Climatic Aggressiveness and Precipitation Concentration in a Peruvian Amazon Basin: Alto Huallaga Interbasin

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Abstract: Precipitation in the central Peruvian Amazon is characterized by being seasonal and with strong intensities during the first months of the year, leading to flooding and the subsequent collapse of the local infrastructure in provinces of San Martin, Huanuco, Pasco and La Libertad Regions of Peru, which are located within the delimitation of the Alto Huallaga Interbasin. Therefore, the objective of this research was to evaluate the climatic aggressiveness and concentration precipitation in the Amazon basin, applying three indices of aggressiveness and a precipitation concentration index (ICP), estimated from the precipitation record of the climatic stations in the study area. The results show a very high correlation between mean precipitation and altitude (R^2 = 0.72) and with respect to the aggressiveness, the modified Fournier-Maule index (IFMM) was the one with the best correspondence with respect to altitude (R^2 = 0.72) and mean precipitation (R^2 = 0.98), however, the ICP shows moderate correlations with altitude (R^2 = 0.21) and mean precipitation (R^2 = 0.16). Likewise, the extreme values of the different indices were estimated for different return periods and a multiple linear regression model was developed to relate climatic aggressiveness and the ICP to estimate the mean precipitation (R^2 = 0.99). Finally, it is concluded that, the Alto Huallaga Interbasin presents a very low climatic aggressiveness and the concentration of rain is moderately seasonal.

Keywords: Climatic aggressiveness; altitude; Amazon basin; mean precipitation

Agresividad Climática y Concentración de Precipitaciones en una Cuenca Amazónica Peruana: Intercuenca Alto Huallaga

Resumen: Las precipitaciones en la Amazonía central peruana se caracterizan por ser estacionales y con fuertes intensidades durante los primeros meses del año, conllevando a que se produzcan inundaciones y el posterior colapso de la infraestructura local de las provincias de las Regiones San Martín, Huánuco, Pasco y La Libertad de Perú, que se encuentran dentro de la delimitación de la Intercuenca Alto Huallaga. Por lo expuesto, la presente investigación tuvo por objetivo evaluar la agresividad climática y concentración de precipitaciones en la Cuenca Amazónica, aplicando para tal fin tres índices de agresividad y un índice de concentración de precipitaciones (ICP), los cuales se estiman a partir del registro de lluvias de las estaciones climáticas de la zona de estudio. Los resultados muestran una alta correlación entre la precipitación media y altitud (R^2 = 0.72) y respecto a la agresividad, el índice de Fournier-Maule modificado (IFMM) fue el de mejor correspondencia con respecto a la altitud (R^2 = 0.72) y precipitación media (R^2 = 0.98), sin embargo, el ICP muestra correlaciones moderadas con la altitud (R^2 = 0.21) y la precipitación media (R^2 = 0.16). Así mismo, se estimaron los valores extremos de los diferentes índices para diferentes períodos de retorno y se desarrolló un modelo de regresión lineal múltiple que relaciona la agresividad climática y el ICP para estimar la precipitación media (R^2 = 0.99). Finalmente, se concluye que la Intercuenca Alto Huallaga presenta una agresividad climática muy baja y la concentración de lluvias es moderadamente estacional.

Palabras clave: Agresividad climática; altitud; cuenca Amazónica; precipitación media

1. INTRODUCTION

Currently there are various climatic indices and statistical parameters that allow studying the behavior of rainfall, whether on a daily, monthly or annual level (López et al., 2019). Within this set of indicators, those related to the estimation of climatic aggressiveness and precipitation concentration stand out; since, over the years, it has been

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shown that both the aggressiveness of the rains and their concentration have made it possible to adequately manage the planning of water resources in the face of possible extreme events that may be associated with climate change, especially in Amazon basins (Zubieta et al., 2019).

This is why the importance of its study arises, since by having seasonal variability in rainfall, these can affect the continental water balance of almost all the countries in South America, whose area of influence mainly includes the Amazon River and its tributaries (Da Mota et al., 2020). Likewise, precipitation is a variable of vital importance for hydrological, climatic, water resource management as well as for evaluating the event of natural disasters (Arriola et al., 2023). It is necessary to know their behavior and distribution throughout a hydrographic basin or in an urban area (Llano, 2018), given that the impact that abnormal rains can cause in short periods of time, will trigger extreme flows and subsequently floods (Caicedo et al., 2024), or in other cases, significant droughts generated by increased erosion (Ilbay-Yupa et al., 2019).

The climatic aggressiveness estimated from the balance of monthly and annual precipitation establishes the erosive hydrological condition to which a geographic area or basin is exposed (Baecheler & Bravo, 2019). Hence, this indicator has served as a reference to adequately estimate erosivity by incorporating it into the original R factor of the universal soil loss equation, the latter known by its acronym as USLE (Bezak et al., 2023; Chen et al., 2023). Usually, arid areas or areas near the coast with low altitude tend to present high climatic aggressiveness, while areas with abundant vegetation and intermediate to high altitude show low aggressive conditions (Arriola et al., 2022).

In relation to the concentration of precipitation, this is determined by means of a numerical index that establishes whether the precipitation obeys a uniform, seasonal or irregular climatic pattern (Azioune et al., 2023). Furthermore, the concentration can be estimated under different rainfall scenarios, whether daily, monthly or annual, depending on the orographic conditions of the study area (Llano, 2023).

That is why both the concentration of precipitation and the climatic aggressiveness tend to show a significant correspondence with respect to latitude, longitude, altitude and mean precipitation (Arriola et al., 2022; Valdés-Pineda et al., 2016). However, these conditions noted above will depend on the amount of historical records and weather stations available in the evaluation area (Bessaklia et al., 2018). Therefore, these indices are not recommended for studies with a limited number of stations and short-duration precipitation records (Lana et al., 2023).

According to the reviewed literature on climate aggressiveness, the Fournier index (IF), the modified Fournier index (IFM), the modified Fournier-Maule index (IFMM), are the most used aggressiveness estimators for the study of erosion processes in hydrographic basins (Back et al., 2019). Meanwhile, for concentration analysis, the precipitation concentration index (ICP) has been widely used to evaluate the behavior of rainfall in relation to altitude and other climatic variables (Olguín, 2019); including changes that have occurred in the precipitation pattern due to climate change (Diodato et al., 2020).
However, a large amount of precipitation data is required at a daily level and with extensive lengths of annual records, which often limits this type of applications for hydrological and climatic studies (García-Barrón et al., 2018).

Throughout the world, there are various investigations directly related to these indices, as indicated by Llano (2021). Despite this, very few studies have focused on Amazonian areas, especially South America. Among the limited scientific contributions, notable work has been developed in Brazil, including studies on precipitation, its extreme pattern and the distribution of its seasonality and variability, which were analyzed by Aguiar et al. (2019), Da Motta et al. (2020), De Moura et al. (2021), De Brito et al. (2022) and Costa et al. (2023).

