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Trend and Return Level Analysis of Extreme Rainfalls in Senegal

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Abstract

In recent years, Senegal has been confronted with increasingly frequent and damaging extreme events. In the context of climate change, we conducted this study to characterize the trends of rainfall extremes in Senegal. In this work, we used daily rainfall data from 27 stations in Senegal from the period 1951 to 2005 (55 years). To study their linear trends, non-stationary extreme value models with time as a covariate are fitted to evaluate them. Our results indicate a decreasing trend of extreme rainfalls at most of the stations except for 5 stations. However, the decreasing trends are only significant for two stations (Thiès and Kidira), however, this can only be taken as information that climate change may have already impacted extreme rainfalls. For the 20-year and 30-year return periods, the results show that they have undergone changes, in fact for almost all stations, the trends in return periods are decreasing.

Keywords

Climate Change, Extreme Rainfall, Rain Trend, Return Level, Senegal

1. Introduction

Over the last two decades, there has been an upsurge in extreme weather events such as droughts, heat waves, extreme rainfall events, and floods with socio-economical and environmental impacts not recorded in over 30 years [1]. In 2002, a cold wave accompanied by unusual rains and uninterrupted winds hit Senegal causing the death of 30 persons and about 600,000 head of livestock, not to mention the 2012 flood that caused the death of 26 people; 264,000 people were affected and more than 5000 families had to be relocated.

Furthermore, the World Bank in its 2010's report states that developing countries will be hit hard by the effects of climate change, even as they strive to overcome poverty and promote economic growth [2]. However, few studies have been done on the evolution of extreme climate in Senegal, most of them based on indices developed by the Expert Group for Detection and Monitoring of Climate Change (ETCC-DMI), nevertheless, the index method remains a descriptive method and does not allow to assess the statistical properties of extreme events [3]. On the other hand, [4] used the extreme value theory to detect non-stationarity in daily rainfall in the Sahelian region. Indeed, this theory which is the most well-founded to study the evolution of extremes remains unexplored or little used. Thus studying the trends of extremes and calculating return levels with the extreme value theory would be necessary for a good understanding of the evolution of these phenomena in our study area. An important assumption of this theory refers to the stationarity (temporal) on our time series, which implies that the model parameters do not change with time [5], but according to the IPCC report [6] statistically, significant trends were observed in extreme values on hydroclimatological series in different areas of the world which imply that the climate series are known to be non-stationary. This is why different studies have considered time as a covariate. This new approach has been widely used on climate data. [4] introduced a trend in the location parameter in order to detect a break in the series, precipitation [7] and temperatures [8].

As Senegal was hit by an unprecedented drought [9], an open question is whether and to what extent extreme rainfall events have already been affected by this drought. The first answer in this paper will be given by using non-stationary extreme value models to study the evolution of rainfall extremes with available daily data for the period from 1951 to 2005. Our methodology consists of fitting non-stationary extreme value models to the annual maxima of our time series for each station. First, we will use Kendall's test to detect possible trends, then for each station showing a trend, the Akaike Information Criterion (AIC) statistical criterion will be used to select the best model and after analyzing the trends of the extremes. Finally, we will compare the non-stationary return levels (20 years and 30 years) in 2005 with the stationary return level.

This paper is organized as follows. Section 2 presents our data and explains la methodology. Section 3 presents the results. Discussion and conclusions are introduced in Section 4 and Section 5, respectively.

2. Data, Methods and Tools

2.1. Data

The daily rainfall data used in our study comes from the database of the Regional Study Center for Drought Adaptation Improvement (CERAAS). It is collected from various network observations, including the National Agency for Civil Aviation and Meteorology (ANACIM) and the one set up by ISRA/CERAAS as part of the agro-sylvopastoral monitoring. These data concern 27 stations representative of different rainfall regimes in Senegal (Figure 1) and cover the period 1951-2005. Table 1 presents different characteristics of the rainfall stations located in the area study (Senegal).

2.2. Methods and Tools

In this framework, the extreme value theory (EVT) will be adopted to characterize the evolution of extreme rainfalls. The ***Kendall test*** will be performed to

Table 1. Names and locations of stations.

