# Assessment of Parameters of the Generalized Extreme Value Distribution in Rainfall of the Peruvian North

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**Abstract:** The maximum rainfall in the Peruvian north behaves seasonally, concentrating between the first months of the year, however, few studies have analyzed its distribution over time through an analysis of extremes. The objective of the research was to evaluate the parameters of location, scale and shape of the generalized extreme value distribution in maximum rainfall in the Peruvian north corresponding to the Pacific 5 and Pacific 6 hydrological regions. The maximum daily rainfall data available was collected in the climatic stations of both regions, considering a minimum number of 15 years of records per station and a filter based on statistical and visual analysis, for which 138 stations were established. Subsequently, the adjustments were applied to ordinary moments and to linear moments of the generalized extreme value distribution and two types of hypothesis tests were used for each region that helped to validate the similarities of each parameter in both regions. The results show significant differences only in the location parameter, while, when contrasting the altitude, average rainfall and maximum rainfall of each hydrological region it was determined that there are high correlations with the location and scale parameters. Finally, it is concluded that both hydrological regions, the scale and shape parameters show a good performance for both adjustments based on the applied hypotheses and the location parameter showed that the Pacific 6 hydrological region is rainier than the Pacific 5 hydrological region.

**Keywords**: Altitude; ordinary moments; linear moments; the Peruvian north; rainfall

# Evaluación de Parámetros de la Distribución Generalizada de Valor Extremo en Precipitaciones del Norte Peruano

**Resumen:** Las precipitaciones máximas del norte peruano se comportan de una manera estacional, concentrándose entre los primeros meses del año, sin embargo, pocos estudios han analizado su distribución a lo largo del tiempo mediante un análisis de extremos. El objetivo de la investigación fue evaluar los parámetros de ubicación, escala y forma de la distribución generalizada de valor extremo en precipitaciones máximas del norte peruano correspondientes a las regiones hidrológicas Pacífico 5 y Pacífico 6. Se realizó la recolección de datos de precipitaciones máximas diarias disponibles en las estaciones climáticas de ambas regiones, considerando una cantidad mínima de 15 años de registros por estación y un filtro basado en el análisis estadístico y visual, por lo que se estableció 138 estaciones. Posteriormente se aplicaron los ajustes a momentos ordinarios y a momentos lineales de la distribución generalizada de valor extremo y se utilizó dos tipos de prueba de hipótesis para cada región que ayudaron a validar las similitudes de cada parámetro en ambas regiones. Los resultados muestran diferencias significativas sólo en el parámetro de ubicación, en tanto, al contrastar la altitud, precipitación media y precipitación máxima de cada región hidrológica se determinó que existen altas correlaciones con los parámetros de ubicación y escala. Finalmente, se concluye en que ambas regiones hidrológicas los parámetros de escala y forma muestran un buen desempeño para ambos ajustes a partir de las hipótesis aplicadas y el parámetro de ubicación demostró que la región hidrológica Pacífico 6 es más lluviosa que la región hidrológica Pacífico 5.

**Palabras clave**: Altitud; momentos ordinarios; momentos lineales; norte peruano; precipitación

## 1. INTRODUCTION

Worldwide, the study of rainfall has been widely addressed over the years, since its analysis has allowed us to know the rainfall seasonality of different geographical areas and, on the other hand, rain as it is a very important component in hydrological studies and drainage, has managed to form part of the determination of the water resource for the different uses and requirements (Campos-Aranda, 2018). However, the current trends associated with climate change and water

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resources management suggest that there must be a careful evaluation of the quality of the rainfall information, as well as the comparison of probabilities and extremes for different return periods (Vivekanandan, 2018).

One of the main applications that rainfall has had from the analysis of maximum frequencies are the so-called intensity, duration, and frequency (IDF) curves or storm curves (Peleg et al., 2018); that by means of various stochastic and multiple correlation methods, it is possible to generate prediction equations for the maximum intensity for a certain duration and different return periods (López et al., 2018). Nevertheless, it is necessary to previously know the behavior of the statistical parameters of said rainfall frequencies for a certain distribution of best fit, especially if the approach is developed on a larger scale, for example in the implementation of hydrological models of hydrographic basins (Halim, 2019; Juma et al., 2021).

Current research indicates that of all the existing distributions for the evaluation of extremes, the one that has shown the best statistical response capacity of its parameters from a record of maximum rainfall, is the generalized extreme value distribution (GEVD) (Campos-Aranda, 2019; Alahmadi & Rahman, 2020; Seo et al., 2021). In addition, as Mashishi et al. (2020) and Klassou & Komi (2021) refer the GEVD can achieve a good adjustment to extreme rainfall for return periods of up to 100 years; including for maximum annual rainfall at daily, subdaily and short duration time scales (Yeo et al., 2021; Ulrich et al., 2021). Another case studied, such as the flow variable, has also shown very good results with the GEVD (Roslan et al., 2020; Campos-Aranda, 2021); reaching a return period of 150 years (Samantaray y Sahoo, 2020).

An extreme event is related to the tails of the probability distribution of the observed values (Guillén-Oviedo et al., 2020), and can be applied to any variable that involves an evaluation of the maximum values within a data set (Flores-Rojas et al., 2021). In this context, the current trend of its use has commonly been extended to climatic variables, whose records can come from conventional climatic, pluviometric or pluviographic stations and even from satellite data (Diriba & Debusho, 2021).

Likewise, if we refer to the application in rainfall, it is mentioned that the maximum rainfall events are important to investigate, since their evaluation allows determining the dangers related to intense and extreme weather (Diriba & Debusho, 2021). For this reason, the interest arises in studying this climatic variable and in somehow associating its maximum values with the GEVD parameters, including the possibility of predicting extreme events during the seasonal rain cycle (Alfaro et al., 2018).

The GEVD is traditionally applied to estimate extreme events and their return period, and within the equation there are three parameters (location, scale and shape) that must be determined to be subsequently applied to some hydroclimatic variable (Hossain et al., 2021). With respect to the location, scale and shape parameters of the GEVD, Guillén-Oviedo et al. (2020) demonstrated that through these estimators, significant differences can be established that help to know the rainfall behavior of Central America, however there is some uncertainty about the validation of the results, well, as Wang & Xuan (2022) affirm in their applied research in England, they determined a series of linear correlations through these three parameters in relation to altitude, thus managing to adequately explain the variability of extreme rainfall.

In Peru, the most recent study that deals with maximum rainfall is the one prepared by SENAMHI (2017a) which mentions that through a process of frequency analysis and an adjustment of five extreme distributions, highlighting among them the GEVD, ten regions of maximum rainfall can be delimited, but it was not possible to compare these results on the parameters of each distribution.

Other investigations such as those of Rollenbeck et al. (2021), Rollenbeck et al. (2022) and, Vavrus et al. (2022) also analyzed the maximum rainfall in Peru, specifically in the northern zone of Peruvian Pacific, but without reaching the contrast of any extreme value distribution with their respective parameters and the quantification of extreme events for different return periods.

Due to the above, there is a need to know the parameters of the GEVD in rainfall of Peru and with greater scope in the northern zone, since as indicated by SENAMHI (2017b) the Pacific 5 and Pacific 6 hydrological regions of Peruvian northwest, they are the ones that are the most prone to extreme storm events, which are mainly influenced by the altitude and seasonality of rainfall (Oruc, 2021; Arriola et al., 2022; Fernandez-Palomino et al., 2022).

