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Phenomenological model of the intensity, duration and frequency of precipitation patterns for the Portoviejo river basin, Ecuador

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Abstract. Phenomenological models represent the behavior of random phenomena in reality, the model and the function it should perform. Similarly, tuning parameters allow us to assess the fit of observed data to a variable in a particular mathematical model and to test the validity of the model for representing a real event. These models, used in the exact and earth sciences, analyze the behavior of complex variables that vary in space and time and are the object of special analysis. The present paper contains statistical and probabilistic analyses of rainfall patterns in the Portoviejo basin over a half-century period. As a result and due to the novelty of the study, a new model of intensity, duration and frequency curves for the most important meteorological stations of the aforementioned basin, such as Portoviejo-UTM and Lodan, was obtained. The data used for the calculation were those provided by the National Institute of Meteorology and Hydrology of Ecuador (INAMHI), the country's state agency for the collection and planning of meteorological data. Calculations were performed separately for the Portoviejo-UTM and Lodan stations. Using the equations obtained, an analysis of the results was done, which made it possible to derive other intensity equations used later in the runoff analysis for the intermediate zones between the two stations considered in this study.

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Феноменологическая модель интенсивности, продолжительности и частоты выпадения осадков для бассейна реки Портовьехо, Эквадор

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гидрология, максимальное количество осадков, гидравлика, вероятностная модель, кривые интенсивности, продолжительности, частоты

Аннотация. Феноменологические модели представляют поведение случайных явлений в реальности, модель и функцию, которую она должна выполнять. Аналогичным образом параметры настройки позволяют оценить соответствие наблюдаемых данных переменной конкретной математической модели и проверить достоверность модели для представления реального события. Эти модели, применяемые в точных науках и науках о Земле, анализируют поведение сложных переменных, которые изменяются в пространстве и времени и являются объектом специального анализа. Настоящая работа содержит статистический и вероятностный анализ моделей осадков, выпавших в бассейне реки Портовьехо за полувековой период. В результате и в связи с новизной исследования получена новая модель кривых интенсивности, продолжительности и частоты для наиболее важных метеорологических станций вышеупомянутого бассейна, таких как Портовьехо-УТМ и Лодана. Для расчета использовались данные, предоставленные Национальным институтом метеорологии и гидрологии Эквадора (INAMHI), государственным агентством страны по сбору и планированию метеорологических данных. Расчеты проводились отдельно для каждой станций. С помощью полученных уравнений выполнен анализ результатов, позволивший вывести другие уравнения интенсивности, используемые в дальнейшем при анализе стока для промежуточных зон между двумя станциями, рассмотренными в исследовании.

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Introduction

Methods and models have been developed to assess the parameters involved in the formation of surface runoff.[1] In accordance with the generality of the hydrological cycle, all moisture that reaches the clouds and falls to the ground in the form of snowfall, rain, hail, thaw, etc., is involved in the formation of runoff.

However, there is a hydrographic basin in Ecuador, the Manabí Hydrographic Demarcation, which is distinguished from the others, because its fluvial regime is formed exclusively by rainfall in the rainy season, which generally begins in December and ends in June [1; 2].

[1] Ismaiylov GJ, Perminov AV. *Balance hídrico mundial y recursos hídricos de la tierra, catastro del agua y supervisión de los elementos hídricos.* Moscow: FGBOU MGUP; 2013; *Sistemas de información geográfica para aplicaciones agropecuarias en el ordenamiento de territorio y manejo integral de cuencas*. Ministerio de Agricultura y Ganadería, IICA, CLIRSEN; 2015. Available from http://www.uazuay.edu.ec/promsa/ecuador.htm (accessed: 03.03.2015); *USDA natural resources conservation service soils*. United States Department of Agriculture; 2015. Available from http://www.nrcs.usda.gov/ (accessed: 03.03.2015).

Considering these particularities, to improve, with data updated to the year 2019[2], the models of Intensity-Duration-Frequency curves for the meteorological stations located in the Portoviejo River basin, this research work has been developed. in which new equations are provided for the estimation of rain intensities of return periods and different durations.

