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Extreme Rainfall Events and Their Return Periods in West Africa

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Abstract

Extreme rainfall events and their return periods are subjects that pose enormous problems. Extreme rainfall causes a great deal of damage in Africa; loss of life, property damage, etc., has been recorded with each disaster. It is therefore important to understand what characterizes climate variability in order to fully grasp its impacts. The objective here is to determine the maximum rainfall threshold that leads to extreme events in West Africa, particularly in certain African cities, and to be able to provide sustainable solutions to this situation. Using the Pareto distribution method, we can obtain an asymptotic characterization of the distribution of these threshold exceedances and be able to model the problem.

Keywords

Extreme Rainfall, Return Period, Pareto Distribution, Climate Variability

1. Introduction

Climate change caused by greenhouse gases is responsible for extreme rainfall events. Certain probability distributions, such as the generalized Pareto distribution, allow us to determine the rainfall threshold that can lead to flooding and also to determine return periods, which correspond to the average time interval between two occurrences of an event. Rainfall is a major cause of natural hazards and is linked to flooding. This last one has direct consequences on society; it can cause numerous losses of human life, completely damaged homes, and can also lead to the destruction of roads, bridges, and schools. Now, faced with all these situations, it is necessary to find suitable methods, such as Pareto's Law, to predict extreme rainfall in order to minimize its impact on society and the environment.

During the Northern Hemisphere summer, the southerly trade winds sweep across West Africa, forming a circulation pattern associated with the monsoon. The key elements of the African monsoon during the Northern Hemisphere summer are illustrated in Figure 1: Lower atmospheric circulation. In the lower atmosphere, the African monsoon is characterized by two main flows: the Harmattan and the monsoon flow. The latter originates continentally from the Sahara; it is a hot, dry northerly flow.

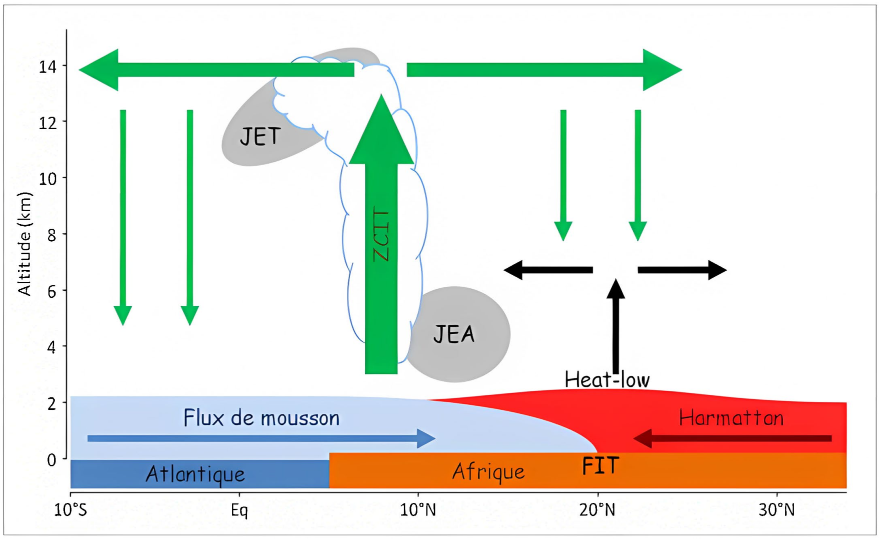

Figure 1. Mean meridional structure of the African monsoon.

Many operational and scientific challenges stem from a significant lack of documentation regarding extreme rainfall in West Africa. The census focusing on precipitation analysis in the West African region is based on only two studies to date. An analysis of six daily stations in West Africa, including two in The Gambia and four in Nigeria, was conducted by [1], which shows an increase in maximum annual daily rainfall at one station. In Côte d'Ivoire, an analysis of trends and breaks was also carried out by [2], including forty-four post-rainfall data points based on three indices: maximum annual rainfall, number of days exceeding the 50 mm threshold, and contribution to the annual total of days exceeding 50 mm. The main study of these results showed the break in some series or a downward trend; however, this is not the case for the majority of stations, which do not exhibit significant non-stationarity. Thus, in order to gain feedback that is, to have the study of extremes focused on characterizing a past event, scientists seek to change the return period of the event, understand its meteorological causes, document its impacts, etc. This feedback was also the subject of the floods in West Africa caused by the 2007 monsoon. This is why the studies by [3] and [4] revisit this exceptional year. Based on rainfall data from TRMM, [3] estimated that the return period for the 2007 events varies between 1 and 50 years (reaching up to approximately 1200 years in the Upper Volta basin). Furthermore, given the short lengths of the 12-year series used and the still significant uncertainties associated with satellite estimates, such estimates should be interpreted with caution. This study also examines the meteorological causes of these exceptional events. Thus, the study by [4] focuses on the media's description of these events. Some studies address this topic using statistical tools to aid in the design of hydraulic structures, such as IDF (Intensity-Duration-Frequency) curves in non-Sahelian Africa, for example in Congo, Ghana, Ivory Coast, and Nigeria. These curves allow us to differentiate the frequency of rainfall intensities. None of these studies include any Sahelian region; they are very localized. Thus, the lack of study in Africa can be explained by two reasons, one being the predominance of the discourse of droughts, which favours wet extremes rather than dry extremes and the other, the problem of having rainfall data at daily and sub-daily time steps over very long periods which allows us to sample extreme and therefore rare events by definition of [3].

