	726	878
Pte Sardinata	3835	4505	4656	589	702	726
Campo Tres	3665	4066	2979	1114	1320	1283
Las Vegas	522	577	578	167	209	346
Pte López	1851	2180	2163	334	396	279
La Donjuana	1338	1516	1434	191	231	253
Pte San Miguel	2337	2594	2256	526	612	660
Pte Ábrego	2155	2497	2353	245	287	263

The values obtained by the modified rational model [3] as shown in Table 5, overestimate the flows measured by the hydrological stations. Therefore, the parameters of the Témez model were calibrated by first applying the Fhrüling factor (Factor C) to reduce the rainfall per basin spatiality, as shown in Table 6. However, as seen in Table 6, the Fhrüling Factor does not allow for data uniformity, which is essential for flow regionalization [6,14]. This may be due to the high overestimation provided by the Témez method [3] for the 11 wathersheds, which are characterized by being in a site of varied topography different from the conditions considered in the modified rational method.

Figure 2 shows the regression graphs according to each characteristic considered, for the regionalization of climatological parameters. Given the results using Figure 2, the R^2 value (< 0.5) shows that there are limitations of the Témez model. These values are unsatisfactory as it is determined in [6], for employing the hydrologic model on wathersheds.

Tabla 6. Fhrüling's factor for watersheds.

Watershed	A (Km^2)	Factor C
La Cabaña	530.8	0.44
Los Pomarrosos	101.0	0.73
Cornejo	460.8	0.44
Pte Sardinata	909.9	0.31
Campo Tres	706.2	0.34
Las Vegas	69.8	0.75
Pte López	834.1	0.39
La Donjuana	422.7	0.49
Pte San Miguel	410.5	0.47
Pte Ábrego	367.4	0.54

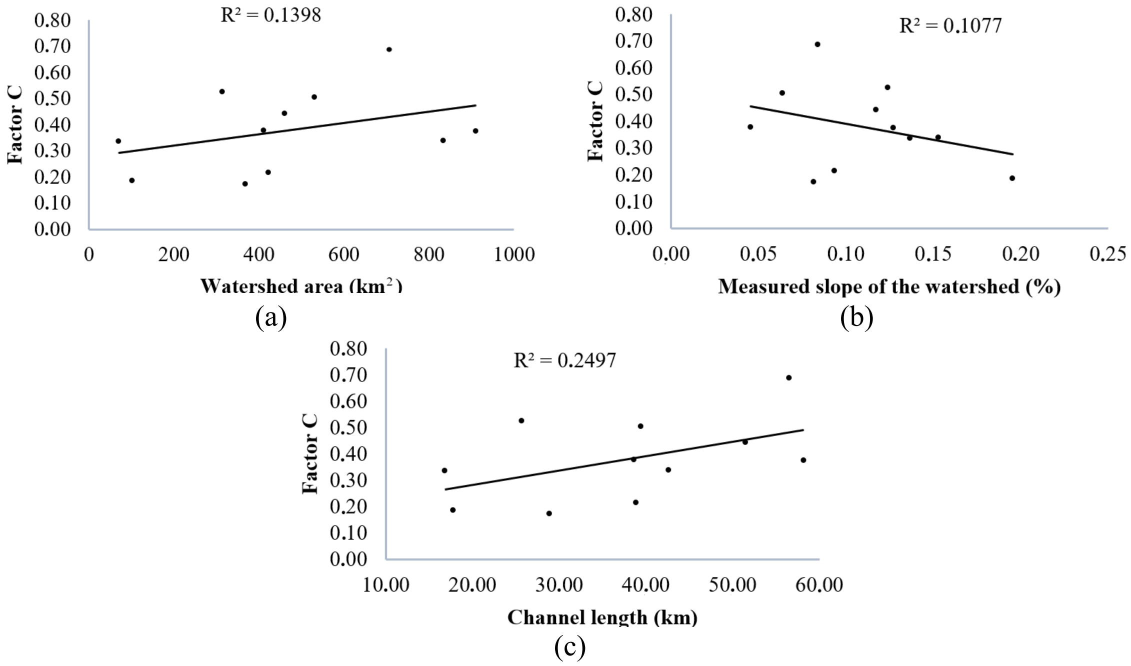

Figure 2. Multivariate regression between morphometric characteristics of the watersheds and the values calculated by the Fhrüling factor; (a) area of the basin vs. Factor C; (b) average slope of the basin vs. Factor C; (c) length of the main channel vs. Factor C.