The methods used in the analysis of the stochastic variables of precipitation are based on statistical and probabilistic methods developed throughout the history of earth sciences [3], among which the following stand out: methods of filling data missing from averages, regression line and orthogonal correlation accompanied by the respective data consistency analysis. For the frequency analysis, the data was subjected to the treatment with the Karl Pearson Type III correlation [4–6], where with the 3 moments and with the help of the Foster – Rybkin tables it was possible to estimate the extraordinary events for probabilities between 0.01 to 99.99%.

To obtain the rainfall intensity equations, the method of least squares was used, where the intensities for rainfall durations corresponding to 0, 15, 30, 45, 60, 90 and 120 minutes were processed.

1. Materials and methods

The basic information used for the analysis and development of the research is composed of the pluviometric records of maximum rainfall in 24 hours recorded at the Portoviejo-UTM meteorological stations (Portoviejo (M005) and Lodana (M298) for the period 1964–2019. These Data were provided by the National Institute of Meteorology and Hydrology (INAMHI) The total number of records used amounts to 1104.

The meteorological stations of the study are in the Portoviejo River basin, which correspond to the Portoviejo-UTM stations, with code MO005, located in the vicinity of the Botanical Garden of the Technical University of Manabí, at coordinates 559523.22 E, 9884982.27N; and the Lodana station, with code MO298, located at coordinates 568606.76 E, 9871040.58N (Figure 1).

To carry out this research, the experience offered by the National Institute of Meteorology and Hydrology (INAMHI)[3] [7; 8], in the studies of intense rains carried out in 1999 with its update in 2015 was taken as a starting point, and that, between others, presented a series of equations for estimating rainfall intensities for the entire national territory based on geographic location, duration of storms and specific return periods.

The present work intends to be a complement to the methods that are currently used for the estimation of rainfall intensities, very useful when calculating runoff, product of rainwater drainage [9; 10]. The records used are updated and consistent and correspond to the period 1964–2019.

The most relevant methodological aspects are inscribed in: a) selection of the meteorological stations;[4] b) collection of the required information; c) analysis of data consistency; d) filling in missing data in the series [11]; e) variability analysis; f) preparation of the probability curve[5] [12]; g) estimation of rainfall intensities [3]; and h) obtaining the intensity – duration – frequency (IDF) curves.

Based on the values of maximum precipitation in 24 hours, obtained with the Pearson Type III distribution analysis, the weighted values of precipitation were obtained in accordance with the distribution of daily precipitation obtained in the hydrological studies of the basins of the Chone and Portoviejo rivers. This served as the basis for obtaining rainfall intensities for specific return periods.

The functionality for estimating the events corresponding to various return periods contemplated by the Pearson Type 3 methodology is indicated in the formula:

$$x = \bar{x}(1 + TC_v), \quad (1)$$

were x – event (precipitation) for specific return period, mm; $\bar{x}$ – arithmetic mean of records, mm; T – Foster – Rybkin coefficient (probability theory); C_v – coefficient of variation.

The equations for estimating rainfall intensities were obtained by analyzing the method of least squares, whose mathematical expression is summarized in the following expression:

[2] *Anuarios meteorológicos.* Instituto Nacional de Hidrología y Meteorología; 2015. Vol. 2015.

[3] Determinación de ecuaciones para el cálculo de intensidades máximas de precipitación. Quito: INAMHI; 2015. Available from https://www.gob.ec › inamhi (accessed: 25.02.2022).

[4] *Anuarios meteorológicos*. Secretaría de Gestión de Riesgos; 2014. Available from http://186.42.174.231/index.php/clima/anuarios-meteorologicos (accessed: 25.02.2022).

[5] Rumyantsev VK. *Hydrological calculations in hydrotechnical constructions.* Moscow: RUDN University; 1992. (In Russ.)

$$i = \frac{a}{b+t}, \quad (2)$$

were i – rain intensity, mm/h; t – rain duration, min; a and b – coefficients according to the return period.