In Peru, only three studies related to climatic aggressiveness and precipitation concentration have been developed, the first addressed by Arriola et al. (2022); while the research by Zubiate et al. (2017) has evaluated only the concentration of precipitation in a Peruvian Amazon area. Subsequently, Zubiate et al. (2019) carried out the largest scale analysis for the entire Amazon basin that covered Bolivia, Brazil, Colombia, Ecuador, Peru and Venezuela, whose results have only been validated for the precipitation concentration at a daily level. Therefore, it is necessary to incorporate the evaluation of climatic aggressiveness, that allows us to know the vulnerability to which the Peruvian Amazon area is exposed, since it could affect the abundance, richness and diversity of its flora and fauna (Llampazo et al., 2023).

The present study aimed to evaluate the climatic aggressiveness and concentration of precipitation in the Alto Huallaga Interbasin, applying three aggressiveness indices: IF, IFM, and IFMM, and one of precipitation concentration: ICP, which are estimated from the rainfall record of the climatic stations available in the Peruvian Amazon area. Then, this area of Peru is susceptible to heavy rains, major floods and thus the subsequent collapse of the local infrastructure of some provinces of the San Martin, Huanuco, Pasco and La Libertad Regions of Peru, which are located within the delimitation of this basin.

That is why, with the findings of this research, it will be possible to know how the aggressiveness and concentration of precipitation is distributed in the Alto Huallaga Interbasin, serving at the same time as an updated scientific basis for researchers interested in understanding the rainfall behavior of this basin of the Peruvian jungle.

2. MATERIALS AND METHODS

2.1 Study zone

The Alto Huallaga Interbasin has a geographical area of 30276 Km^2, it is located between the coordinates 76 ° 00 ´ to 77 ° 00 ´ west longitude and 7 º 00 ' to 11 º 00 ' south latitude (Figure 1). Likewise, the basin has an altitude that varies between 750 m. s. n. m. up to 5500 m. s. n. m. above sea level and it has a rugged relief, whose slope varies from 0.20 % to 12.00 %, highlighting in its orography the presence of various mountainous areas and valleys, which cause various ecosystems and extensive plant coverage to occur in this basin (Carrión, 2018).

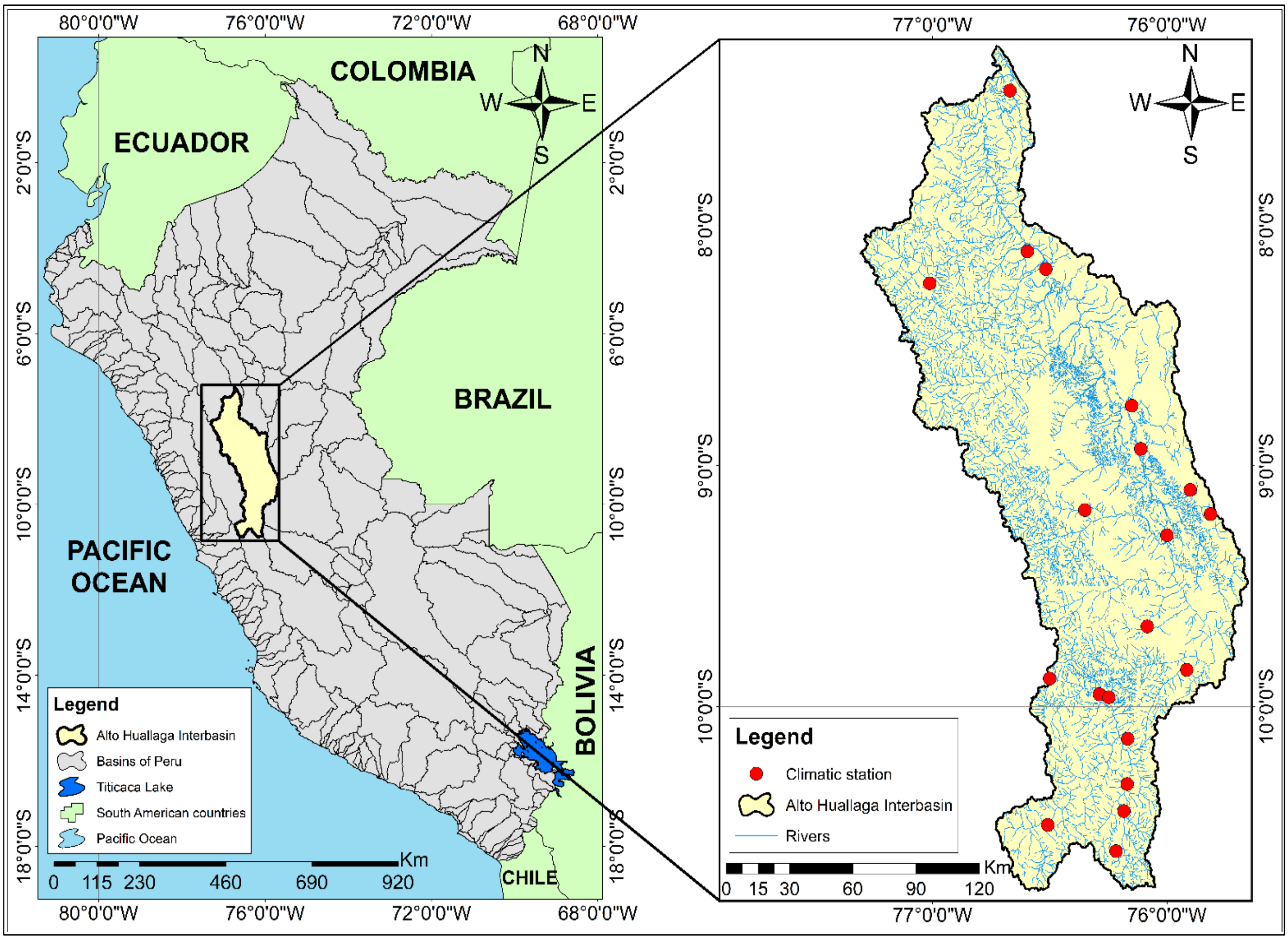

Figure 1. Location of the Alto Huallaga Interbasin, South America, Peru

Politically, the Alto Huallaga Interbasin covers some provinces in the San Martin, Huanuco, Pasco and La Libertad Regions of Peru. Located in a strategic area of the central jungle, it allows the constant exchange of essential products and export such as coffee and cocoa.

Regarding the availability of its water resources, the Alto Huallaga Interbasin is part of the set of basins of the Huallaga River, since this river in the study area has a length close to 770 km, whose route goes from west to east. In relation to the rainfall pattern, these usually occur between the months of November to April, with maximum values between February and April, as shown in Figure 2 for some climatic stations of the Alto Huallaga Interbasin.

2.2 Data collection and processing

Through the collection of data, it was possible to establish that the Alto Huallaga Interbasin has a total of 29 climate stations of the conventional type. However, for the purposes of this investigation, only 20 stations were considered (Table 1), since it was decided to select a minimum record amount of 15 years and in each year the full 12 months for each station, as recommended by the SENAMHI (2018), using this criterion as a protocol for the collection and selection of precipitation information. The data collection source was obtained from the open access electronic portal of the Autoridad Nacional del Agua (ANA) of Peru, which is available for any consultation.

To process the precipitations information, data quality control was initially used, with the purpose of establishing possible erroneous ranges that could originate from existing operational problems or that may be associated with the observation and collection of the precipitations in each of the climatic stations, as suggested by Luna-Romero et al. (2018).