The application of the GEVD with respect to other distributions in the present investigation is justified because said distribution is the one that presents the most adequate adjustments and optimal statistical performances for the analysis of maximum rainfall extremes and their corresponding return periods, especially for rainy and seasonal periods, as indicated by research by Campos-Aranda (2018), Min & Halim (2020), Hossain et al. (2021), Mohamed & Adam (2022) and Abreu et al. (2023). Likewise, its location, scale, and shape parameters are better related to the climatic variables altitude and average rainfall, compared to other indicators of other distributions, which later helps to differentiate areas of greater or lesser rainfall, as well as its intensity, these results are in agreement with the findings of Campos-Aranda (2019) for Mexico, Guillén-Oviedo et al. (2020) for Costa Rica, Mashishi et al. (2020) for South Africa, Back & Bonfante (2021) for Brazil, Klassou & Komi (2021) for West Africa, Wang & Xuan (2021) for England and Australia, and Ulrich et al. (2021) for Germany.

As noted, the application of the GEVD as indicated by the various investigations cited above related to the topic presented, is valid for the analysis of extremes in rainfall and for the prediction of maximum events in various return periods, also due to its ease of study makes its use very practical and valid in the evaluation of maximum rainfall, in this case in Peruvian north, compared to other more complex distributions that require specialized software.

For these reasons, the objective of this research was to evaluate the parameters of location, scale, and shape of the generalized extreme value distribution in maximum rainfall in Peruvian north corresponding to the Pacific 5 and Pacific 6 hydrological regions.

## 2. MATERIALS AND METHODS

### *2.1 Study area*

The Pacific 5 and Pacific 6 hydrological regions are located in Peruvian north (Figure 1), also these zones are part of the six hydrological regions of the Pacific of Peru. The SENAMHI (2017b) indicates that in the Pacific 5 hydrological region there are a total of 17 basins totaling an area of 31700.32 km$^2$, while in the Pacific 6 hydrological region there are a total of 18 basins totaling an area of 42304.87 km$^2$.

Regarding altitude (Figure 2a), average rainfall (Figure 2b) and maximum rainfall (Figure 2c), they are variable in both hydrological regions, since the Pacific 5 region presents areas with higher altitudes than the Pacific 6 region, also the pattern of rainfall is different, since in the Pacific 6 region the average rainfall reaches 450 mm and the maximum rainfall up to 1200 mm, while for the Pacific 5 region the average rainfall fluctuates up to 90 mm and the maximum ranges up to 360 mm.

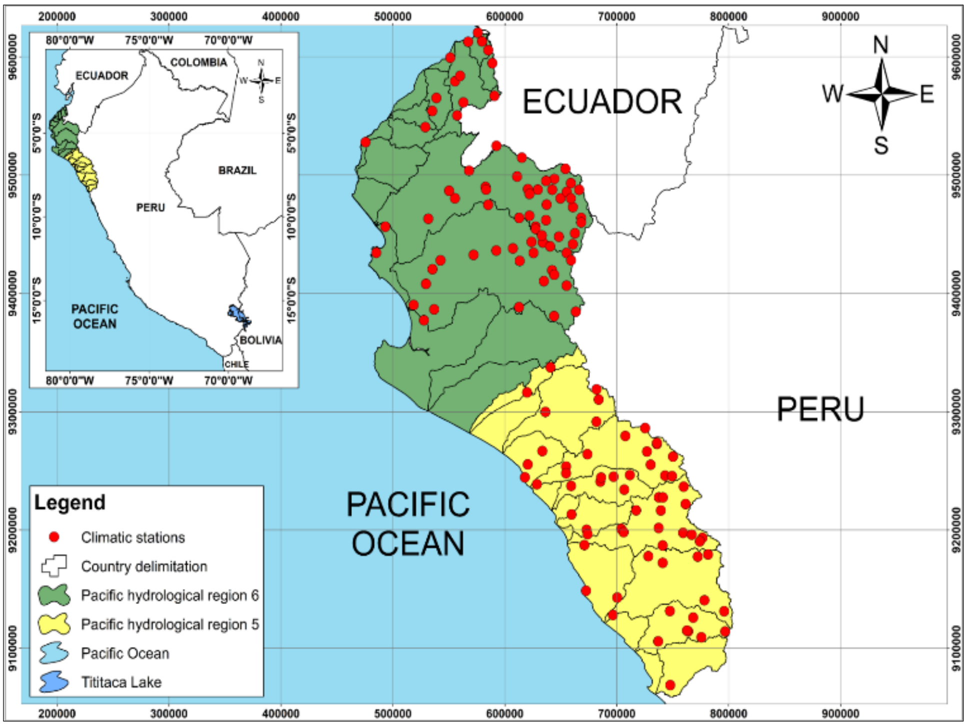


**Figure 1**. Ubication of the Pacific 5 and Pacific 6 hydrological regions of Peruvian north

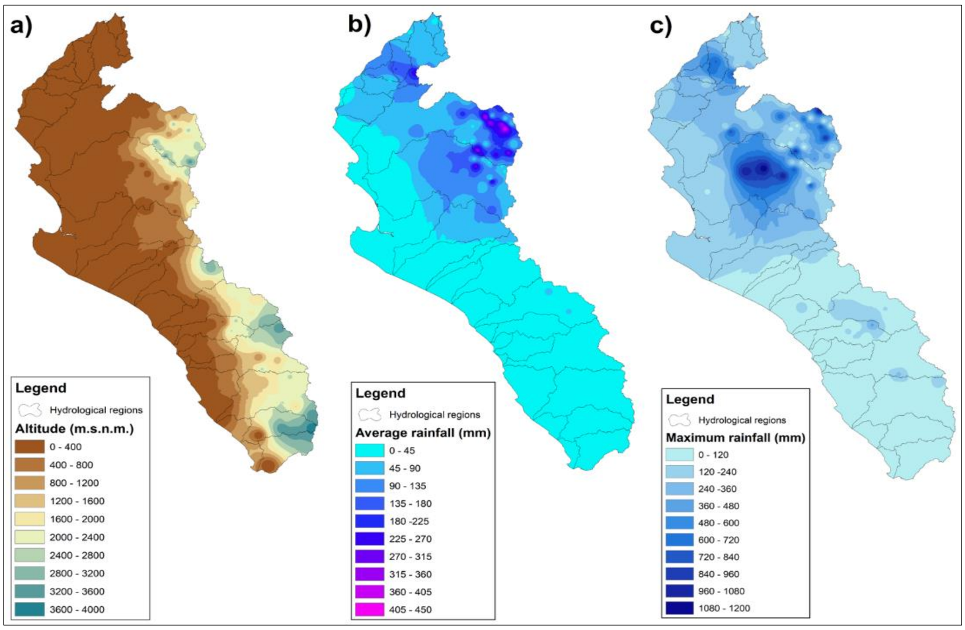


**Figure 2**. a) Altitude, b) average rainfall and c) maximum rainfall of the Pacific 5 and Pacific 6 hydrological regions of Peruvian north

*2.2 Methodology*

The type of research was applied and quantitative approach. The population corresponded to a total of 138 climatic stations in the Peruvian north, of which 63 stations belong to the Pacific 5 hydrological region and 75 stations belong to the Pacific 6 hydrological region. The sources of data collection were obtained from the open access electronic portal of the ANA (Autoridad Nacional del Agua) from Peru, which is available for any consultation.

The data collection instruments used were the formats of records of maximum daily rainfall with date ranges from January of the year 1942 to December of the year 2020, however this was variable since there are stations with few data, so it was opted to consider a minimum of 15 years of complete records for each station as recommended by SENAMHI (2018) for studies in the hydrological regions of the Peruvian Pacific, using this criterion as a protocol in the collection and selection of rainfall information, for consequently, the statistical analysis involved a quality control of the data to determine possible erroneous values that could result from some operational, systematic or observation problem (Luna-Romero et al., 2018). Due to the above, a graphical analysis was applied to identify outliers, box diagrams being very common at 95% probability, excluding months that differed by more than three standard deviations from the monthly average of the respective season (Lavado et al., 2013); and complementary to this, the Kolmogorov-Smirnov goodness-of-fit test was evaluated at each climatic station for the adjustment to the GEVD, fulfilling satisfactorily in all cases.