Functioning of the West African monsoon:

The monsoon is a wind whose existence results from a strong interaction between the ocean, the atmosphere, and the continent. This has allowed it to be compared to a sea breeze on a continental scale. It blows in the lower atmospheric layers of maritime origin and has a significant influence in the regions where it occurs. Globally, West Africa is the driest region, which is why the monsoon's contribution to its humidification is very important, not to mention the western atmosphere. In this region, the pressure gradient arises from the contrast between the Saharan region and the colder waters of the Gulf of Guinea. Geographically, West Africa has a strong zonal organization between 10˚W and 10˚E, so a meridional description is often used to present the main features of the average monsoon structure [5]. The West African Monsoon (WAM) exhibits daily and seasonal cycles and strong interannual variability. It plays a very important role in the climatic system of our region. Several sensitivity tests have been conducted to evaluate hypotheses about the mechanism of WAM development. This phenomenon, known as the establishment of the Mechanized Atmospheric System (MAO), brings the Intertropical Convergence Zone (ITCZ) over the Sahel and simultaneously signals the beginning of the wet season for the region. The ITCZ is located around the Earth between the tropics and constitutes a zone of deep convection due to the convergence of the trade winds in the lower atmosphere. These trade winds from the Southern Hemisphere originate from the Saint Helena High and are deflected eastward over the Gulf of Guinea as they cross the equator due to the Coriolis effect. The ITCZ carries the majority of rainfall to the tropics, according to meteorology.

Throughout the year in West Africa, a positive temperature anomaly forms, following the maximum solar forcing at ground level. Between the Atlas Mountains and the Hoggar Mountains (Sahara Heat-Low; SHL), this anomaly is established over the Sahara Desert in summer. [6] showed that atmospheric circulation in the lower layers was strongly linked to the SHL. The latter is composed of a heated layer which can reach an altitude of 600 hPa with two meridional circulations which induces subsidence at the northern and southern extremities of the heated zone and which reinforces the dryness convention (due to the lack of humidity in this region) in the center. Consequently, the low-level winds (the MAO in the south and the Harmattan in the north) converge in the plateau region located between the Atlas Mountains and the Hoggar massif, driven by a cyclonic circulation generated by a thermal depression. Due to the different origins of these air masses (the MAO is cold and humid, while the Harmattan is hot and dry), a front (Intertropical Convergence Zone; ITCZ) similar to those of the mid-latitudes is created near the thermal depression (blue dashed line).

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Extracted from [6], **Figure 2** shows the results of an idealized two-dimensional simulation whose model is forced by the surface temperature field similar to that of West Africa.

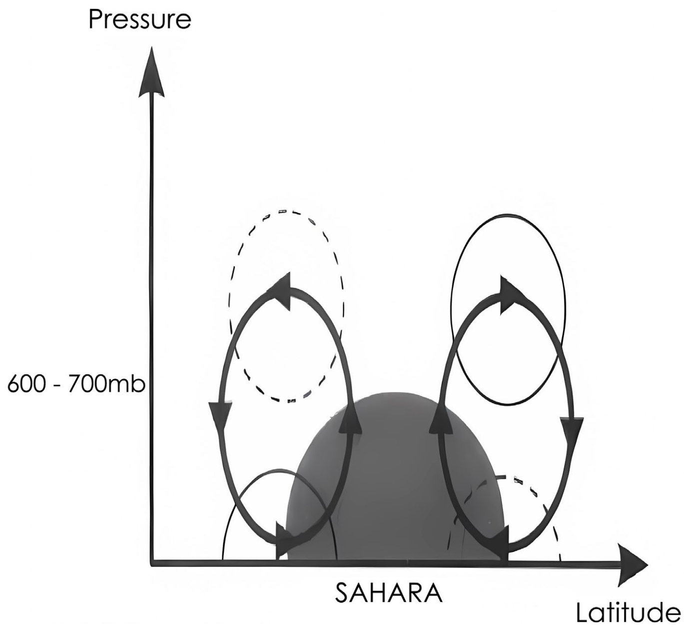

Figure 2. Illustration representing the atmospheric circulation response to sensible surface heat flux. The black area represents the heated region, the arrows indicate meridional circulation, and the solid and dashed circles represent zonal circulation (solid line for west wind and dashed line for east wind) [6].

[7] conducted studies on the climatology of the SHL, using the Geopotential Thickness (GE) between 925 hPa and 700 hPa as a criterion. This is consistent with the study by [6].

2. Data and Methodology

Description of the Study Areas

Dakar:

Dakar is the capital of Senegal in West Africa. This port city on the Atlantic Ocean is located on the Cap Vert peninsula and covers an area of 550 km^2, representing 0.28% of the national territory, and has a population of 3,938,358. It lies between 70˚10' and 17˚32' West longitude and 14˚53' and 14˚35' North latitude. Its traditional quarter, the medina, is home to the Great Mosque, distinguished by its imposing minaret. The Théodore Monod Museum displays cultural objects such as sculptures, percussion instruments, clothing, and tools. In Dakar, rainfall occurs mainly during the summer months and is irregular from year to year. Dakar benefits from a climate influenced by geographical and atmospheric factors. Located in a subtropical zone, Dakar is characterized by a mild desert climate according to the Köppen-Geiger classification. It is influenced by the maritime trade winds and the monsoon, which provide it with high humidity and coolness. Thus, as one moves away from the coast during the dry season, the trade winds and the Harmattan become weak. The Dakar region has temperatures ranging from 17˚C to 5˚C from December to April and from 27˚C to 30˚C from May to November. Rainfall varies between three and four months, for example, from June to the beginning of October, accompanied by both hot and cold weather.

Abidjan:

The Abidjan metropolitan area is located in the south of Côte d'Ivoire, on the Gulf of Guinea, and is crossed by the Ebrié Lagoon. It covers an area of 57,735 hectares. As the crow flies, it measures approximately twelve kilometers from north to south and ten kilometers from east to west. It has a population of 5,515,790. In Abidjan, flooding is a major problem. Due to heavy rainfall, the risk of flooding is unavoidable in urban areas because of changes in hydrological processes and conditions of uncontrolled and haphazard urbanization. Flood management in these areas has become a major concern. In Abidjan, rainfall varies between 23 mm in January and 525 mm in June, the wettest month, and its rainfall is very significant. The region is characterized by an equatorial climate, composed of four seasons: two dry seasons and two rainy seasons. From March to July, an annual rainfall of 1922 mm is recorded. A short dry season follows from August to September, before the second peak of rainfall from October to November. From December to March, the region is characterized by the long dry season. Temperatures vary from 24.2˚C in August, the coldest month, to 27.4˚C in March, the hottest month.