Therefore, an initial graphic evaluation was applied using box diagrams at 95 % probability, which helped to exclude the months considered as atypical cases found in some records, which exceeded the monthly mean of precipitation by more than three standard deviations, as refers by Manikanta, et al. (2023).

2.3 Climate aggressiveness and precipitation concentration

To determine the climatic aggressiveness and the concentration of precipitation, as well as their respective classifications, the equations presented in Table 2 were used.

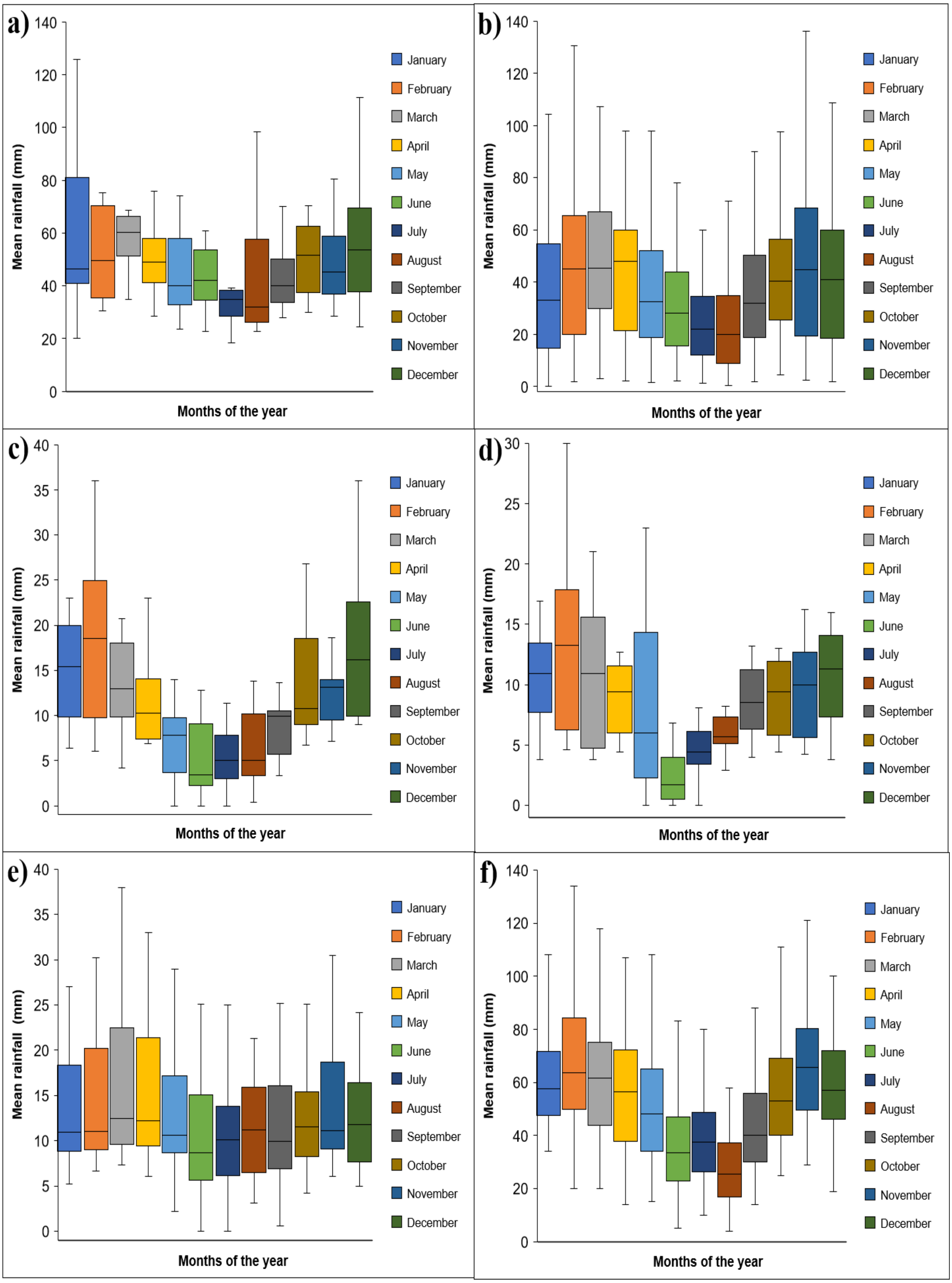

Figure 2. Box diagram of the mean rainfall of some climatic stations of the Alto Huallaga Interbasin: a) Cachicoto; b) Campanilla; c) Huariaca; d) Milpo; e) Ongon and f) Tingo Maria

Table 1. Climatic stations considered in this study

N°	Station name	Altitude (m. s. n. m.)	South latitude	West longitude	Registration period
1	Ambo	3025	10.13 °	76.17 °	1964 - 1998
2	Aucayacu	586	8.93 °	76.11 °	1974 - 2018
3	Cachicoto	1140	9.18 °	76.35 °	1964 - 1978
4	Campanilla	290	7.44 °	76.67 °	1963 - 2022
5	Canchan	1986	9.95 °	76.29 °	1988 - 2018
6	Carpish	1950	9.67 °	76.08 °	1994 - 2018
7	Chaglla	2800	9.85 °	75.92 °	1993 - 2018
8	Huanuco	1947	9.96 °	76.25 °	1964 - 2018
9	Huariaca	3355	10.43 °	76.18 °	1964 - 1980
10	Jacas Chico	3673	9.88 °	76.50 °	1974 - 2018
11	La Divisoria	1961	9.20 °	75.81 °	1995 - 2018
12	La Morada	542	8.75 °	76.15 °	1966 - 1981
13	Milpo	4256	10.60 °	76.22 °	1963 - 1981
14	Ongon	1315	8.24 °	77.01 °	1963 - 1989
15	San Rafael	2722	10.32 °	76.17 °	1966 - 2018
16	Tananta	480	8.11 °	76.59 °	1993 - 2018
17	Tingo María	660	9.29 °	75.99 °	1964 - 2018
18	Tocache	512	8.18 °	76.52 °	1966 - 2011
19	Tulumayo	640	9.10 °	75.90 °	1965 - 2018
20	Yanahuanca	3150	10.49 °	76.51 °	1978 - 2018

Table 2. Applied indices and their respective classifications

Index	Equation	Classification	
		Quantitative	Qualitative
Fournier index (IF)	$IF_j = \frac{(P_{\max j})^2}{P}$	< 50	Very low
		51 - 100	Low
		101 - 150	Moderate
		151 - 200	High
		> 201	Very high
Modified Fournier index (IFM)	$IFM_j = \frac{\sum_{i=1}^{12}(P_{ij})^2}{P}$	< 100	Very low
		101 - 200	Low
		201 - 300	Moderate
		301 - 400	High
		> 401	Very high
Modified Fournier-Maule index (IFMM)	$IFMM_j = \frac{(\sum_{i=1}^{12} P_{ij})^2}{P}$	< 400	Very low
		401 - 1000	Low
		1001 - 1800	Moderate
		1801 - 2800	High
		> 2801	Very high
Precipitation concentration index (ICP)	$ICP_j = 100 \frac{\sum_{i=1}^{12} P_{ij}^2}{P_j^2}$	< 10 %	Uniform
		11 % - 15 %	Moderately seasonal
		16 % - 20 %	Seasonal
		21 % - 50 %	Strongly seasonal
		≥ 51 %	Irregular

Where $P_{max\ j}$ is the mean precipitation of the rainiest month of the year j, P is the mean annual precipitation, P_{ij} is the monthly precipitation of the month i in the year j and P_j is the annual precipitation for the year j.