Station	Longitude (decimal ˚)	Latitude (decimal ˚)
Dakar	−17.5	14.7
Thiès	−16.82	14.95
Tivaouane	−16.49	14.57
Diourbel	−16.23	14.65
Fatick	−16.4	14.33
Gossas	−16.08	14.5
Mbacké	−15.92	14.8
Kaffrine	−15.55	14.1
Kaolack	−16.07	14.13
Nioro	−15.78	13.73
Boulel	−15.53	14.28
Louga	−16.22	15.62
Linguére	−15.12	15.38
Kébémer	−16.45	15.37
Dahra	−15.48	15.33
Matam	−13.25	15.65
Podor	−14.97	16.65
Saint-Louis	−16.45	16.05
Dagana	−15..5	16.52
Goudiry	−12.72	14.18
Kidira	−12.22	14.47
Kolda	−14.97	12.88
Koungheul	−14.83	13.97
Tamba	−13.68	13.77
Ziguinchor	−16.27	12.55
Kédougou	−12.22	12.57
Bakel	−12.47	14.9

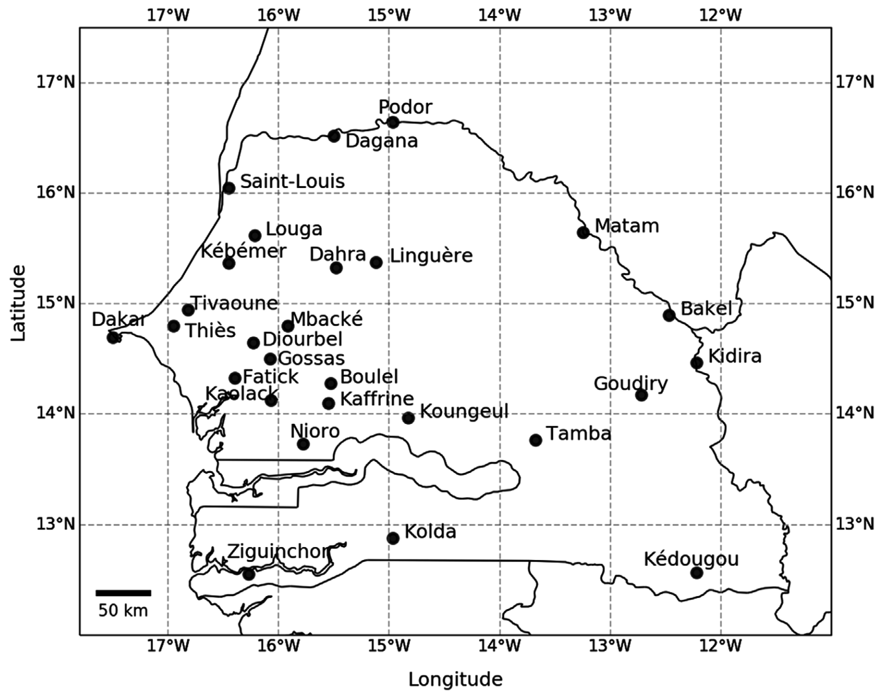

Figure 1. Spatial distribution of different stations under study.

detect the existence of trend within our time series of rainfall for each station. For stations without trend, a ***stationary Generalized Extreme Values*** (***GEV***) model will be fitted. The case where the trend is detected in some stations, three (03) ***non-stationary GEV*** models will be fitted in order to choose the best model among these three with the AIC statistical criterion. The likelihood ratio test will be also used to find the goodness of fitin on extreme value distributions **(Fréchet; Gumbel; Weibull)**, in order to better estimate the 20-year and 30-year return levels.

Finally, to analyze the trends of extreme rainfalls, relative values will be calculated to quantify decreasing or increasing of such extremes. Therefore, we will study what would be the impact of using a stationary model to the detriment of a non-stationary one to predict the return levels.

2.2.1. Stationarity Test

The ***Mann-Kendall test*** was applied to our daily precipitation data [10]. This test is used to examine the existence of a linear trend (upward or downward) in a time series. It compares the null hypothesis H_0 tested with "**there is no trend**" to the alternative hypothesis H_1 "presence of a trend". If the p-value $p < \alpha$ chosen significance threshold, the H_0 hypothesis is rejected and it is concluded that there is a significant trend, at the chosen threshold ($100 \times (1 - \alpha)\% = 95\%$ confidence).