Bamako:

Located on the banks of the Niger River, called Djoliba ("the river of blood") in Mandinka, the city of Bamako is built in a basin surrounded by hills. It stretches 22 km from west to east and 12 km from north to south, covering an area of 267 km^2 and with a population of 2,816,943. It lies between 12˚38' North and 7˚59' West. Bamako has a tropical climate, with hot weather year-round, a dry season from November to April, and a rainy season from June to September. Before the rains arrive, the hottest period in Bamako is from March to May. Bamako is the area of the country that receives the most rain from the African monsoon. The total annual rainfall is 990 mm. In January, February, and December, the driest months, rainfall amounts to 1 mm, while in August, the wettest month, it reaches 290 mm. Its average temperature is 24.8˚C in January, the coldest month, and in

April, the hottest month, its temperature is 32.4˚C.

Niamey:

Niamey is the capital of Niger and the country's most populous city, located on the Niger River in the far west of the country. It is built on a plateau overlooking the Niger River on its left bank and the alluvial plain on its right bank, at an altitude of between 180 and 240 meters. In 2018, it had a population of 1,802,910, comprising five communes that make up the urban community of Niamey. It has an area of 240 km^2 and a population density of 7,070 inhabitants per km^2. It lies between 13˚28' and 13˚35' North latitude and 2˚03' and 2˚10' East longitude. It has a Sahelian climate and an average annual rainfall of 500 to 750 mm. Its average temperature is 29.5˚C and the average rainfall is 635.3 mm.

Ouagadougou:

Ouagadougou is the capital and largest city of Burkina Faso. It is located in the center of the country, in the heart of the intertropical zone. In 2015, it had 2.5 million inhabitants, and in 2022, its population was 3 million. The city of Ouagadougou is the cultural, economic, and administrative center of the country. It has a tropical savanna climate with two seasons: dry and rainy. Its population density is 1089 inhabitants per km^2, and its area is 280,500 hectares (2805 km^2). It has an altitude of 294 meters. Its latitude is 12.35 and its longitude is −1.516667. Its average temperature is 28.1˚C, and its average rainfall is 933.5 mm.

3. Data Description

The NetCDF daily rainfall data used in our study at the level of the different cities are rainfall data from the meteorological stations: Dakar/Yoff (14.73˚N/17.50˚W), Bamako/Senou (12.53˚N/7.95˚W), Abidjan (5.25˚N/3.93˚W), Niamey (13.48˚N/2.17˚E) and Ouagadougou (12.35˚N/1.52˚W). The Inverse Distance Weighted (IDW) interpolation method was used to extract the data. The year covering our data from the different stations is from 1979 to 2019. The minimum and maximum rainfall for the different cities is shown in **Table 1**, along with the first quartile, the median, and the mean.

Table 1. Minimum and maximum rainfall for different cities.

Statistiques	Dakar	Abidjan	Bamako	Niamey	Ouagadougou
Min	0.000	0.000	0.000	0.000	0.000
1St Qu.	0.000	0.000	0.000	0.000	0.000
Median	0.000	0.000	0.000	0.000	0.000
Mean	1.186	4.864	2.609	1.3765	2.0915
3rd Qu.	0.000	7.013	1.329	0.2383	0.6027
Max	165.987	165.836	126.478	134.5319	156.3456

Several factors make these estimates difficult in this region: Strong interannual variability: the rainfall disruption of the years 1968-1985 (a deficit of 20 - 30 compared to the 1950-1967 averages) introduces non-stationarity into the series, which skews the estimates if a stationary distribution is assumed. Short or incomplete series: many stations have less than 30 - 40 years of reliable data, which increases the uncertainty on rare quantiles ($T \geq 100$ years). Marked spatial gradient: from the Sahel (<400 mm/year in northern Mali/Niger) to the Guinean zones (>1500 mm/year in the Ivory Coast/southern Senegal), the distributions are not homogeneous.

4. Threshold Estimation Method

Determining the threshold above which daily rainfall can be modeled by the generalized Pareto distribution is often the result of a compromise so that the determined threshold is large enough to reduce bias because it satisfies convergence towards extreme value theory, but the opposite is true for variance; instead of reducing variance, it increases it for estimators of the generalized distribution parameters (GPD), because there will be less data from which to estimate the parameters. Thus, the opposite is true for choosing a low threshold, as it can lead to uncertainties in the number of extreme observations and consequently produce biased estimates and a poor approximation of the asymptotic distribution. Several methods for determining the threshold have been found, including two approaches: a graphical approach and a numerical approach. The quantification of these methods is very important because it is surjective. Therefore, we will work with the graphical method. Developed by researchers, the Peak Over Threshold (POT) technique is frequently used at the level of extreme value structure. It allows us to evaluate whether the choice of threshold is adequate to be represented by an asymptotic model.

4.1. Residual Average

The residual average lifespan plot (MRL plot) uses the expected value of excess GPD. $E(X-u \mid X>u)=\sigma_u/(1-\zeta)$, $\zeta<1$. And for $u>u^*$ higher, we have $e^u=E(X-u \mid X>u)=\dfrac{\sigma_*}{1+\zeta}+\dfrac{\zeta}{1-\zeta}u$, $\zeta<1$ which is linear in u^* with $\dfrac{\zeta}{1-\zeta}$ and $\dfrac{\sigma_*}{1+\zeta}$. where *u*: is the threshold.

ζ : represents the shape parameter.

σ_u : represents the scale parameter corresponding to the threshold *u*.

e^u : is the average of the excesses beyond the threshold *u*. The graph of the average residual lifespan is the graph of the points $\{(u;e_n(u)), X_{1:n}<u<X_{n:n}\}$.