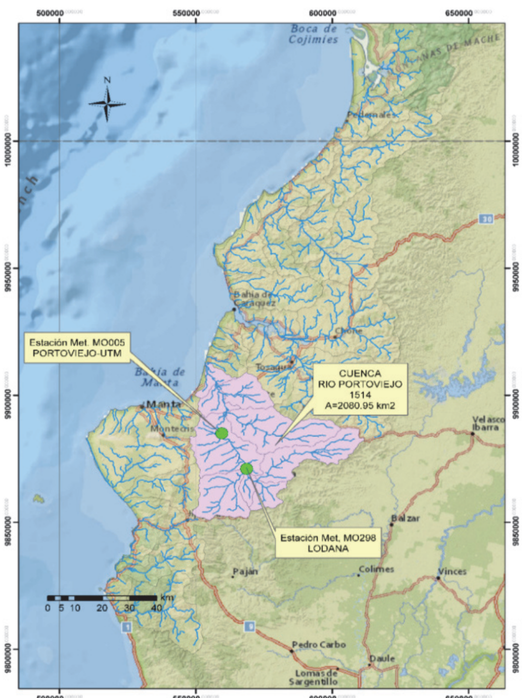

Figure 1. Location of the study area

2. Results and discussion

Based on the guidelines and methodological aspects displayed in the materials and methods section, the rain intensity equations were obtained for the Portoviejo-UTM and Lodana stations, which became a fundamental input for the elaboration of the respective rainfall curves. Intensity – duration – frequency (IDF).

Figure 2 shows the histograms of the variability of the maximum annual rainfall observed in 24 hours for both the Portoviejo-UTM and Lodana stations. In general, it is observed that there is a great non-uniformity in the analyzed values, which is quantitatively evidenced with the calculation of the coefficients of variation, which were obtained equal to 0.54 and 0.56 for the Portoviejo-UTM and Lodana stations respectively. Despite being two geographically distant stations, separated from each other at an approximate distance of 17 km, the climatic variability conditions are similar, which allows statistical inferences to be made on the physical variables of the environment [2].

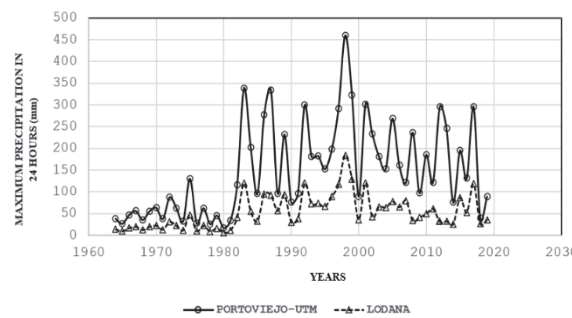

Figure 2. Histograms of maximum precipitation in 24 hours

Tables 1 and 2 show the results of the coefficients of the rain intensity equations for the return periods corresponding to 2, 3, 5, 10, 20, 25, 50, 100, 200, 500 and 1000 years for the stations under study.

In the case of the Portoviejo-UTM station, applying the equations obtained, various values of rainfall intensities ranging from 5 to 120 minutes, values ranging from 22.17 to 249.88 mm/h, were estimated. These detailed results are summarized in Table 3.

Table 1

Coefficients of the rain equations – Portoviejo-UTM station

Tr, years	a	b
1000	44327.56	155.85
500	40184.24	155.85
200	35508.82	155.85
100	31393.40	155.85
50	27510.75	155.85
25	23183.22	155.85
20	22052.07	155.85
10	17936.65	155.85
5	13690.59	155.85
3	10324.26	155.85
2	7615.46	155.85

Table 2

Coefficients of the rainfall equations – Lodana Station

Tr, years	a	b
1000	16626,45	155,85
500	15331,83	155,85
200	13487,90	155,85
100	12008,29	155,85
50	10509,73	155,85
25	9273,29	155,85
20	8712,82	155,85
10	7255,63	155,85
5	5776,03	155,85
3	4636,64	155,85
2	3691,13	155,85