It should also be noted that among the indices shown in Table 2, IF, IFM and ICP were cited from Ilbay et al. (2019), while IFMM was cited from Pizarro et al. (2008). It should be added that all these indices are also cited and explained in the research of Arriola et al. (2022).

Subsequently, the correlations of these indices were established with respect to the altitudes and mean precipitations of the climatic stations of the Alto Huallaga Interbasin, a procedure suggested by Ilbay et al. (2019), Fernandez et al. (2020), Amiri & Gocić (2021), Arriola et al. (2022) and Lana et al. (2023), whose ranges of the correlation coefficient r and its variations (Table 3) were taken from Herrera et al. (2017).

Table 3. Correlation coefficient ranks and classification

Coefficient ranks	Classification
r = 1.00	Perfect
0.80 < r < 1.00	Very high
0.60 < r < 0.80	High
0.40 < r < 0.60	Moderate
0.20 < r < 0.40	Low
0.00 < r < 0.20	Very low
r = 0.00	Null

Then, the extreme values of the IFM, IFMM and ICP were estimated for different return periods, applying for this purpose six theoretical distributions (Table 4) with linear moments, as suggested by Hosking (1990), for a significance level of 5 % and with the Kolmogorov-Smirnov goodness-of-fit test, whose best-performing distributions and the values of the tabular delta and theoretical delta obtained for each index are shown in Table 5. The equations of the theoretical distributions shown in Table 4 were cited from the research by Vargas et al. (2023).

Table 4. Theoretical distributions used for extreme value analysis

Theoretical distribution	Probability density function
Normal	$F(x) = \left(\frac{1}{\sqrt{2\pi S}}\right)\int_{-\infty}^{x} e^{-\left[\left(\frac{1}{2}\right)\left(\frac{x-\bar{x}}{S}\right)^2\right]}$
Exponential	$F(x) = 1 - e^{\left[-\left(\frac{x-\varepsilon}{\alpha}\right)\right]}$
Generalized Extreme Value (GEV)	$F(x) = e^{-\left[\left\{\frac{1-k(x-\varepsilon)}{\alpha}\right\}^{\frac{1}{k}}\right]}$
Gumbel	$F(x) = e^{\left[-e^{\left\{\frac{-(x-\varepsilon)}{\alpha}\right\}}\right]}$
Weibull	$F(x) = 1 - e^{\left[-\left(\frac{x-\varepsilon}{\beta}\right)^{\beta}\right]}$
Pareto	$F(x) = 1 - \left[1 - \left\{\frac{k(x-\varepsilon)}{\alpha}\right\}\right]^{\frac{1}{k}}$

Additionally, a multiple linear regression model was developed to relate climatic aggressiveness and precipitation concentration to estimate the mean precipitation in the Alto Huallaga Interbasin, with the purpose of knowing whether or not there is a significant relationship between said variables.

3. RESULTS AND DISCUSSION

According to the results found in this research, it is deduced from Figure 3a, that there is a high correlation between mean precipitation and altitude (r = 0.85; R^2 = 0.72), and in relation to climatic aggressiveness with respect to altitude, the IF (Figure 3b) showed a moderate correlation (r = 0.53; R^2 = 0.28), while the IFM (Figure 3c) and the IFMM (Figure 3d) showed very high correlations with this variable, that is, they were r = 0.82 and r = 0.85, respectively. In the case of the ICP

(Figure 3e), a moderate correlation was established in relation to altitude (r = 0.46; R^2 = 0.21).

Regarding of mean precipitation, the IFMM was the one with the best correlation (r = 0.99; R^2 = 0.98) in correspondence to this variable (Figure 3h).

Table 5. Theoretical distributions of best fit chosen for each climatic station and for each applied index according to Kolmogorov - Smirnov test

N°	Station name	For IFM			For IFMM			For ICP		
		Tabular delta	Theoretical delta	Chosen distribution	Tabular delta	Theoretical delta	Chosen distribution	Tabular delta	Theoretical delta	Chosen distribution
1	Ambo	0.272	0.0954	Pareto	0.272	0.0713	Pareto	0.272	0.124	GEV
2	Aucayacu	0.2206	0.104	GEV	0.2206	0.0874	GEV	0.2206	0.1186	GEV
3	Cachicoto	0.3512	0.0815	GEV	0.3512	0.0995	GEV	0.3512	0.0968	GEV
4	Campanilla	0.1756	0.0876	Normal	0.1756	0.0987	Pareto	0.1756	0.1384	GEV
5	Canchan	0.2443	0.0603	Gumbel	0.2443	0.0694	Weibull	0.2443	0.118	GEV
6	Carpish	0.272	0.1457	Weibull	0.272	0.0964	GEV	0.272	0.0949	GEV
7	Chaglla	0.2667	0.065	GEV	0.2667	0.0558	GEV	0.2667	0.1085	GEV
8	Huanuco	0.1886	0.0708	GEV	0.1886	0.0644	Gumbel	0.1886	0.0553	GEV
9	Huariaca	0.34	0.066	Pareto	0.34	0.1016	Weibull	0.34	0.0904	Pareto
10	Jacas Chico	0.2027	0.0843	Pareto	0.2027	0.1102	Pareto	0.2027	0.0605	Gumbel
11	La Divisoria	0.2776	0.1011	GEV	0.2776	0.1218	GEV	0.2776	0.1607	GEV
12	La Morada	0.34	0.1152	GEV	0.34	0.1176	Pareto	0.34	0.0826	GEV
13	Milpo	0.3772	0.1009	Pareto	0.3772	0.1104	Gumbel	0.3772	0.3498	Normal
14	Ongon	0.2617	0.0801	Weibull	0.2617	0.068	Weibull	0.2617	0.0733	GEV
15	San Rafael	0.1943	0.1209	GEV	0.1943	0.1107	GEV	0.1943	0.0977	Pareto
16	Tananta	0.2667	0.0534	Normal	0.2667	0.0788	Normal	0.2667	0.1144	GEV
17	Tingo Maria	0.1834	0.0581	Gumbel	0.1834	0.0734	Normal	0.1834	0.1093	GEV
18	Tocache	0.2443	0.0657	GEV	0.2443	0.1077	Normal	0.2443	0.1526	Pareto
19	Tulumayo	0.1963	0.0718	GEV	0.1963	0.0969	Weibull	0.1963	0.1281	GEV
20	Yanahuanca	0.2236	0.0764	Normal	0.2236	0.0658	Normal	0.2236	0.0713	GEV

Likewise, with the IFM (Figure 3g) a high correlation was also established (r = 0.94; R^2 = 0.88), while the IF (Figure 3f) was the opposite since its correlation was moderate (r = 0.53; R^2 = 0.28). Finally, the ICP (Figure 3i) showed a low correlation with the mean precipitation (r = 0.40; R^2 = 0.16).