For the analysis of extremes, it began with the application of the GEVD function, which is shown in Equation 1:

$$\mathrm{f}(x,\xi,\theta,\gamma)=\left(\frac{1}{\theta}\right)*\exp\left[-\left(1+\gamma*\left(\frac{x-\xi}{\theta}\right)\right)^{-\frac{1}{\gamma}}\right]*\left(1+\gamma*\left(\frac{x-\xi}{\theta}\right)\right)^{-\frac{1}{\gamma}} \quad (1)$$

Where, $x$ is the variable to evaluate, being in this case the maximum rainfall, $\xi$, $\theta$, and $\gamma$ are the location, scale, and shape, parameters respectively of the GEVD. It should be noted that the function must always be with $\gamma \neq 0$; $\theta > 0$ and $1+\gamma\left(\frac{x-\xi}{\theta}\right) > 0$, and that the shape and location parameters can take any real value (Guillén-Oviedo et al., 2020).

Continuing with the sequence of the investigation and with the purpose to achieving a greater scope and validation in the differences of the three parameters in each hydrological region, the adjustments to ordinary moments and to linear moments of the generalized extreme value distribution were applied to each record, which is included in the Hydrognomon program developed by Kozanis et al. (2010) and also because it is freely accessible software, it can be used in the different specialties of hydrology for statistical analysis (Arriola, 2021).

As previously mentioned, the estimation methods used in the present investigation to adjust the GEVD to the maximum daily rainfall of both hydrological regions were ordinary moments and linear moments, which are based on the general theory of method of moments (Bowman & Shenton, 2014).

The Ordinary moments provide the location measure that relates to the arithmetic average, the variance measure that relates to the standard deviation, the coefficient of variation that relates the standard deviation to the arithmetic average, the skewness coefficient that relates to the bias and the measure of kurtosis related to the coefficient of kurtosis (Bowman & Shenton, 2014).

Regarding linear moments, Hosking (1990) developed the theory of linear moments, commonly known as L-moments, which is based on statistical ordering from the linear combination of data and using four linear moments, starting with the first linear moment that corresponds to the arithmetic average, then the second linear moment that is equivalent to the standard deviation, then the third linear moment is obtained from the product of the asymmetry coefficient with the second linear moment and finally, the fourth linear moment is determined by the product of the kurtosis coefficient with the second linear momentum.

In order to know the significant differences between the two hydrological regions, two types of hypotheses were contrasted, which were based on the bootstrap method and the t-test for two samples of equal variances.

The bootstrap method is a non-parametric technique that was established by Efron (1979) for the random resampling of an original data set and to develop subsets of data similar to the initial one, which are statistically in correspondence with the original series, since they are based on the main statistical estimators such as the average, the standard deviation, the coefficient of variation, the coefficient of bias and the correlation. This resampling technique has applications in various fields of science, among which hydrology and its different specialties stand out, so its use in the analysis of maximum rainfall extremes to compare significant differences in different areas is very efficient (Padiyedath-Gopalan et al., 2019; Guillén-Oviedo et al., 2020).

Regarding the t-test for two samples of equal variances, Lee & Kim (2023) point out that it is a test that assumes equality in the data of two samples, but in relation to the statistical value of the variance of said samples, since to test the equal means under independent normal samples, this test is the one that presents the best results, under the criterion that there is a similarity of the analyzed variable, being in the case of the present investigation a very practical application, because the two hydrological regions evaluated, present similar conditions both in the amount of data on maximum daily rainfall, in the number of weather stations and their location in Peruvian northwest.

In addition, for these hypothesis tests, the criteria suggested by Guillén-Oviedo et al. (2020), which indicate a comparison through the expected values of the parameters of location (Equation 2 and Equation 3), scale (Equation 4 and Equation 5) and shape (Equation 6 and Equation 7).

$$H_{O-\xi}: \xi_5 = \xi_6 \quad (2)$$
$$H_{1-\xi}: \xi_5 \neq \xi_6 \quad (3)$$
$$H_{O-\theta}: \theta_5 = \theta_6 \quad (4)$$
$$H_{1-\theta}: \theta_5 \neq \theta_6 \quad (5)$$
$$H_{O-\gamma}: \gamma_5 = \gamma_6 \quad (6)$$
$$H_{1-\gamma}: \gamma_5 \neq \gamma_6 \quad (7)$$

Where $H_{O-\xi}$, $H_{O-\theta}$ and $H_{O-\gamma}$ are the null hypothesis for location, scale and shape parameter, $H_{1-\xi}$, $H_{1-\theta}$ and $H_{1-\gamma}$ are the alternate hypothesis for location, scale and shape parameter, $\xi_5$ and $\xi_6$ correspond to the expected value of the location parameter for the Pacific 5 and Pacific 6 hydrological regions, respectively; $\theta_5$ and $\theta_6$ correspond to the expected value of the scale parameter for the Pacific 5 and Pacific 6 hydrological regions, respectively; $\gamma_5$ and $\gamma_6$ correspond to the expected value of the shape parameter for the Pacific 5 and Pacific 6 hydrological regions, respectively.

These criteria were carried out with the purpose of having a global balance of these estimators for each hydrological region, since there is no method of analysis of comparison of the three parameters one by one in each climatic station, in the same way, in each comparison of hypothesis, the GEVD parameters were established with the adjustments to ordinary moments and linear moments, which were estimated with the Hydrognomon program (Kozanis et al., 2010).

## 3. RESULTS AND DISCUSSION

Table 1 shows the results of the average values of the three GEVD parameters for both hydrological regions of the Peruvian north, both with the adjustment to ordinary moments and to linear moments.

**Table 1.** GEVD parameters with ordinary and linear moments of the two hydrological regions of Peruvian north

| Hydrological region | Average values of the GEVD parameters | | | | | |
|---|---|---|---|---|---|---|
| | With adjustment to ordinary moments | | | With adjustment to linear moments | | |
| | Location | Scale | Shape | Location | Scale | Shape |
| Pacific 5 | 11.304 | 1.651 | 0.144 | 8.944 | 1.928 | 0.278 |
| Pacific 6 | 53.896 | 1.570 | 0.131 | 43.871 | 1.757 | 0.246 |

The location parameter obtained with both adjustments shows a direct relationship with the behavior of maximum rainfall in the two hydrological regions, since, as can be seen their values (Table 1), are higher compared to the other parameters, as this is supported in their respective investigations by Guillén-Oviedo et al. (2020), Lima et al. (2021), Wang & Xuan (2021) and Wang & Xuan (2022). In addition, the ranges of this parameter indicate that the Pacific 6 region has more rainfall than the Pacific 5 region, since the values of one region with respect to the other varied up to 5 times for the two settings.

Regarding the parameter of scale and shape, it was not possible to find a correspondence with the rainfall pattern, however, their values show similarities in each setting and in the two regions, so these findings could indicate the variability of rainfall in this part of Peru. In this sense, as mentioned by Guillén-Oviedo et al. (2020) and Wang & Xuan (2022) as there is seasonality in the analysis of rainfall in a geographic area, the scale and shape parameters will assume a certain tendency to statistical dispersion with respect to extreme rainfall. Then, based on these results, the distribution maps of each GEVD parameter were generated with the adjustment to ordinary moments (Figure 3) and with the adjustment to linear moments (Figure 4), using the inverse distance weighted procedure, commonly known as IDW, that determines the values of each point without data, but at the same time, they are based on the records available in the climatic stations that do have values, being in this case the data of the location, scale, and shape parameters of the GEVD, as recommended by Adeola et al. (2021) and Arriola et al. (2022).