Table 3

Rain intensity for the Portoviejo-UTM station, mm/h

t, min	Return period, years										
	1000	500	200	100	50	25	20	10	5	3	2
0	284.42	257.83	227.83	201.43	176.52	148.75	141.49	115.09	87.84	66.24	48.86
5	275.58	249.82	220.75	195.17	171.03	144.13	137.09	111.51	85.11	64.18	47.34
10	267.27	242.29	214.10	189.28	165.87	139.78	132.96	108.15	82.55	62.25	45.92
15	259.45	235.20	207.83	183.74	161.02	135.69	129.07	104.98	80.13	60.43	44.57
30	238.51	216.21	191.06	168.91	148.02	124.74	118.65	96.51	73.66	55.55	40.98
45	220.69	200.07	176.79	156.30	136.97	115.42	109.79	89.30	68.16	51.40	37.92
60	205.36	186.16	164.50	145.44	127.45	107.40	102.16	83.10	63.43	47.83	35.28
120	160.69	145.67	128.72	113.80	99.73	84.04	79.94	65.02	49.63	37.43	27.61

Table 4

Rain intensity for Lodana station, mm/h

t, min	Return period, years										
	1000	500	200	100	50	25	20	10	5	3	2
0	106.7	98.4	86.5	77.0	67.4	59.5	55.9	46.6	37.1	29.7	23.7
5	103.4	95.3	83.9	74.7	65.3	57.7	54.2	45.1	35.9	28.8	22.9
10	100.2	92.4	81.3	72.4	63.4	55.9	52.5	43.7	34.8	28.0	22.3
15	97.3	89.7	78.9	70.3	61.5	54.3	51.0	42.5	33.8	27.1	21.6
30	89.5	82.5	72.6	64.6	56.5	49.9	46.9	39.0	31.1	24.9	19.9
45	82.8	76.3	67.2	59.8	52.3	46.2	43.4	36.1	28.8	23.1	18.4
60	77.0	71.0	62.5	55.6	48.7	43.0	40.4	33.6	26.8	21.5	17.1
120	60.3	55.6	48.9	43.5	38.1	33.6	31.6	26.3	20.9	16.8	13.4