4.2. Return Period

The return period, called the recurrence interval or repetition interval, denoted *Tr*, is the average duration during which an event of the same intensity occurs. It is widely used for floods, storms, etc. To calculate it, data must be collected for the desired type of event, classified by intensity. Thus, the probability of seeing a hazard (a) occur can be defined by: P(a) = (favorable case)/(possible case). We can try to determine the probability that the intensity *i* is less than or equal to a value x_i. This probability is called the probability of not exceeding the limit. It is given if *i* is represented as a random variable: $F(x_i) = prob(I \le x_i)$. Thus, Tr is defined as the inverse of the frequency of occurrence of the event. $Tr = \frac{1}{1-F(x_i)}$ with Tr: return time in years and F: non-exceedance frequency. In this work, the generalized extreme value distribution (GEV) is used to analyze floods.

- The Generalized Extreme Value (GEV) distribution: The GEV distribution is one of the most widely used distributions for analyzing extreme events such as floods. It has three parameters, including scale, location, and shape. It combines three distribution shapes, each determined by the shape parameter *k*. Its distribution function is given by:

$$F(x) = \begin{cases} \exp\left[-\left(1+\frac{k(x-a)}{b}\right)^{\frac{-1}{K}}\right] & \text{si } k = 0 \\ \exp\left[-\exp\left(\frac{x-a}{b}\right)\right] & \text{si } k \ne 0 \end{cases}$$

with a the location parameter, b the scale parameter and k the shape parameter; $b > 0$, for $k > 0$, $-\infty < x \le a + \frac{k}{b}$, for $k < 0$, $a + \frac{k}{b} \le x < +\infty$ and for $k = 0$, $-\infty < x < +\infty$.

The parameter of form *k*, between $-\frac{1}{2} < k < \frac{1}{2}$, determines the distribution of extreme values. For example, for $k = 0$, we have a Gumbel distribution; if $k > 0$, we have a Frechet distribution; and if $k < 0$, we have a Weibul distribution.

- Gumbel distribution: The Gumbel distribution, also called the extreme value distribution of type 1, is a continuous probability distribution. It was named after Emil Julius Gumbel. It is used to predict natural disasters such as floods, etc. Its probability density function is:

$$f(x) = \frac{1}{b}\left[-\frac{x-a}{b} - \exp\left(-\left(\frac{x-a}{b}\right)\right)\right]$$

and its distribution function is:

$$F(x) = \exp\left(-\exp\left(-\frac{x-a}{b}\right)\right)$$

- Frechel distribution:

It is a special case of the generalized law of extremum. Its name comes from Maurice Fréchet. Its density function is given by:

$$f(x) = \frac{k}{b}\left(\frac{x-a}{b}\right)^{-1-k} \exp\left[-\left(\frac{x-a}{b}\right)^{-k}\right]$$

and its distribution function is given by:

$$F(x)=\begin{cases} F(X<x)=\exp\left[-\left(\frac{x-a}{b}\right)^{-k}\right] & \text{si } x>0 \\ 0, & \text{sinon} \end{cases}$$

with *a*; *b*; *k* being the respective parameters (position, scale, shape).

- Weibull distribution

Named by Walodoli Weibul in 1951, it is often used in the field of lifetime analysis. It is known as the three-parameter Weibul distribution, which can work with zero and negative data. If the position parameter is zero, it is called the two-parameter Weibul distribution. Its distinctive feature is that it is defined for positive variables. Its probability density function is: for three parameters,

$$f(x)=\begin{cases} \frac{k}{b}\left(\frac{x-a}{b}\right)^{-1-k}\exp\left[-\left(\frac{x-a}{b}\right)^{-k}\right] & \text{si } x\geq 0 \\ 0, & \text{si } x<0 \end{cases}$$

and its distribution function is given by:

$$F(x)=\begin{cases} 1-\exp\left[-\left(\frac{x-a}{b}\right)^{k}\right] & \text{si } x\geq 0 \\ 0, & \text{si } x<0 \end{cases}$$

- Pareto distribution

It was in the 20th century that an Italian economist named Vilfredo Pareto highlighted this principle. Originating in the field of economics, this law has been applied to many other areas. Called Pareto's Law or the 80/20 rule, it serves to illustrate a principle of unequal distribution of actions and results. It is applied in the analysis of precipitation. Its density function is given by:

$$f(x)=b^{-1}\exp\left[-(1-k)y\right];$$

with

$$y=\begin{cases} -k^{-1}\log\left(1-\frac{k(x-a)}{b}\right) & \text{si } k\neq 0 \\ \frac{x-a}{b}, & \text{si } k=0 \end{cases}$$

Its distribution function is:

$$F(x)=1-\exp(-y)$$

5. Modeling Extreme Events and Their Return Period Using the Pareto Distribution

5.1. Extreme Event Threshold

Using the Pareto distribution, we were able to graphically determine the threshold beyond which extreme daily rainfall can be modeled. The various figures below represent the function of excess rainfall averages for daily rainfall at the stations of Dakar, Bamako, Abidjan, Niamey, and Ouagadougou. The advantage of using the mean excess rainfall function in this study is that it allows us to determine the interval within which the threshold lies.

For peaks over thresholds (POTs): All precipitation values exceeding a predefined threshold are extracted, and then a generalized Pareto distribution (GPD) is fitted to these excesses. This method uses more data than annual maxima, which is advantageous in Sahelian regions where rainfall series are short or discontinuous.

The maximum annual precipitation is retained, and a generalized extreme value (GEV) law is fitted-often reduced to the Gumbel distribution (GEV type I) in Sahelian contexts. This is the most widespread approach in studies in Sahelian countries.

- **Dakar**

Observing **Figure 3**, we note a linearity in the graph between 3 and 36. Thus, we can say that the threshold is between [3, 36]. Looking at **Figure 4**, the parameters of shape and scale of the Pareto distribution are stable over the interval [24, 29]. Thus, the conclusion we can draw is that the precipitation threshold for the Dakar station is 26.5.

- **Abidjan**

Figure 5 shows a linearity of the graph between 10 and 50, therefore the threshold is between [10, 50]. Observing the stability **Figure 6**, the shape and scale parameters of the Pareto distribution are stable between [20, 31]. Therefore, we can conclude that the precipitation threshold for Abidjan is 25.5.

- **Bamako**

Looking at **Figure 7**, we observe a linearity in the graph between 3 and 38.