Regarding the spatial distribution of the GEVD parameters with ordinary moments (Figure 3) and with linear moments (Figure 4) for the study area, it can be observed that in terms of the location parameter. The smallest values are they mostly in the Pacific 5 hydrological region and the highest ranges are found in the Pacific 6 hydrological region, especially in the northwest of Peru, this effect is mainly due to the alteration of rainfall by the El Niño Phenomenon during the periods 1982-1983, 1997-1998 and the first months of 2017.

In relation to the scale parameter (Figure 3b and Figure 4b), it is shown that the smallest values are oriented towards the coast and the highest values tend to move away from this area. Regarding the shape parameter (Figure 3c and Figure 4c), it had a different pattern, that is, the low values move away from the coast and the high values tend to approach the Peruvian coast. From the foregoing, it can be inferred that in terms of these last two parameters of the GEVD, there is some variability of rainfall in this area, due to the behavior of extreme rainfall and altitude.

The results of the hypothesis tests applied to the hydrological regions are shown in Table 2, obtaining a significant difference between the two regions for the location parameter, since the null hypothesis was rejected, which is interpreted as a variation in the rainfall regime extreme between the two study areas. Null hypotheses were accepted for the scale and shape parameters. Subsequently, the correlations of the three parameters of the GEVD with respect to altitude, average rainfall and maximum rainfall of each hydrological region were made, applying ordinary moments (Figure 5), and linear moments (Figure 6).

**Table 2.** Hypothesis test for the three parameters of the GEVD based on the total number of climatic stations of both hydrological regions

| GEVD parameter | Type of statistical adjustment | | | | Type of validated hypothesis |
|---|---|---|---|---|---|
| | With ordinary moments | | With linear moments | | |
| | Bootstrap | T-test for two samples of equal variances | Bootstrap | T-test for two samples of equal variances | |
| Location | $5.3 \times 10^{-10}$ | $1.4 \times 10^{-10}$ | $3.4 \times 10^{-10}$ | $1.1 \times 10^{-10}$ | $H_{1-\xi}$: $\xi_5 \neq \xi_6$ |
| Scale | 0.975 | 0.647 | 0.803 | 0.277 | $H_{O-\theta}$: $\theta_5 = \theta_6$ |
| Shape | 0.692 | 0.400 | 0.588 | 0.330 | $H_{O-\gamma}$: $\gamma_5 = \gamma_6$ |

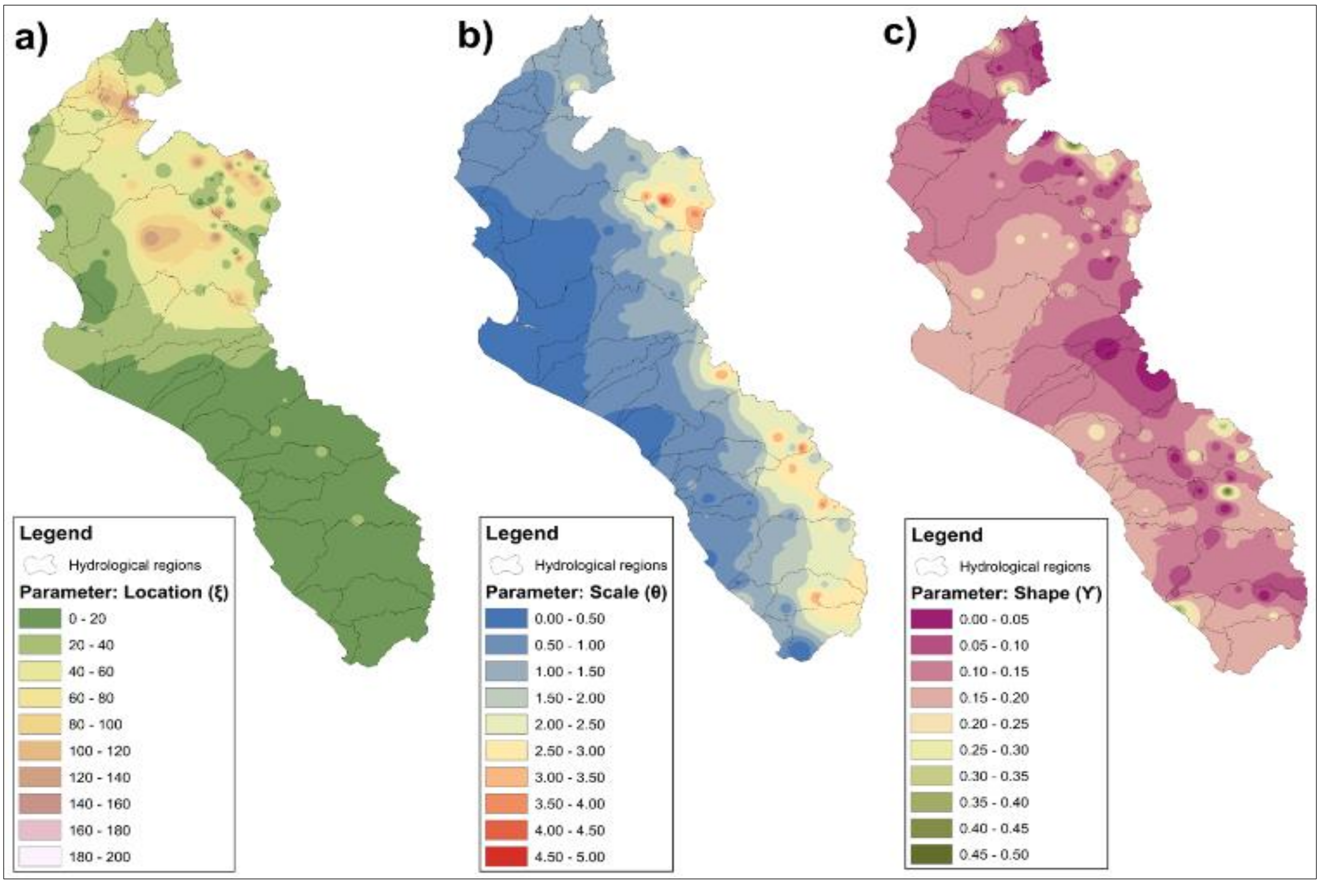


**Figure 3.** Spatial distribution of the parameters: a) location, b) scale and c) shape for the Pacific 5 and Pacific 6 hydrological regions of Peruvian north with adjustment to ordinary moments