The results of these indices are similar to the variations reported in studies from various countries, highlighting Baecheler & Bravo (2019) and Valdés et al. (2016) for Chile, Gallardo et al. (2018) for Cuba, Back et al. (2019) for Brazil, Olguín (2019) for Bolivia, Ilbay-Yupa et al. (2019) for Ecuador, Fernandez et al. (2020) for Portugal and Arriola et al. (2022) for Peru. Despite these results, other researches carried out by Zubieta et al. (2017), Bessaklia et al. (2018), Huang et al. (2018), Amiri & Gocić (2021) and Azioune et al. (2023), note that there are significant variations in the low to moderate correlations of the ICP with respect to altitude and mean precipitation.

However, as stated by Zubieta et al. (2019), the concentration of precipitation in different parts of the world is irregular and does not necessarily have a spatial dependence on altitude or the same precipitation. Furthermore, in what corresponds to the Amazon basins, the spatial distribution of this indicator is influenced by winds, temperature changes and extreme precipitation (Zubieta et al., 2017).

In relation to the Alto Huallaga Interbasin, similar results of the ranges obtained from the IFM are shown in the research by Back et al. (2019) and Nunes et al. (2023), since their monthly values ranged between 10 and 70. Regarding the other indices, no other scientific contributions related to Amazonian areas were found to make the corresponding comparison.

From the above and from the research findings, it is inferred that the IFMM is the one with the best correlation with both altitude and mean precipitation, while in second place corresponds to the IFM, consequently, both indices are suitable for estimating the climatic aggressiveness of the Alto Huallaga Interbasin. That is why Figure 4 was developed, corresponding to the distribution of these indices, while Figure 5 indicates the analysis of extremes of the IFM, IFMM and ICP, for return periods of 5, 10 and 25 years.

Likewise, the importance of using the analysis of extreme value adjustment for the different climatic indicators is to know how these indicators are spatially distributed in the study area and that according to the distribution of best performance, the possible pattern or change that they may have for different return periods can be known.

It should be noted that both Figure 4 and Figure 5 were developed through the process known as inverse distance weighting (IDW) interpolation from the value of each index obtained at the respective climatic station. The IDW method is highly recommended for the spatial analysis of climatic variables in different areas and hydrographic basins, as suggested by Wang et al. (2022), Arriola et al. (2023), Lee et al. (2024) and Kabolizadeh et al. (2024).

This is why this IDW technique is the most appropriate, especially when you want to extrapolate ranges of climatic indices in geographical areas where not much data is available,

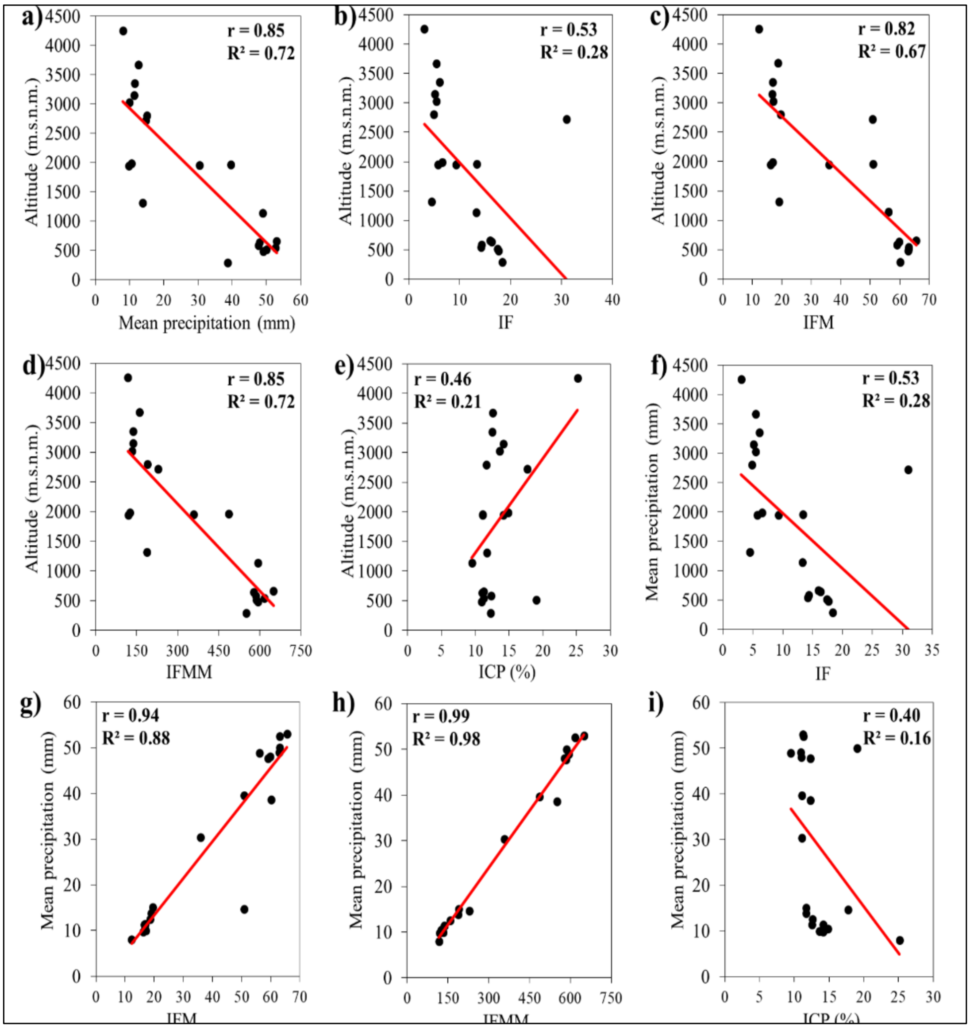

Figure 3. Correlations with respect to altitude and: a) Mean precipitation; b) IF; c) IFM; d) IFMM; e) ICP; and mean precipitation in relation to: f) IF; g) IFM; h) IFMM; i) ICP