4. Conclusions

The modified rational model proposed by Témez overestimates the real flows of the 11 watersheds in the Department of Norte de Santander, in which none of the climatological parameters are used in the Fhrüling factor and the multivariate regression, achieved an acceptable correlation. Therefore, in the framework of this study, the modified rational model is not valid for watersheds not instrumented in the Department of Norte de Santander. The proposed methods for estimating peak flows based on rainfall should be validated in other regions.

References

[1] Shu C, Ouarda T 2012 Improved methods for daily streamflow estimates at ungauged sites *Water Resources Research* **48(2)** W02523

[2] Yang X, Magnusson J, Huang S, Beldring S, Xu C 2020 Dependence of regionalization methods on the complexity of hydrological models in multiple climatic regions *Journal of Hydrology* **582** 124357

[3] Kang J, Kayhanian M, Stenstrom M 2008 Predicting the existence of stormwater first flush from the time of concentration *Water Research* **42(1-2)** 220

[4] Martínez E 2012 A geographical approach to post-flood analysis: The extreme flood event of 12 October 2007 in Calpe (Spain) *Applied Geogr*aphy **32(2)** 490
[5] Rico M, Benito G, Barnolas A 2001 Combined palaeoflood and rainfall-runoff assessment of mountain floods (Spanish Pyrenees) *Journal of Hydrology* **245(1–4)** 59
[6] da Silva L, Garcia J, Nascimento S, Bicioni A, Duarte R, Wolff W 2020 Assessment of hydrological regionalization methodologies for the upper Jaguari River basin *Journal of South American Earth Sciences* **97** 102402
[7] Bery A, Saad R 2015 Enhancement in electrical resistivity tomography resolution for environmental and engineering geophysical study *InCIEC 2014: Proceedings of the International Civil and Infrastructure Engineering Conference 2014* ed Hassan R, Yusoff M, Alisibramulisi A, Mohd N, Ismail Z (Singapore: Springer Science+Business Media) pp. 459-467
[8] Ng J L, Yap S Y, Huang Y F, Md Noh N, Al-Mansob R, Razman R 2020 Investigation of the best fit probability distribution for annual maximum rainfall in Kelantan River basin *IOP Conference Series: Earth Environmental Science* **476** 012118
[9] Naghettini M 2017 *Fundamentals of Statistical Hydrology* (Cham: Springer International Publishing Switzerland)
[10] Harahap R, Jeumpa K, Hadibroto B 2018 Flood discharge analysis with nakayasu method using combination of HEC-RAS method on Deli River in Medan City *Journal of Physics: Conference Series* **970(1)** 012011:1
[11] Davie T, Quinn N 2019 *Fundamentals of Hydrology* (London: Routledge)
[12] Abboud I, Nofal R 2017 Morphometric analysis of wadi Khumal basin, western coast of Saudi Arabia, using remote sensing and GIS techniques *Journal African Earth Sciences* **126** 58
[13] Altaf F, Meraj G, Romshoo S 2013 Morphometric analysis to infer hydrological behaviour of lidder Watershed, Western Himalaya, India *Geography Journal* **2013** 178021
[14] de Souza G, Merwade V, de Oliveira L, R, Viola M, de Sá Farias M 2021 Regional flood frequency analysis and uncertainties: Maximum streamflow estimates in ungauged basins in the region of Lavras, MG, Brazil *Catena* **197** 104970