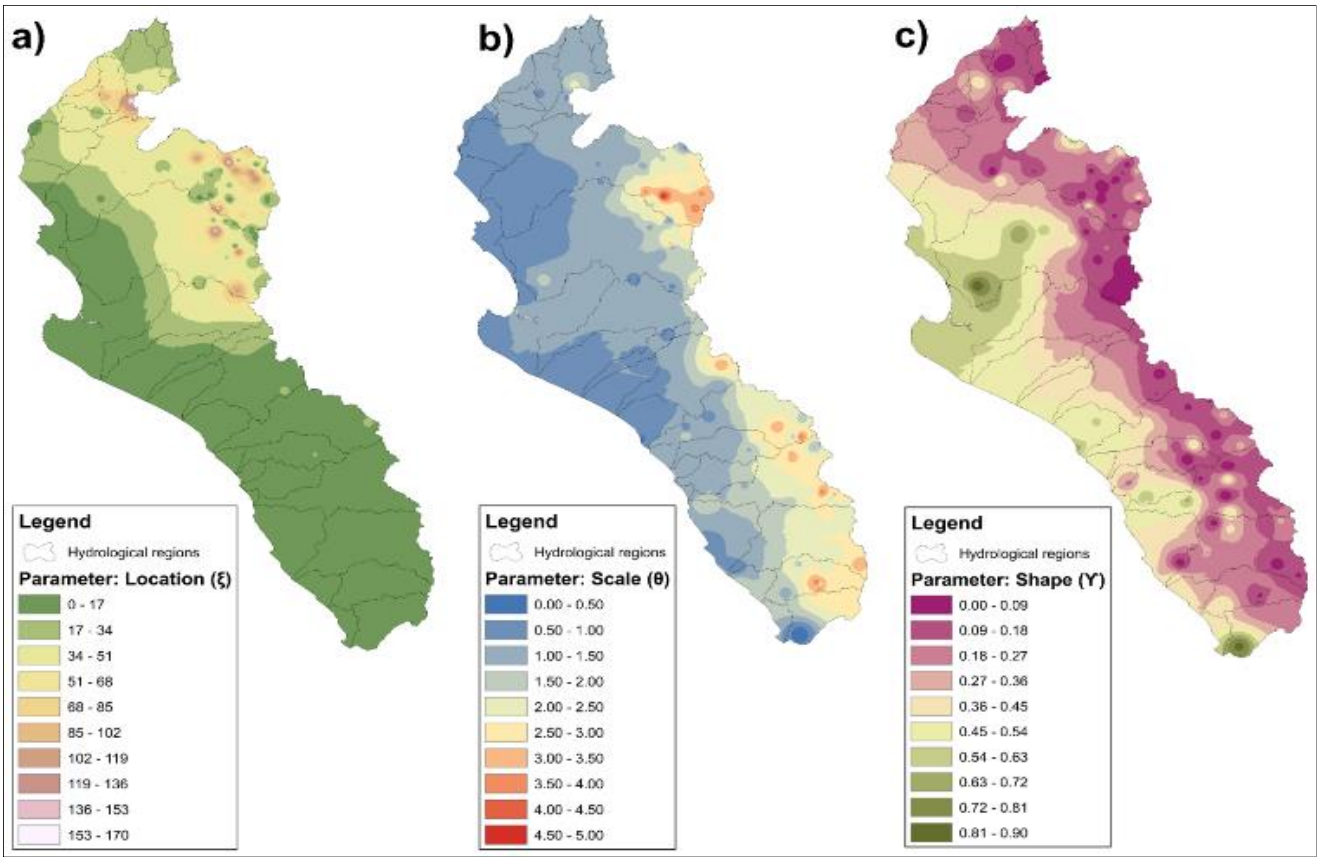


**Figure 4.** Spatial distribution of the parameters: a) location, b) scale and c) shape for the Pacific 5 and Pacific 6 hydrological regions of Peruvian north with the adjustment to linear moments

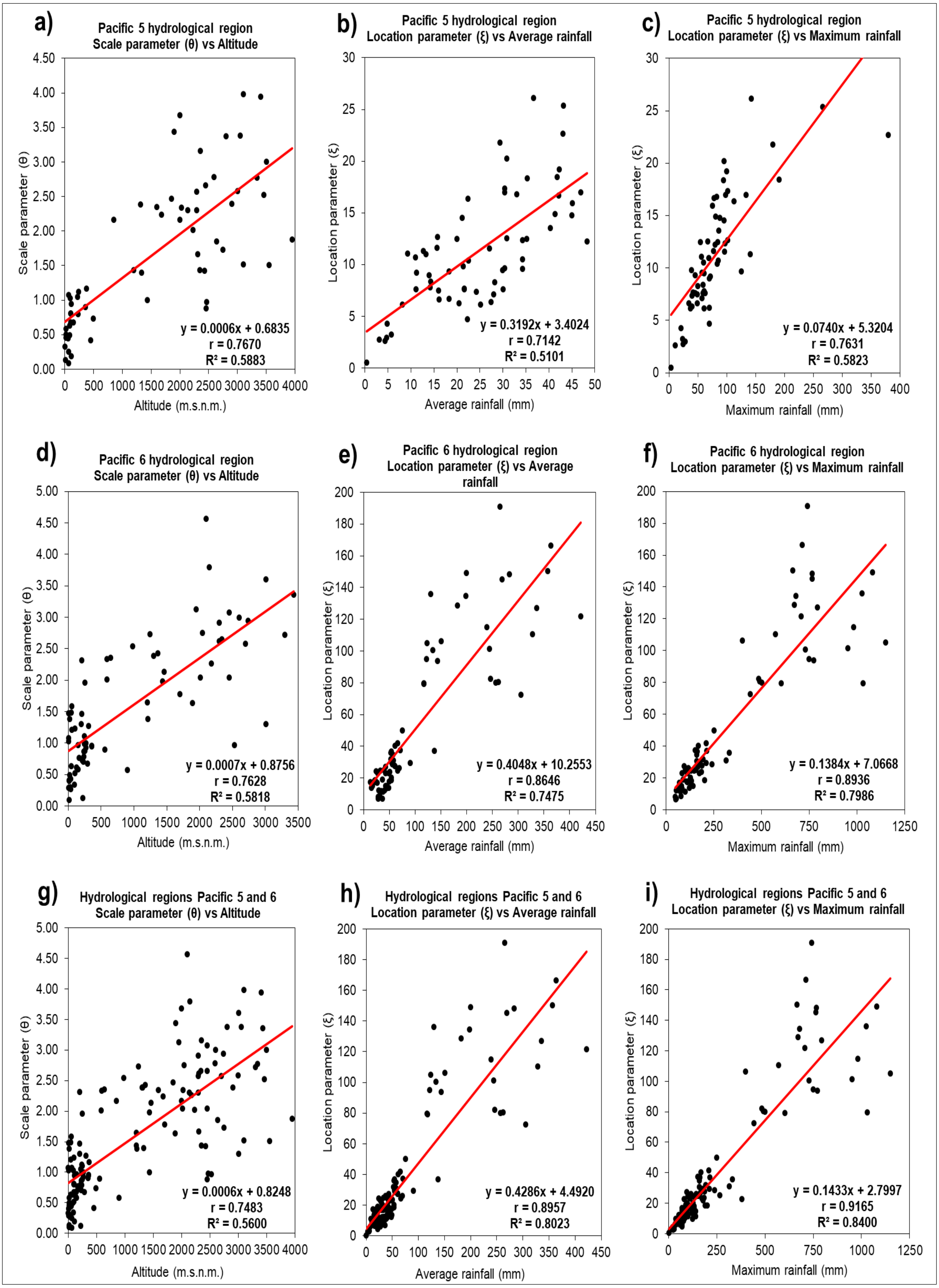


**Figure 5.** Correlations of the location, scale and shape parameters for the Pacific 5 and Pacific 6 hydrological regions of Peruvian north with the adjustment to ordinary moments

These results show only the best correlations, that is, with r ≥ 0.60 (Herrera et al., 2017), given that in the other cases the correlations were very low and null, as happened with the shape parameter, since in none of the relationships was there a correspondence with any of these variables.

In the same way, with the adjustment of linear moments for the location parameter in the Pacific 5 hydrological region, regarding its correlation with the maximum rainfall (Figure 6i), it did not show correspondence (r = 0.4354), while for the ordinary moments it was the opposite, since that r = 0.7631 was determined (Figure 5c).