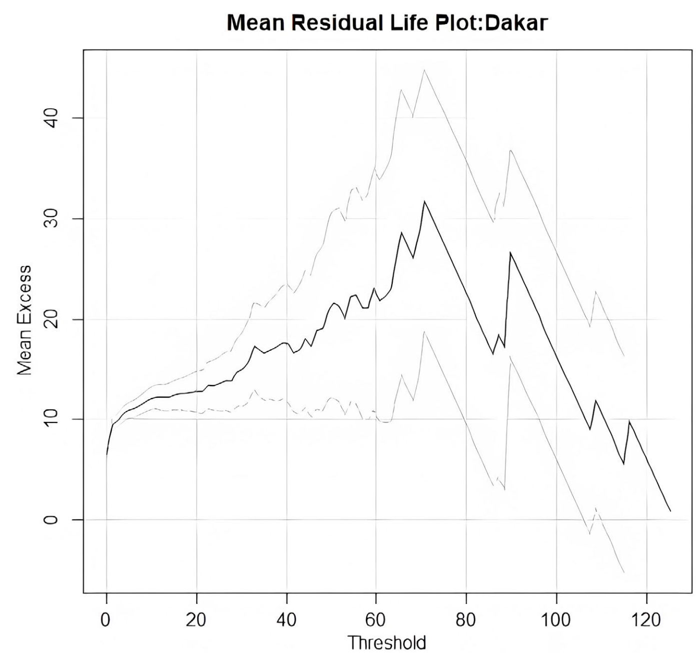

Figure 3. MRL-plot for: Dakar.

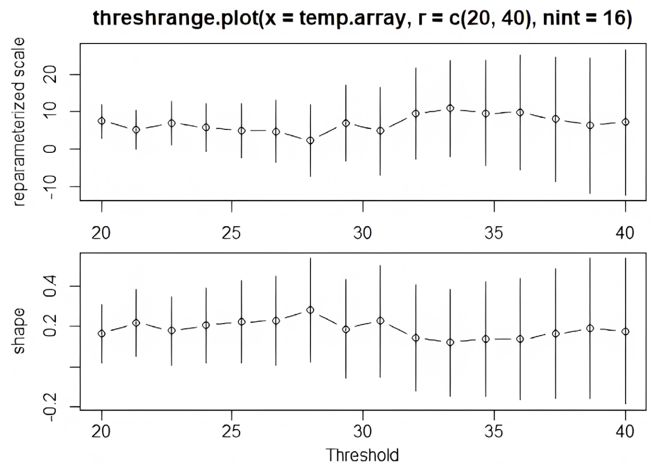

Figure 4. Shape and scale parameter stability graphs for GPD: Dakar.

Figure 5. MRL-plot for GCD: Abidjan.

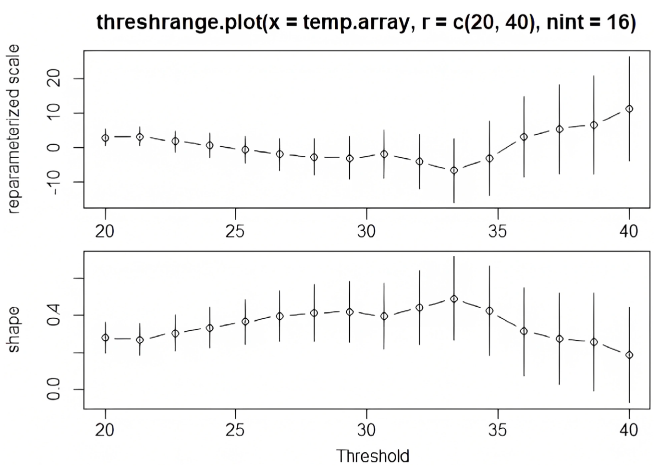

Figure 6. Stability graphs of shape and scale parameters for GPD: Abidjan.

Consequently, we can state that the threshold is between [3, 38]. We see in the stability **Figure 8** that the shape and scale parameters of the Pareto distribution are stable over the interval [20, 34]. Therefore, we can conclude that the precipitation threshold recorded at the Bamako station is 27.

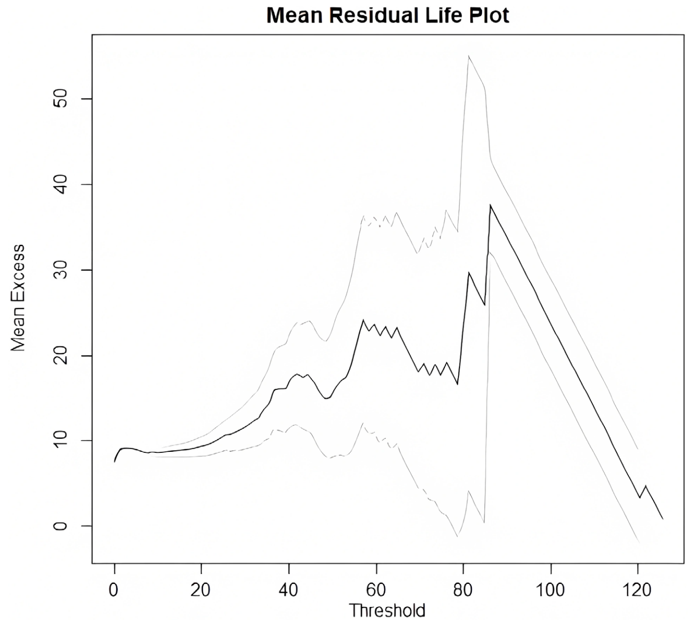

Figure 7. MRL-plot for GCD: Bamako.