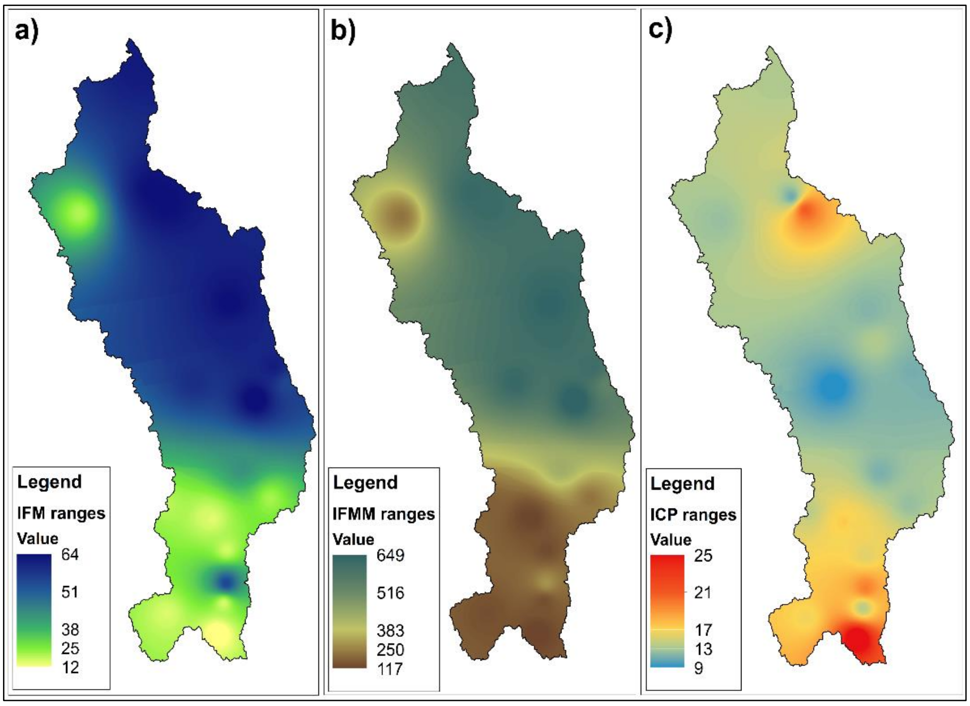

Figure 4. Spatial distribution of climatic aggressiveness and precipitation concentration for the Alto Huallaga Interbasin: a) IFM; b) IFMM; c) ICP

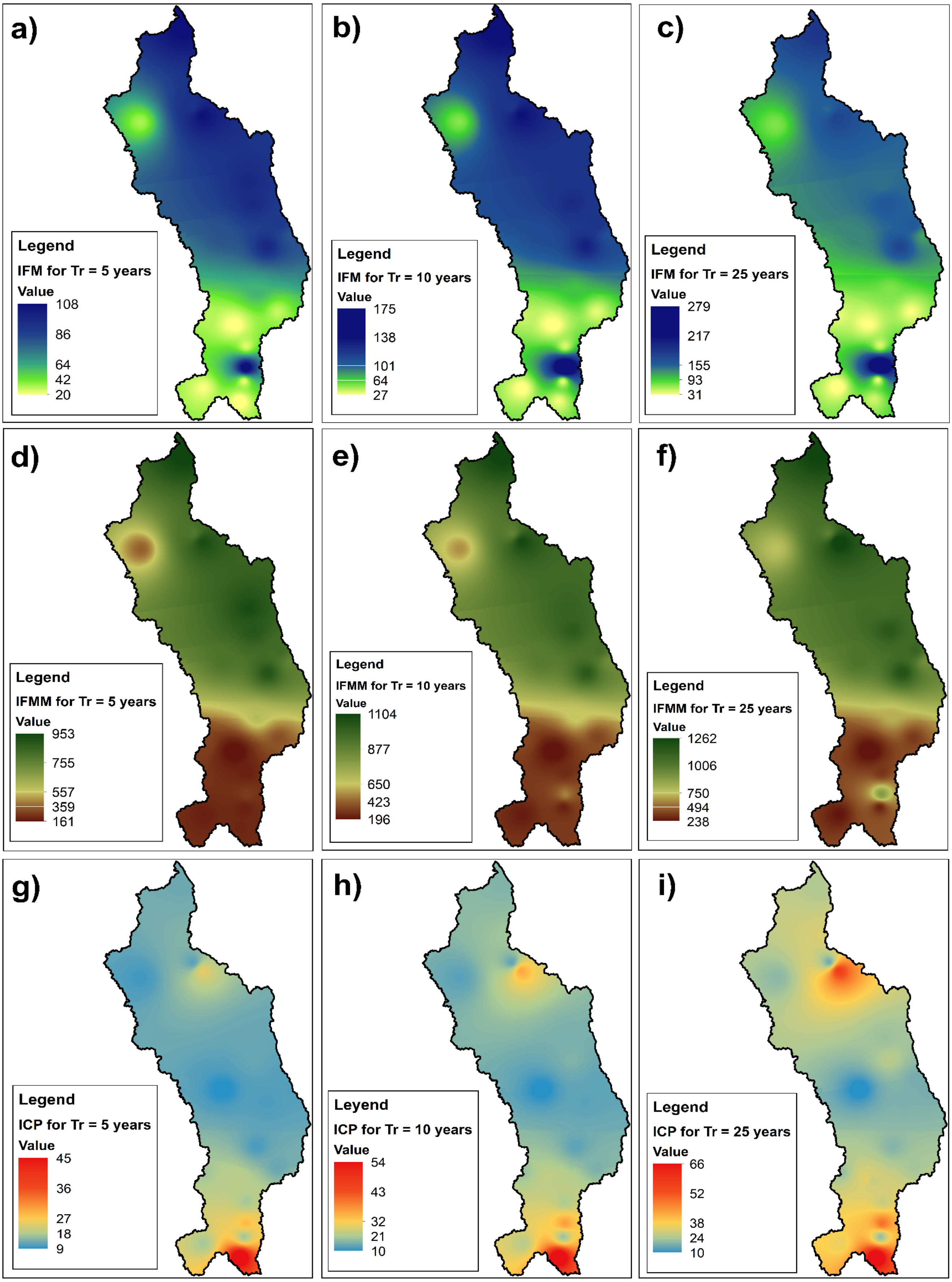

Figure 5. Distribution of extreme values of climatic aggressiveness and precipitation concentration for the Alto Huallaga Interbasin for 5 years return periods: a) IFM; d) IFMM; g) ICP; 10 years: b) IFM; e) IFMM; h) ICP, and 25 years: c) IFM; f) IFMM; i) ICP

being in this case study the estimation of the IFM, IFMM and the ICP for all the Alto Huallaga Interbasin.

Likewise, the spatial pattern of the IFM (Figure 4a), IFMM (Figure 4b) and the ICP (Figure 4c) is shown, whose classifications according to Table 2, corresponded predominantly to very low for the first two indices and moderately seasonal for ICP.

As indicated previously, Figure 5 shows the analysis of extremes for three return periods, by applying the theoretical distributions adjusted to linear moments, but unlike Gallardo et al. (2018) only used a distribution for the study of extremes of the IFM, which is not very significant for the estimation of maximum values.

Moreover, as can be seen in Table 5, of all the theoretical distributions applied to each index, the GEV (Generalized Extreme Value) and Pareto distribution stand out as those with the best fit for the study area. This is because generally both distributions are the ones that best fit climatic variables where it is necessary to analyze extreme values for different return periods, being in this case the climatic aggressiveness index and the ICP.

On the other hand, as expected, the patterns of climatic aggressiveness present low values in the southern zone, while the highest ranges are located in the northwest part of the Alto Huallaga Interbasin (Figure 5). Quite the opposite happened with the ICP, as this occurs because the highest precipitation is recorded in the middle and high areas, since said area of the basin covers a greater territory of the Peruvian jungle and the elevations are lower.

4. CONCLUSIONS

Climatic aggressiveness was determined using three climatic indices, among which the IFMM stands out as the best estimator. According to the qualitative classification criterion, the Alto Huallaga Interbasin has a very low aggressiveness, and is therefore, not prone to phases of erosion or degradation.