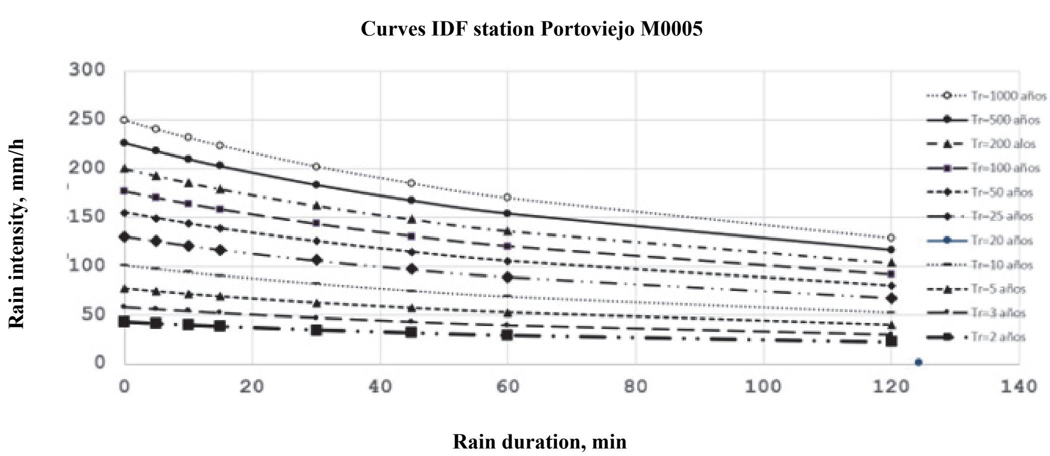

Figure 3. Curves IDF – station Portoviejo

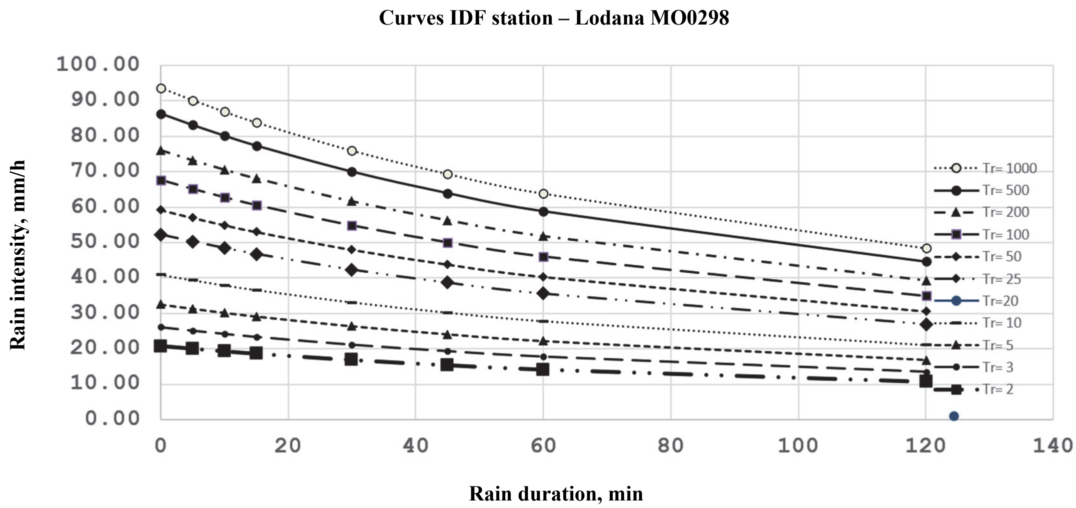

Figure 4. Curves IDF – station Lodana

Similarly, in Table 4, the corresponding rain intensity values for the Lodana station are broken down. In this case, the amounts obtained are in the range of 10.74 to 93.72 mm/h.

The graphic representation of the intensity – duration – frequency (IDF) curves are contained in Figures 3 and 4. Each of these graphs presents three variables, which are important to consider when planning, designing, and controlling water resources that are the result of surface runoff, such as: the intensity of rain, the duration of the storm with its respective frequency of recurrence [2; 13; 14].

Conclusion

Regarding the study and development of information related to the determination of the curves of intensity, duration, and frequency, for different territories of Ecuador, the institution that has led the execution of these projects has been the National Institute of Meteorology and Hydrology, with the support of related development institutions, such as the Manabí Rehabilitation Center, the Manabí Water Resources Corporation, the Water Resources Board, among others. One of the products generated in this context has been the so-called Study of Intense Rainfall, whose initial version came to light in 1999, with an update to the year 2015.

Comparing the values of maximum precipitation in 24 hours obtained through the equations proposed by the National Institute of Meteorology and Hydrology in the study of intense rains with those obtained from this study, it has been established that the former exceeds to the seconds in average values equivalent to 114.44%. This situation is since the proposed model of this institution considers in the same function the variables of duration of rain and return periods, which could lead to obtaining the results.

Intensity duration and frequency curves were obtained for the Portoviejo-UTM and Lodana stations, located in the Portoviejo River basin. Each of the graphs consists of 11 curves for the corresponding return periods 2, 3, 5.10, 20, 25.50, 100, 200, 500 and 1000. These curves constitute updated information for the year 2019 and serve as support within the field of management and optimization of water resources within the territory within the basin in question.

Once the rainfall intensity equations were obtained, for their validation, rainfall durations ranging from 5 to 120 minutes were considered for both stations. For the case of the Portoviejo-UTM station (MO005), it was estimated that the intensities for return periods between 2 and 1000 years are in the range of 22.17 to 249.88 mm/h; while for the Lodana station (MO298) between 10.74 and 93.72 mm/h. For the intermediate zones between the stations, an inference was made by way of weighting, which allowed, through specific regression analyses, to obtain another 11 equations for the two stations.

According to the analysis of variability in the series of maximum rainfall in 24 hours, it has historically been determined that there is a great nonuniformity in the distribution of rainfall with coefficients of variation greater than 0.5, which leads to the formation of peaks recurring, estimating in accordance with the trend, that in the future there will be an increase in the values of maximum precipitation in 24 hours above 89.9 mm.

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