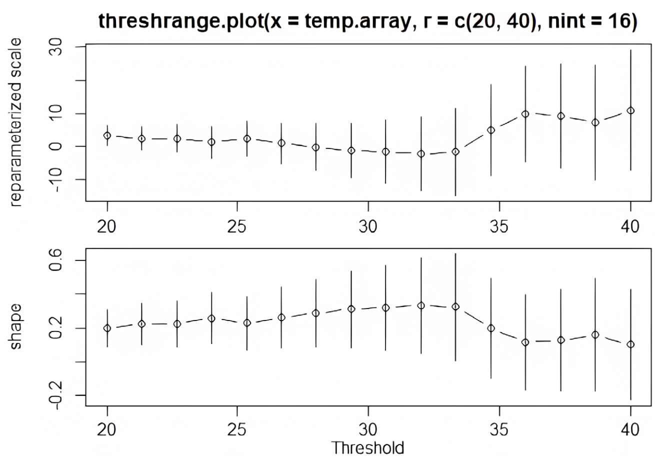

Figure 8. Stability graphs of shape and scale parameters for GPD: Bamako.

- **Niamey**
- **Wagadougou**

Analysis of **Figure 9** for Niamey and **Figure 10** for Ouagadougou shows that linearity is found between 3 and 45. Consequently, the threshold is in the interval [3, 45]. Analysis of the stability curve of **Figure 11** and **Figure 12** shows that the shape and scale parameters of the Pareto distribution are stable on [20, 34]. Therefore, we conclude that the precipitation threshold for the Niamey and Ouagadougou stations is 27.

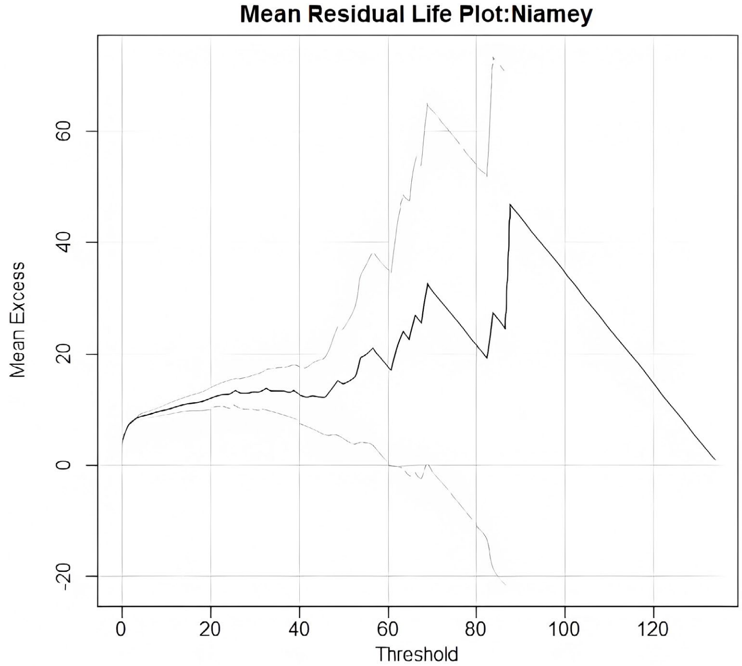

Figure 9. MRL-plot for GCD: Niamey.

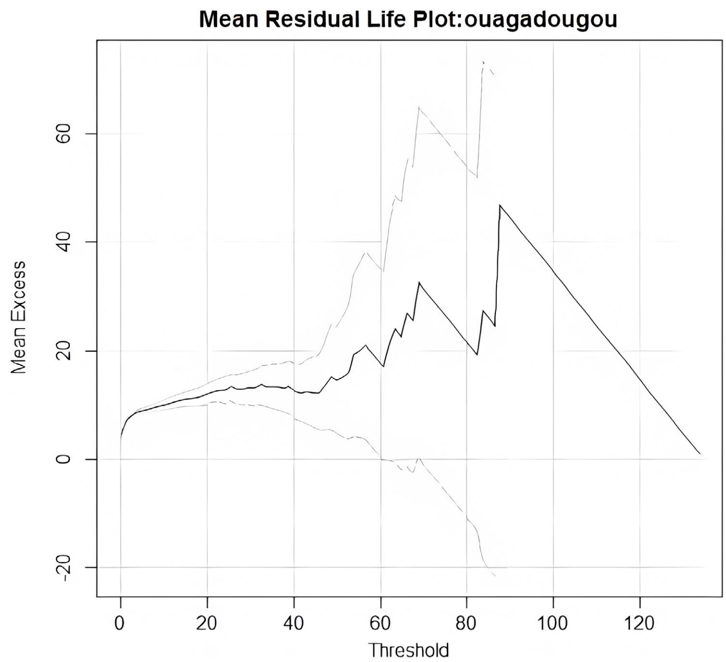

Figure 10. MRL-plot for GCD: Ouagadougou.

5.2. Periods of Return of Extreme Precipitation

In this study, we fitted the precipitation data with the generalized Pareto distribution, which was chosen as the model that most closely represents our sample. Using this Pareto distribution, we will examine, based on the figures, the relationship between return levels in millimeters (mm) and return periods in years. The graphs show that our data follow the distribution fit in a linear and increasing

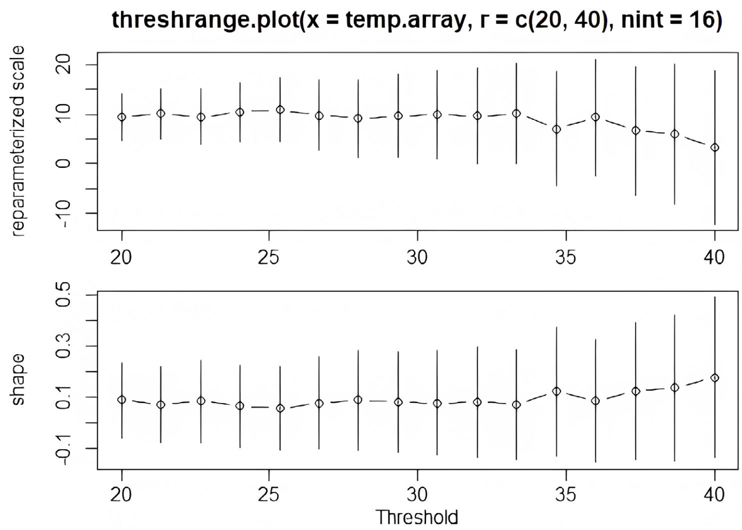

Figure 11. Stability graphs of shape and scale parameters for GPD: Niamey.