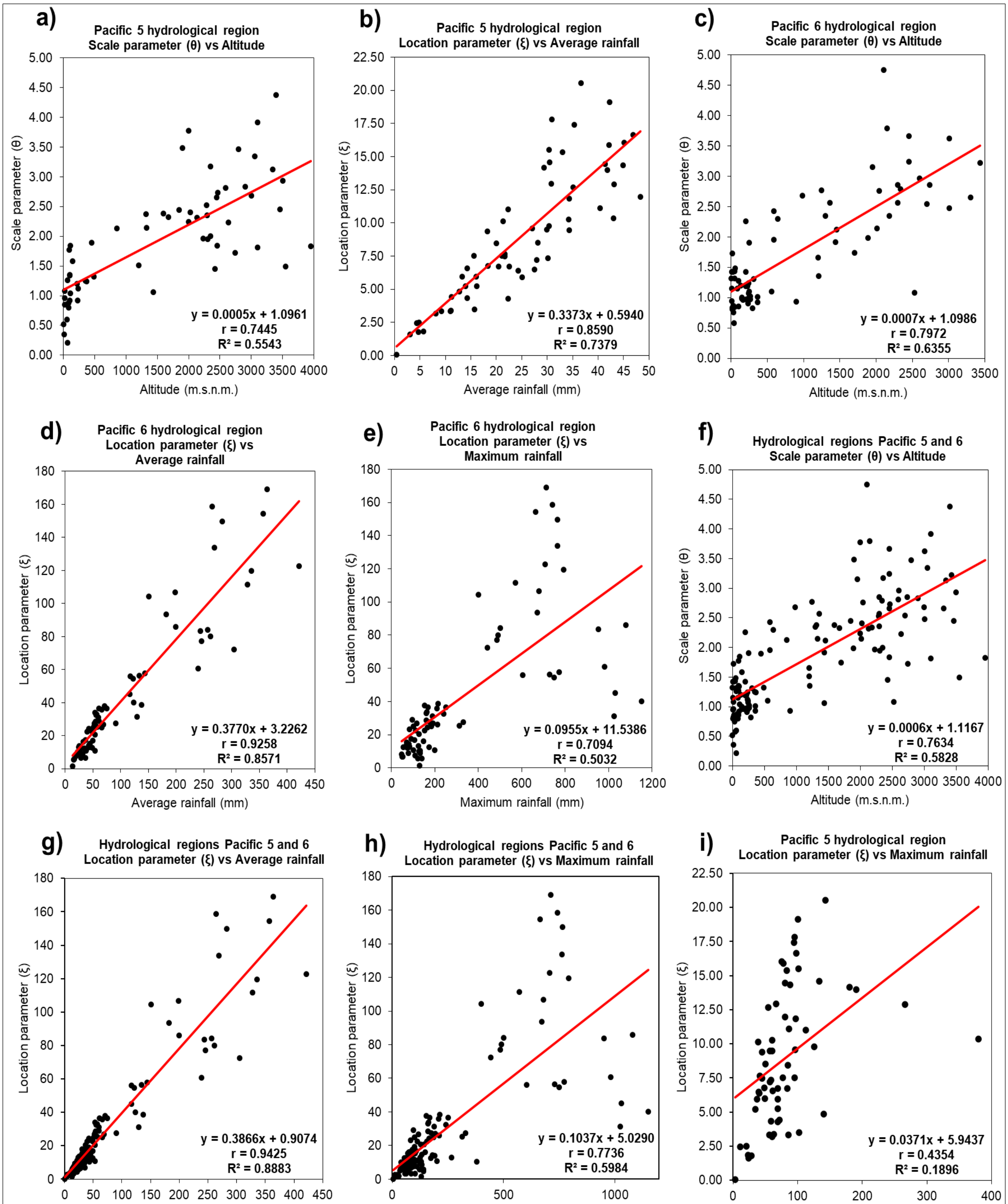


**Figure 6.** Correlations of the location, scale and shape parameters for the Pacific 5 and Pacific 6 hydrological regions of Peruvian north with the adjustment to linear moments

For these reasons, when contrasting the altitude, average rainfall and maximum rainfall of each hydrological region and with the application of both adjustments with respect to each parameter of the GEVD, it was possible to determine that there are high correlations with the parameters of location and scale.

The case of the location parameter (Figure 5f) stands out, since it was obtained that the highest correlation was with the maximum rainfall in the Pacific 6 hydrological region ($r = 0.8936$) and by joining both hydrological regions and then correlating them with the maximum rainfall an $r = 0.9165$ was achieved (Figure 5i), in both cases it was with the adjustment to ordinary moments (Figure 5). While with the adjustment to linear moments (Figure 6d) the best correlation of the location parameter of the Pacific 6 hydrological region was obtained with respect to the average rainfall ($r = 0.9258$) and the same happened when the two regions were combined to correlate them with the average rainfall, since its $r = 0.9425$ (Figure 6g).

In this sense, and according to these results, the setting that best suits the study area is the GEVD with ordinary moments, since the best correlations of the location parameter with respect to maximum rainfall were achieved, as justified by Mohamed & Adam (2022), since they indicate that the GEVD is one of the distributions that best fits extreme rainfall events and for the subsequent determination of their magnitude and frequency, despite this Nerantzaki & Papalexiou (2022), together with Vivekanandan (2022) maintain that other adjustments should be examined, such as that of linear moments of the GEVD, for which reason the comparison of both adjustments in both hydrological regions in the present investigation is justified.

Lastly, and as a complementary part to the results obtained in this investigation, the maximum rainfall of hydrological regions 5 and 6 of Peruvian north were determined for various return periods, as shown in Figure 7, also using the inverse distance weighted procedure, commonly known as IDW.

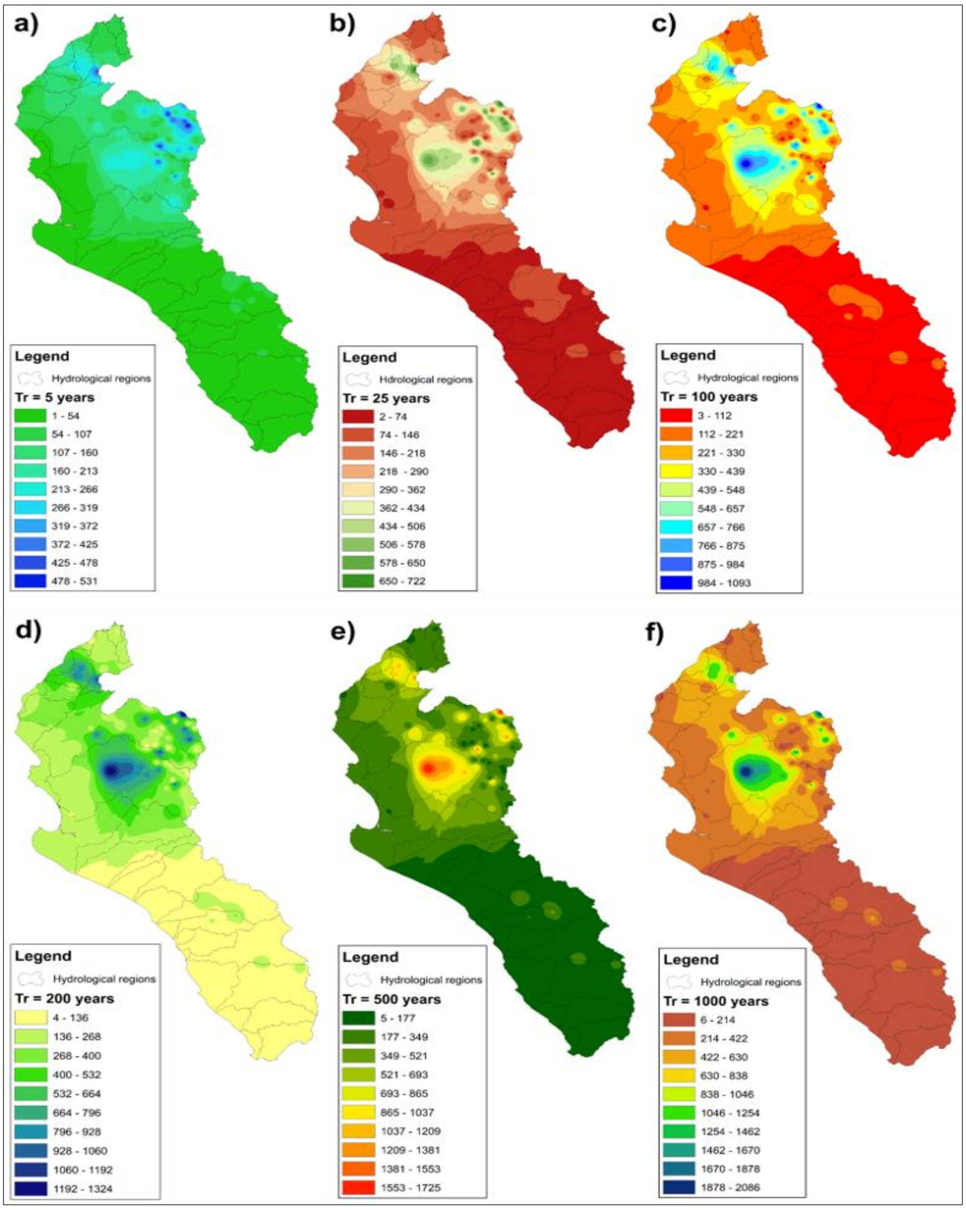


**Figure 7.** Maximum rainfall of hydrological regions 5 and 6 of Peruvian north for return periods of: a) 5 years; b) 25 years; c) 100 years; d) 200 years; e) 500 years and f) 1000 years