Regarding the precipitation concentration evaluated through the ICP, they did not show good correlations, but they were in a moderate range, in that sense, it is inferred that the basin has a moderately seasonal behavior, which is a typical pattern of the Amazon basins of Peru.

Of the theoretical distributions applied to the three climate indices, both the GEV distribution and the Pareto distribution stood out with the best fit, which allowed estimating the IFM, IFMM and the ICP, for return periods of 5, 10 and 25 years, determining that the Alto Huallaga Interbasin would become moderately aggressive and the precipitation concentration would remain in an irregular condition.

A multiple linear regression equation was developed to associate climate aggressiveness and precipitation concentration, using the IFM, IFMM and the ICP indices, to estimate the mean precipitation, establishing very high correlations, which finally makes the application of these indices valid for the area evaluated and can be replicated for the study of other basins of the Peruvian Amazon.

Finally, it is recommended that water resource planners and authorities in the Alto Huallaga Interbasin prioritize vulnerable areas, particularly those located in the central and northwest regions, as they are the most affected by extreme events and floods.

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REFERENCES

Aguiar, R., Da Rocha, E., De Souza, J., Dos Santos, J., & Dos Santos, J.S. (2019). Analysis of hydrological regime component of the Amazonas River basin in years of climate events. *Revista Brasileira de Geografia Fisica, 12*(3), 988-1002. https://doi.org/10.26848/rbgf.v12.3.p988-1002

Amiri, M., & Gocić, M. (2021). Analyzing the applicability of some precipitation concentration indices over Serbia. *Theoretical and Applied Climatology, 146*(1-2), 645-656. https://doi.org/10.1007/s00704-021-03743-5

Arriola, G., Villegas, L., Fernandez, J., Vallejos, J., & Idrogo, C. (2023). Assessment of parameters of the generalized extreme value distribution in rainfall of the Peruvian north. *Revista Politécnica, 52*(2), 99-112. https://doi.org/10.33333/rp.vol52n2.10

Arriola, G., Villegas, L., Marín, N., Idrogo, C., Piedra, J., & Arbulú, J. (2022). Assessment of climatic aggressiveness and precipitation concentration in the Chancay-Lambayeque basin, Peru. *Revista Politécnica, 50*(2), 15-22. https://doi.org/10.33333/rp.vol50n2.02

Azioune, R., Benhamrouche, A., Tatar, H., Martin-Vide, J., & Pham, Q. (2023). Analysis of daily rainfall concentration in northeastern Algeria 1980–2012. Theoretical and Applied Climatology, *153*(3-4), 1361-1370. https://doi.org/10.1007/s00704-023-04526-w

Back, Á., Gonçalves, F., & Fan, F. (2019). Spatial, seasonal, and temporal variations in rainfall aggressiveness in the south of Brazil. *Engenharia Agricola, 39*(4), 466-475. https://doi.org/10.1590/1809-4430-Eng.Agric.v39n4p466-475/2019

Baecheler, J., & Bravo, B. (2019). Analysis of aggressiveness rainfall in the far north of Chile. *Proceedings of the IAHR World Congress*. 3717-3725. https://doi.org/10.3850/38WC092019-1820

Bessaklia, H., Ghenim, A., Megnounif, A., & Martin-Vide, J. (2018). *Journal of Water and Land Development, 36*(1), 3-15. https://doi.org/10.2478/jwld-2018-0001

Bezak, N., Lebar, K., Huang, Y., & Chen, W. (2023). Data on 33 years of erroneous usage of rainfall erosivity equations. *Data, 8*(5). https://doi.org/10.3390/data8050075

Caicedo, M., Villegas, L., Arriola, G., Cayatopa, R., García, J., & Marín, N. (2024). Generation of flows applying a simple method of flood routing to monthly level in La Leche basin, Peru. *Revista Politecnica, 53*(1), 99-110. https://doi.org/10.33333/rp.vol53n1.09

Calixto, M. (2021). *Modelamiento hidrológico con GRAJ para el pronóstico de caudales medios diarios con horizonte de 72 horas en la cuenca del Alto Huallaga* [Tesis para optar el título de Ingeniero Agrícola, Universidad Nacional Agraria La Molina]. Repositorio institucional de la Universidad Nacional Agraria La Molina. https://hdl.handle.net/20.500.12996/5230

Carrión, S. (2018). *Evaluación de la Intercuenca Alto Huallaga haciendo uso de la hidrología de bosques* [Tesis para optar el título de Ingeniero Civil, Pontificia Universidad Católica del Perú]. Repositorio institucional de la Pontificia Universidad Católica del Perú. http://hdl.handle.net/20.500.12404/14598

Chen, W., Huang, Y., Lebar, K., & Bezak, N. (2023). A systematic review of the incorrect use of an empirical equation for the estimation of the rainfall erosivity around the globe. *Earth-Science Reviews, 238*. https://doi.org/10.1016/j.earscirev.2023.104339

Costa, A., Guimarães, S., Sales, D., Das Chagas, J., Marinho, M., Pereira, J., Martins, E., & Da Silva, E. (2023). Precipitation extremes over the tropical Americas under RCP4.5 and RCP8.5 climate change scenarios: Results from dynamical downscaling simulations. *International Journal of Climatology, 43*(2), 787-803. https://doi.org/10.1002/joc.7828

Da Motta, V., Espinoza-Dávalos, G., Moreira, D., & Comair, G. (2020). Variability of trends in precipitation across the Amazon river basin determined from the CHIRPS precipitation product and from station records. *Water (Switzerland), 12*(5). https://doi.org/10.3390/W12051244

De Brito, A., Da Silva, N., Tomasella, J., Ferreira, S., & Monteiro, M. (2022). Analysis of the rain anomaly index and precipitation trend for pluviometric stations in Central Amazonia. *Revista Brasileira de Meteorologia, 37*(1), 19-30. https://doi.org/10.1590/0102-778637014521

De Moura, R., Correia, F., Veiga, J., Capistrano, V., & Kubota, P. (2021). Evaluation of the Brazilian global atmospheric model in the simulation of the water budget components in the Amazon basin. *Revista Brasileira de Meteorologia, 36*(1), 23-37. https://doi.org/10.1590/0102-77863540078

Diodato, N., Ljungqvist, F., & Bellocchi, G. (2020). Fingerprint of climate change in precipitation aggressiveness across the central Mediterranean (Italian) area. *Scientific Reports, 10*(1). https://doi.org/10.1038/s41598-020-78857-3

Fernandez, H., Martins, F., & Isidoro, J. (2020). Mapping rainfall aggressiveness from physiographical data: Application to the Grândola Mountain Range (Alentejo, Portugal). *Physical Geography, 41*(5), 451-466. https://doi.org/10.1080/02723646.2019.1674557

Gallardo, Y., Fernández, P., Brown, O., & Valdimar, G. (2018). Estimación de la agresividad climática en el sector hidrogeológico CA-II-I del municipio de Venezuela, Ciego de Ávila, Cuba. *Revista Científica Ciencia y Tecnología, 18*(17), 1-13. https://doi.org/10.47189/rcct.v18i17.148