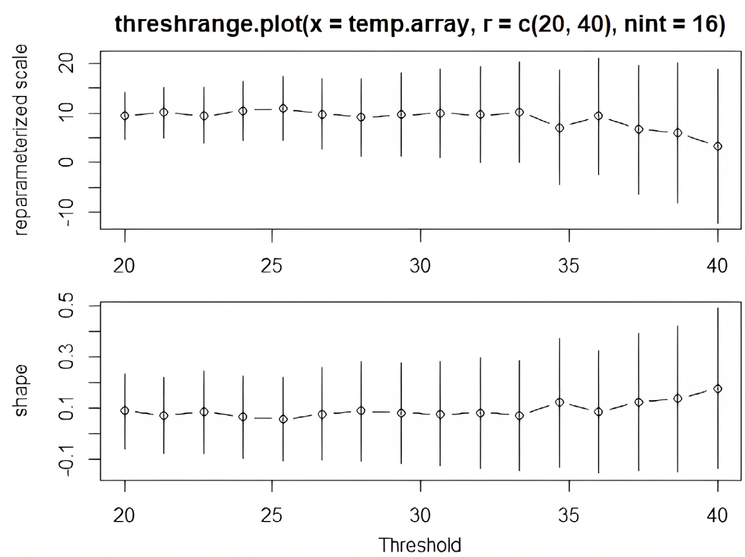

Figure 12. Stability graphs of shape and scale parameters for GPD: Ouagadougou.

manner. In our graph, the points represent the return periods. Note that for low return levels, the points are completely on the regression line, and as the return levels increase, these points are above the line, and their return period also increases. Based on the analysis of the return periods of the following five cities: Dakar, Abidjan, Bamako, Niamey, and Ouagadougou, we observed that their return period does not exceed 50 years. For example, in Dakar and Abidjan, we noted that a quantity of 125 mm requires 50 years to materialize (see Figure 13 and Figure 14). In Bamako, Niamey, and Ouagadougou, a quantity of 160 mm of rainfall requires a return period of 50 years (see Figures 15-17). Therefore, we can state that the Average rainfall in the West Africa zone varies considerably depending on latitude and country. The climate ranges from arid in the north to humid tropical in the south, with overall average rainfall generally ranging from 300 mm to over 1600 mm per year.

Here is an overview of the annual average precipitation by country within the West Africa area: Niger et Mali (Sahelian zone): 200 to 600 mm Burkina Faso et Senegal (Sudan-Sahelian zone): 600 to 1000 mm Benin, Togo et Guinea-Bissau: 1000 to 1200 mm Ivory Coast (Tropical/equatorial zone): 1200 to more than 1600!

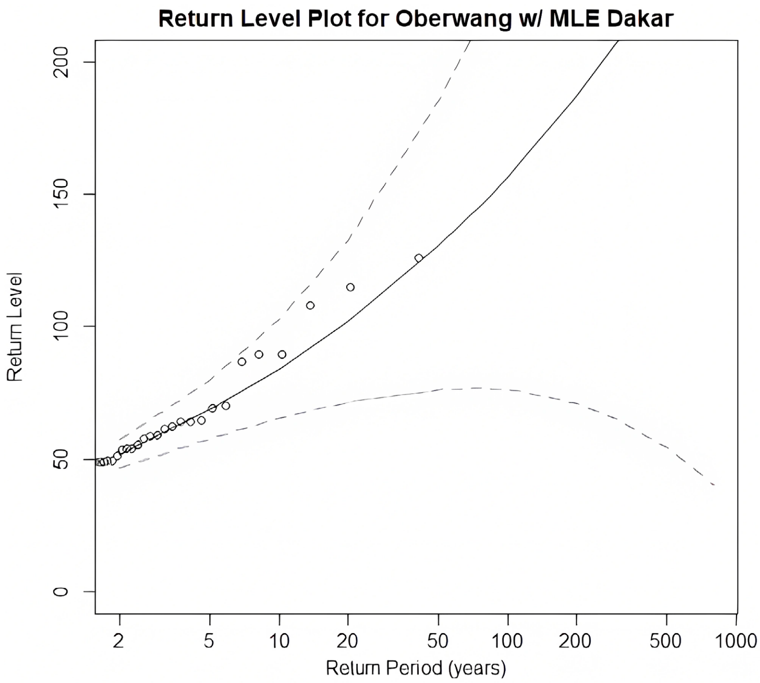

Figure 13. Return periods and levels: Dakar.

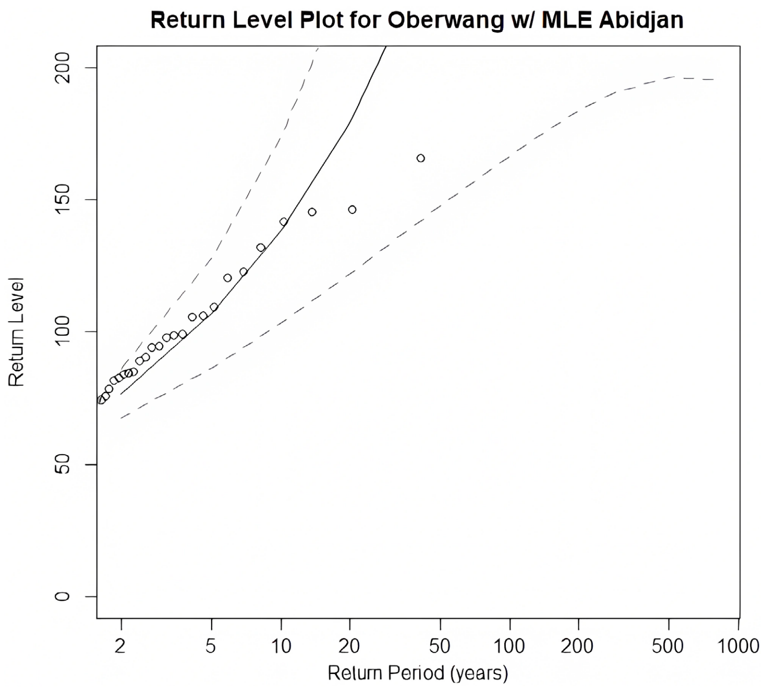

Figure 14. Return periods and levels: Abidjan.