It should be noted that these rainfalls were estimated with the application of the GEVD through ordinary moments, since as the findings of this investigation indicate, this adjustment achieved the best correlation in terms of maximum rainfall in both hydrological regions.

As expected, the greatest accumulation of rainfall occurs in the Pacific 6 hydrological region than in the Pacific 5 hydrological region, for example, in Figure 7c for a return period of 100 years, in region 6 the rainfall reached exceed 1000 mm, while region 5 reached a maximum of 330 mm, this same behavior occurred with all return periods, which also corroborates the hypothesis obtained that the location parameter of both hydrological regions are different.

## 4. CONCLUSIONS

There are few studies related to the determination of maximum rainfall in northern Peru, so this research contributes not only to the analysis of the GEVD, but also to the evaluation of the location, scale, and shape parameters in the Pacific 5 and Pacific 6 hydrological regions, as well as their distribution in this area of Peru, considering a total of 138 climatic stations with a minimum record of 15 years.

The scale and shape parameters of both hydrological regions show a good performance for the adjustment both with ordinary moments and with linear moments, which could be demonstrated by applying the respective hypotheses, since for these two parameters the null hypotheses were accepted, for what we know it can be inferred that in both hydrological regions there is variability in the rainfall pattern, however in terms of correlations with altitude, average and maximum rainfall, only the scale parameter was the one that presented the best performance with respect to these climatic variables.

The location parameter showed that the Pacific 6 hydrological region is rainier than the Pacific 5 hydrological region, since the average value of this parameter in region 5 was much lower than region 6; likewise, it is justified with the contrasting of the hypothesis, because the null hypothesis was rejected and according to the best correlations achieved with the maximum rainfall, they suggest that the adjustment of the GEVD with ordinary moments is adequate for both hydrological regions. However, it is recommended to study this type of adjustment in the other hydrological regions of the Pacific of Peru to help validate the findings achieved in this research.

## REFERENCES


Abreu, M., de Souza, A., Lyra, G., de Oliveira-Júnior, J., Pobocikova, I., de Almeida, L., de Souza, F., Aristone, F., & Cecílio, R. (2023). Assessment and characterization of the monthly probabilities of rainfall in Midwest Brazil using different goodness-of-fit tests as probability density functions selection criteria. *Theoretical and Applied Climatology*, *151*(1-2), 491-513. https://doi.org/10.1007/s00704-022-04286-z

Adeola, O., Masinde, M., Botai, J., Adeola, A., & Botai, C. (2021). An analysis of precipitation extreme events based on the SPI and EDI values in the Free State province, South Africa. *Water (Switzerland)*, *13*(21). https://doi.org/10.3390/w13213058

Alahmadi, F., & Rahman, N. (2020). Climate change impacts on extreme rainfall frequency prediction. *Journal of Water and Climate Change*, *11*(4), 935-943. https://doi.org/10.2166/wcc.2019.138

Back, Á., & Bonfante, F. (2021). Evaluation of generalized extreme value and Gumbel distributions for estimating maximum daily rainfall. *Brazilian Journal of Environmental Sciences*, *56*(4), 654-664. https://doi.org/10.5327/Z217694781015

Alfaro, E., Chourio, X., Muñoz, Á., & Mason,S. (2018). Improved seasonal prediction skill of rainfall for the primera season in Central America. *International Journal of Climatology*, *38*, e255-e268. http://doi.org/10.1002/joc.5366

Arriola, G. (2021). Uso del software libre como aporte al sílabo hidrología de la Universidad Señor de Sipán en tiempos de Covid-19. *Revista Hacedor*, *5*(2), 10-18. https://doi.org/10.26495/rch.v5i2.1923

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 Politecnica*, *50*(2), 15–22. https://doi.org/10.33333/rp.vol50n2.02

Bowman, K., & Shenton, L. (2014). Estimation: Method of moments. *Wiley StatsRef: Statistics Reference Online*. https://doi.org/10.1002/9781118445112.stat01679

Campos-Aranda, D. (2018). Fitting with mobile L moments of the GEV distribution with variable location and scale parameters. *Agrociencia*, *52*(7), 933-950. https://agrociencia-colpos.mx/index.php/agrociencia/article/view/1714

Campos-Aranda, D. (2019). Fitting with L-moments of the non-stationary distributions GVE1 and GVE2 to PMD series. *Tecnologia y Ciencias del Agua*, *10*(5), 75-103. https://doi.org/10.24850/j-tyca-2019-05-03

Campos-Aranda, D. (2021). Flood frequency analysis with the GEV distribution for r-annual events. *Tecnologia y Ciencias del Agua*, *12*(4), 163-218. https://doi.org/10.24850/J-TYCA-2021-04-04

Diriba, T., & Debusho, L. (2021). Statistical modeling of spatial extremes through max-stable process models: Application to extreme rainfall events in South Africa. *Journal of Hydrologic Engineering*, *26*(10). https://doi.org/10.1061/(ASCE)HE.1943-5584.0002123

Efron, B. (1979). Bootstrap methods: Another look at the Jackknife. *The Annals of Statistics*, *7*(1), 1-26. https://doi.org/10.1214/aos/1176344552

Fernandez-Palomino, C., Hattermann, F., Krysanova, V., Lobanova, A., Vega-Jácome, F., Lavado, W., Santini, W., Aybar, C., & Bronstert, A. (2022). A Novel high-resolution gridded precipitation dataset for Peruvian and Ecuadorian watersheds: Development and hydrological evaluation. *Journal of Hydrometeorology*, *23*(3), 309-336. https://doi.org/10.1175/JHM-D-20-0285.1

Flores-Rojas, J., Silva, Y., Suárez-Salas, L., Estevan, R., Valdivia-Prado, J., Saavedra, M., Giraldez, L., Piñas-Laura, M., Scipión, D., Milla, M., Kumar, S., & Martinez-Castro, D. (2021). Article analysis of extreme meteorological events in the central andes of Peru using a set of specialized instruments. *Atmosphere, 12*(3). https://doi.org/10.3390/atmos12030408

Guillén-Oviedo, H., Cid-Serrano, L., & Alfaro-Martínez, E. (2020). Comparison of parameters of the generalized extreme value distribution associated with extreme rainfall events in Central America. *Uniciencia, 34*(1), 111-128. http://dx.doi.org/10.15359/ru.34-1.7

Halim, S. (2019). Delta change method with cyclic covariate generalized extreme value model for downscaling extreme rainfall. *International Journal of Recent Technology and Engineering, 8*(2S2), 158-161. https://doi.org/10.35940/ijrte.B1029.0782S219

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 (Methodological), 52*(1), 105-124. https://doi.org/10.1111/j.2517-6161.1990.tb01775.x