García-Barrón, L., Morales, J., & Sousa, A. (2018). A new methodology for estimating rainfall aggressiveness risk based on daily rainfall records for multi-decennial periods. *Science of the Total Environment, 615*, 564-571. https://doi.org/10.1016/j.scitotenv.2017.09.305

Herrera, C., Campos, J., & Carrillo, F. (2017). Estimación de datos faltantes de precipitación por el método de regresión lineal: Caso de estudio Cuenca Guadalupe, Baja California, México. *Investigación y Ciencia de la Universidad Autónoma de Aguascalientes, 25*(71), 34-44. https://doi.org/10.33064/iycuaa201771598

Hosking, J. (1990). L-moments: analysis and estimation of distributions using linear combinations of order statistics. *Journal of the Royal Statistical Society, Series B, 52*, 105-124. https://www.jstor.org/stable/2345653

Huang, Y., Wang, H., Xiao, W., Chen, L., Yan, D., Zhou, Y., Jiang, D., & Yang, M. (2018). Spatial and temporal variability in the precipitation concentration in the upper reaches of The Hongshui River basin, Southwestern China. *Advances in Meteorology, 2018*. https://doi.org/10.1155/2018/4329757

Ilbay-Yupa, M., Barragán, R., & Lavado-Casimiro, W. (2019). Regionalization of precipitation, its aggressiveness and concentration in the Guayas River basin, Ecuador. *Granja, 30*(2), 52-69. https://doi.org/10.17163/lgr.n30.2019.06

Kabolizadeh, M., Rangzan, K., Mohammadi, S., & Rabiei-Dastjerdi, H. (2024). Challenges of rainfall erosivity prediction: A novel GIS-Based optimization algorithm to reduce uncertainty in large country modeling. *Earth Science Informatics, 17*(1), 365-384. https://doi.org/10.1007/s12145-023-01178-2

Lana, X., Rodríguez-Solà, R., Casas-Castillo, M., Serra, C., Kirchner, R., & Martínez, M. (2023). Rainfall disparity at monthly scale on Catalonia (NE Spain): Dependence on geographic coordinates, altitude and distance to the Mediterranean coast. *Theoretical and Applied Climatology, 153*(3-4), 1293-1306. https://doi.org/10.1007/s00704-023-04533-x

Lee, J., Choi, J., Jang, S., & Kim, S. (2024). Effect of mountainous rainfall on uncertainty in flood model parameter estimation. *Hydrology Research, 55*(2), 221-236. https://doi.org/10.2166/nh.2024.144

Llampazo, G., Dávila, E., Del Águila, R., Cardozo, N., Díaz, A., & Del Castillo, D. (2023). Survival of plants species in seasonally flooded forests of the Peruvian Amazonia. *Folia Amazonica, 32*(1), 1-15. https://doi.org/10.24841/fa.v32i1.627

Llano, M. (2018). Spatial distribution of the daily rainfall concentration index in Argentina: Comparison with other countries. *Theoretical and Applied Climatology, 133*(3-4), 997-1007. https://doi.org/10.1007/s00704-017-2236-0

Llano, M. (2021). Temporal variability of daily concentration of precipitation in Argentina. *Meteorologica, 46*(2). https://doi.org/10.24215/1850468Xe005

Llano, M. (2023). Spatiotemporal variability of monthly precipitation concentration in Argentina. *Journal of Southern Hemisphere Earth Systems Science, 73*(2), 168-177. https://doi.org/10.1071/ES22040

López, M., Carmenates, D., Valero, L., & López, L. (2019). Indicadores de cambio climático en las precipitaciones. *Revista Bases de la Ciencia, 4*(2), 21-34. https://doi.org/10.33936/rev_bas_de_la_ciencia.v4i2.1566

Luna-Romero, A., Ramírez, I., Sánchez, C., Conde, J., Agurto, L., & Villaseñor, D. (2018). Distribución espacio-temporal de la precipitación en la cuenca del río Jubones, Ecuador: 1975-2013. *Scientia Agropecuaria, 9*(1), 63-70. https://doi.org/10.17268/sci.agropecu.2018.01.07

Manikanta, V., Nikhil, K., Das, J., & Umamahesh, N. (2023). On the verification of ensemble precipitation forecasts over the Godavari River basin. *Journal of Hydrology, 616*. https://doi.org/10.1016/j.jhydrol.2022.128794

Nunes, M., Cardoso, D., Melo, T., Dorneles, V., Knapp, A., & Cecconello, S. (2023). Erosivity and seasonal rainfall for Pelotas-RS, Brazil with the RainfallErosivityFactor package and Modified Fournier Index. *Journal of South American Earth Sciences, 132*. https://doi.org/10.1016/j.jsames.2023.104649

Olguín, J. (2019). Índices de agresividad climática como estimadores del factor de riesgo de la erosión hídrica en el Departamento de Tarija. *Agrociencias, 4*(7): 1-10. https://dicyt.uajms.edu.bo/revistas/index.php/agrociencias/article/view/1113

Pizarro, R., Cornejo, F., González, C., Macaya, K., & Morales, C. (2008) Análisis del comportamiento y agresividad de las precipitaciones en la zona central de Chile. *Ingeniería Hidráulica en México, 23*(2), 91-109. Retrieved from SCOPUS database

SENAMHI (2018). *Estudio: Estimación de umbrales de inundación en la Región Hidrográfica del Pacífico*. Lima, Perú: Dirección de Hidrología del Servicio Nacional de Meteorología e Hidrología del Perú. https://repositorio.senamhi.gob.pe/handle/20.500.12542/241

Valdés-Pineda, R., Pizarro, R., Valdés, J., Carrasco, J., García-Chevesich, P., & Olivares, C. (2016). Spatio-temporal trends of precipitation, its aggressiveness and concentration, along the Pacific coast of South America (36–49°S). *Hydrological Sciences Journal, 61*(11), 2110-2132. https://doi.org/10.1080/02626667.2015.1085989

Vargas, M., Beskow, S., de Moura, M., da Cunha, Z., Beskow, T., & de Morais da Silveira, J. (2023). GAM-IDF: a web tool for fitting IDF equations from daily rainfall data. *International Journal of Hydrology Science and Technology, 16*(1), 37-60. https://doi.org/10.1504/IJHST.2023.131882

Wang, Z., Wang, Z., Feng, P., Dong, Y., Zhang, Z., & Yang, Y. (2022). Study on applicability of remote sensing precipitation products in hilly-plain-wetland complex area of northeast China. *Water Supply, 22*(3), 3498 – 3507. https://doi.org/10.2166/WS.2021.387

Zubieta, R., Saavedra, M., Silva, Y., & Giráldez, L. (2017). Spatial analysis and temporal trends of daily precipitation concentration in the Mantaro river basin: Central Andes of Peru. *Stochastic Environmental Research and Risk Assessment, 31*(6), 1305-1318. https://doi.org/10.1007/s00477-016-1235-5

Zubieta, R., Saavedra, M., Espinoza, J., Ronchail, J., Sulca, J., Drapeau, G., & Martin-Vide, J. (2019). Assessing precipitation concentration in the Amazon basin from different satellite-based data sets. *International Journal of Climatology, 39*(7), 3171-3187. https://doi.org/10.1002/joc.6009

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