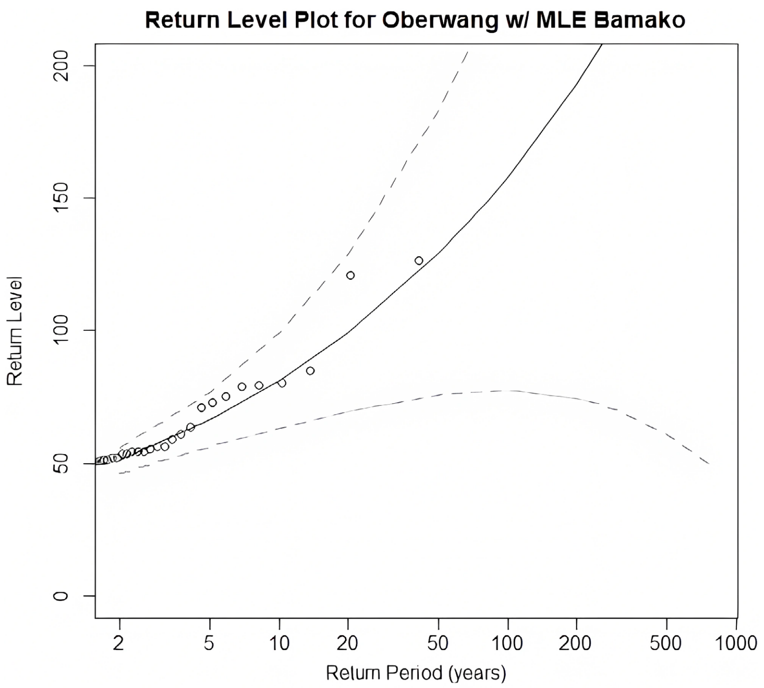

Figure 15. Return periods and levels: Bamako.

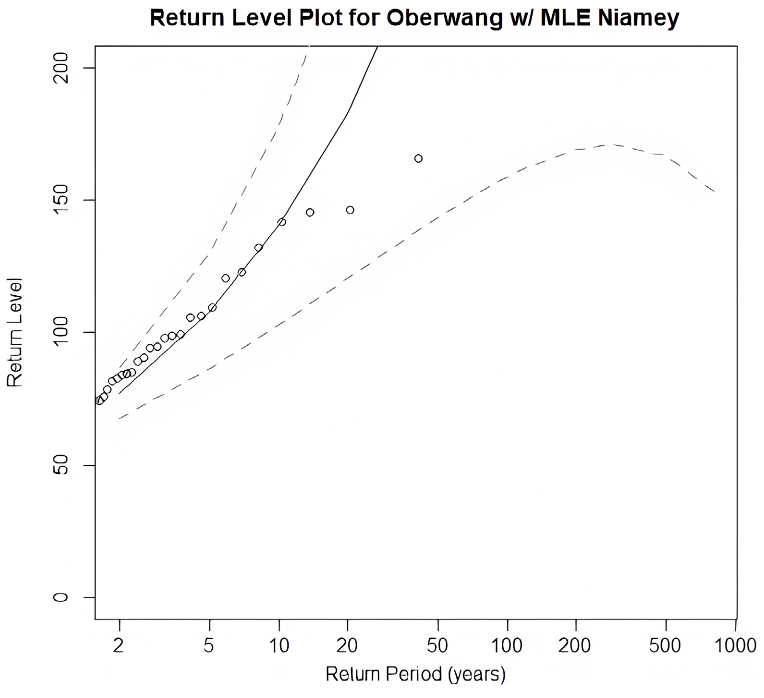

Figure 16. Return periods and levels: Niamey.

- In Dakar
- In Abidjan
- In Bamako
- In Niamey
- In Ouagadougou

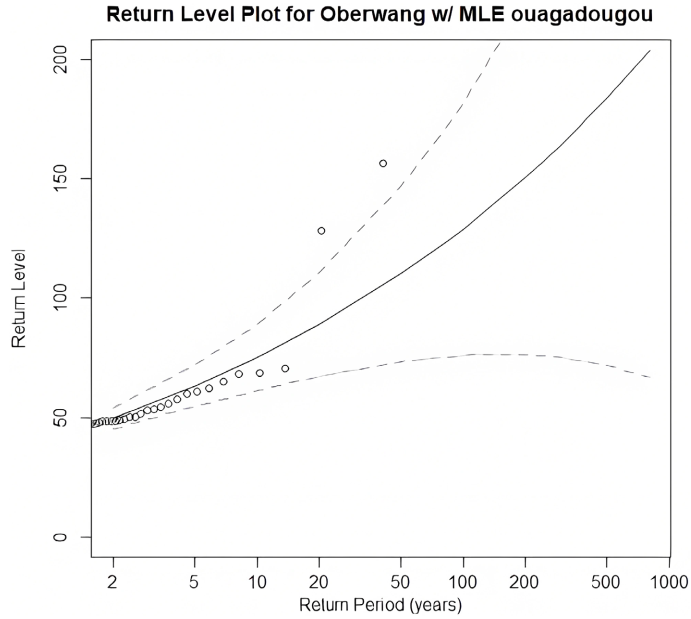

Figure 17. Return periods and levels: Ouagadougou.

6. Conclusion

In order to document extreme rainfall events and their return periods in West Africa and to better understand the phenomena that occur there, the generalized Pareto distribution method was implemented to model and simulate data from different stations over the period from 1979 to 2019 in the following regions: Dakar, Bamako, Abidjan, Niamey, and Ouagadougou. This study discussed the estimation of return periods for maximum annual daily rainfall for the regions mentioned above. The results obtained by the Pareto probability distribution were satisfactory overall. The main results obtained in this study showed that the cities of Dakar, Abidjan, Bamako, Niamey, and Ouagadougou each have their own threshold, and each city also has its own stability threshold.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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