Hossain, I., Khastagir, A., Aktar, M., Imteaz, M., Huda, D., & Rasel, H. (2021). Comparison of estimation techniques for generalised extreme value (GEV) distribution parameters: a case study with Tasmanian rainfall. *International Journal of Environmental Science and Technology*. *19*(8), 7737-7750 https://doi.org/10.1007/s13762-021-03693-5

Juma, B., Olang, L., Hassan, M., Chasia, S., Bukachi, V., Shiundu, P., & Mulligan, J. (2021). Analysis of rainfall extremes in the Ngong River Basin of Kenya: Towards integrated urban flood risk management. *Physics and Chemistry of the Earth, 124*. https://doi.org/10.1016/j.pce.2020.102929

Kozanis, S., Christofides, A., Mamassis, N., Efstratiadis, A., & Koutsoyiannis, D. (2010). Hydrognomon - Open source software for the analysis of hydrological data. *Conference: European Geosciences Union General Assembly 2010, 12*. https://doi.org/10.13140/RG.2.2.21350.83527

Klassou, K., & Komi, K. (2021). Analysis of extreme rainfall in Oti river basin (West Africa). *Journal of Water and Climate Change, 12(*5), 1997-2009. https://doi.org/10.2166/wcc.2021.154

Lavado, W., Labat, D., & Ronchail, J. (2013). Trends in rainfall and temperature in the Peruvian Amazon–Andes basin over the last 40 years (1965-2007). *Hydrological Processes, 27*(20), 2944-2957. https://doi.org/10.1002/hyp.9418

Lee, S., & Kim, H. (2023). Two tests using more assumptions but lower power. *Communications for Statistical Applications and Methods, 30*(1), 109-117. https://doi.org/10.29220/CSAM.2023.30.1.109

Lima, A., Lyra, G., Abreu, M., Oliveira-Júnior, J., Zeri, M., & Cunha-Zeri, G. (2021). Extreme rainfall events over Rio de Janeiro State, Brazil: Characterization using probability distribution functions and clustering analysis. *Atmospheric Research, 247*. https://doi.org/10.1016/j.atmosres.2020.105221

López, J., Delgado, O., & Campo, M. (2018). Determinación de las curvas IDF en Igueldo-San Sebastián. Comparación de diferentes métodos. *Ingeniería del Agua, 22*(4), 209-223. https://doi.org/10.4995/Ia.2018.9480

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://dx.doi.org/10.17268/sci.agropecu.2018.01.07

Mashishi, D., Maposa, D., & Lesaoana, M. (2020). Comparative analysis of the 100-year return level of the average monthly rainfall for South Africa: Parent distribution versus extreme value distributions. *Applied Mathematics and Information Sciences, 14*(5), 801-807. https://doi.org/10.18576/amis/140507

Min, J., & Halim, S. (2020). Rainfall modelling using generalized extreme value distribution with cyclic covariate. *Mathematics and Statistics, 8*(6), 762-772. https://doi.org/10.13189/ms.2020.080617

Mohamed, J., & Adam, M. (2022). Modeling of magnitude and frequency of extreme rainfall in Somalia. *Modeling Earth Systems and Environment*. *8*(3), 4277-4294. https://doi.org/10.1007/s40808-022-01363-0

Nerantzaki, S., & Papalexiou, S. (2022). Assessing extremes in hydroclimatology: A review on probabilistic methods. *Journal of Hydrology, 605*. https://doi.org/10.1016/j.jhydrol.2021.127302

Oruc, S. (2021). Non-stationary investigation of extreme rainfall. *Civil Engineering Journal (Iran), 7*(9), 1620-1633. https://doi.org/10.28991/cej-2021-03091748

Padiyedath-Gopalan, S., Kawamura, A., Amaguchi, H., Takasaki, T., & Azhikodan, G. (2019). A bootstrap approach for the parameter uncertainty of an urban-specific rainfall-runoff model. *Journal of Hydrology, 579*. https://doi.org/10.1016/j.jhydrol.2019.124195

Peleg, N., Marra, F., Fatichi, S., Paschalis, A., Molnar, P., & Burlando, P. (2018). Spatial variability of extreme rainfall at radar subpixel scale. *Journal of Hydrology, 556*, 922-933. https://doi.org/10.1016/j.jhydrol.2016.05.033

Rollenbeck, R., Orellana-Alvear, J., Bendix, J., Rodriguez, R., Pucha-Cofrep, F., Guallpa, M., Fries, A., & Célleri, R. (2022). The Coastal El Niño event of 2017 in Ecuador and Peru: A weather radar analysis. *Remote Sensing, 14*(4). https://doi.org/10.3390/rs14040824

Rollenbeck, R., Orellana-Alvear, J., Rodriguez, R., Macalupu, S., & Nolasco, P. (2021). Calibration of X-band radar for extreme events in a spatially complex precipitation region in north peru: Machine learning vs. empirical approach. *Atmosphere, 12*(12). https://doi.org/10.3390/atmos12121561

Roslan, R., Na, C., & Gabda, D. (2020). Parameter estimations of the generalized extreme value distributions for small sample size. *Mathematics and Statistics, 8*(2), 47-51. https://doi.org/10.13189/ms.2020.081308

Samantaray, S., & Sahoo, A. (2020). Estimation of flood frequency using statistical method: Mahanadi River basin, India. *H2Open Journal, 3*(1), 189-207. https://doi.org/10.2166/h2oj.2020.004

Seo, J., Won, J., Choi, J., Lee, J., Jang, S., & Lee, O. (2021). Uncertainty of rate of change in Korean future rainfall extremes using non-stationary GEV model. *Atmosphere, 12*(2). https://doi.org/10.3390/atmos12020227

SENAMHI. (2017a). *Estudio: Regionalización de las precipitaciones máximas del Perú.* Lima, Perú: Dirección de Hidrología del Servicio Nacional de Meteorología e Hidrología del Perú. https://repositorio.senamhi.gob.pe/handle/20.500.12542/239

SENAMHI. (2017b). *Nota técnica N° 002: Atlas de erosión de suelos por regiones hidrológicas del Perú.* Lima, Perú: Dirección de Hidrología del Servicio Nacional de Meteorología e Hidrología del Perú. https://repositorio.senamhi.gob.pe/handle/20.500.12542/261

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

Ulrich, J., Fauer, F., & Rust, H. (2021). Modeling seasonal variations of extreme rainfall on different timescales in Germany. *Hydrology and Earth System Sciences, 25*(12), 6133-6149. https://doi.org/10.5194/hess-25-6133-2021

Vavrus, S., Wang, F., & Block, P. (2022). Rainy season precipitation forecasts in coastal Peru from the North American multi-model ensemble. *International Journal of Climatology*. *42*(12), 6221-6234. https://doi.org/10.1002/joc.7586

Vivekanandan, N. (2018). Comparison of probability distributions in extreme value analysis of rainfall and temperature data. *Environmental Earth Sciences, 77*(5). https://doi.org/10.1007/s12665-018-7356-z

Vivekanandan, N. (2022). Intercomparison of estimators of extreme value family of distributions for rainfall frequency analysis. *Mausam, 73*(1), 59-70. https://doi.org/10.54302/MAUSAM.V73I1.5080

Wang, H., & Xuan, Y. (2021). Spatial variation of extreme rainfall observed from two century-long datasets. *Geophysical Research Letters, 48*(8). https://doi.org/10.1029/2020GL091933

Wang, H., & Xuan, Y. (2022). Spatial variation of catchment-oriented extreme rainfall in England and Wales. *Atmospheric Research, 266*(2022), 105968. https://doi.org/10.1016/j.atmosres.2021.105968

Yeo, M., Nguyen, V., & Kpodonu, T. (2021). Characterizing extreme rainfalls and constructing confidence intervals for IDF curves using Scaling-GEV distribution model. *International Journal of Climatology, 41*(1), 456-468. https://doi.org/10.1002/joc.6631

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