2.2.2. Extreme Value Theory (EVT)

The approach followed in this paper is based on the extreme value theory. According to the ***IPCC's report*** in 2012, most studies rely on climate extreme indices to study moderate extremes [11]. However, in rarer events, it is recommended to use the extreme value theory [12] in order to describe the behavior of such events. The purpose of this theory is to study the asymptotic distribution of the maximum of a sequence of random variables. It states that the maxima of independent and identically distributed data can be modeled by the generalized extreme value distribution [13]. This model merges the three distributions (**Gumbel, fréchet, Weibull**) into the following single parameterization.

$$H_{\mu,\sigma,\xi} = \begin{cases} \exp\left\{-\left(1+\xi\dfrac{x-\mu}{\sigma}\right)^{-\xi}\right\}; \xi \neq 0, 1+\xi\dfrac{x-\mu}{\sigma} > 0 \\ \exp\left\{-\exp\left(-\left(\dfrac{x-\mu}{\sigma}\right)\right)\right\}; \xi = 0 \wedge x \in R \end{cases} \quad (1)$$

where ξ, μ and σ are the shape, location and scale parameters, respectively. The shape (ξ) describes the behavior of the tail, the location (μ) specifies where the distribution is centered, and the scale (σ) its spread or diffusion. If $\xi > 0$ one has a Fréchet distribution, a light-tailed (Gumbel) distribution if $\xi = 0$, and a finite-tailed (Weibull) distribution if $\xi < 0$.

Different methods are used to estimate these parameters, the two most commonly used are: maximum likelihood and the L-moments method. In this work, the *maximum likelihood* method is preferred because it allows us to incorporate covariates in order to detect trends in the extreme rainfalls. In the non-stationary framework, these parameters vary as a function of GEV time ($\mu(t)$, $\sigma(t)$, $\xi(t)$) to account for variations due to climate change.

The location and scale parameters are assumed to be depending on the time t. However, the shape parameter (ξ) is difficult to estimate accurately in practice, it will remain constant in this work. Four (04) GEV models are used to fit the annual maximum precipitation for each station.

The basic Stationary GEV (SGEV) model (called **Model 1**) is fitted with the location (μ), the scale (σ) and the shape (ξ) that are constant over time in contrast to the nonstationary case (NSGEV model) where location μ and scale σ depend on the time t for the three (03) different models (See: **Table 2**). The so-called **Model 2** corresponds to the case of location trend (we have an increasing trend if $\mu_1 > 0$ and decreasing trend if $\mu_1 < 0$). The so-called **Model 3** gives a scale trend (upward trend if $\sigma_1 > 0$, downward trend if $\sigma_1 < 0$). **Model 4** represents a trend in both magnitude and dispersion of extreme values.

Table 2. Representation of the 04 different non-stationary GEV models.

Models	Location (μ)	Scale (σ)	Shape (ξ)
Model 1	constant	constant	constant
Model 2	$\mu(t) = \mu_0 + \mu_1 t$	constant	constant
Model 3	constant	$\sigma(t) = \sigma_0 + \sigma_1 t$	constant
Model 4	$\mu(t) = \mu_0 + \mu_1 t$	$\sigma(t) = \sigma_0 + \sigma_1 t$	constant

2.2.3. Akaike's Information Criterion (AIC)

The AIC criterion [14] is applied to the estimated models by a maximum likelihood method. It is defined by:

$$\text{AIC} = 2K - 2\log(L) \tag{2}$$

where K is the number of parameters in the model and L is the likelihood function. For each station showing a trend, three models (**model 2**, **model 3** and **model 4**) will be fitted. The choice of the best model is given by the lowest AIC among these three (03) non-stationary GEV models estimated for each station. This goodness of fit model will be taken to study the trends of extremes. The use of the AIC criteria is justified by the fact that when the best model has a linear trend in location and scale parameters, the AIC outperforms all other selection criteria and also it is suitable for small sample sizes [15].

2.2.4. Return Level (RL)

The T-year return level for a given random variable is its quantile that exceeds on average once every T years. An event has a return period of N years if this event is statistically expected every N years. The relationship between the probability of occurrence of an event corresponding to the quantile of level p and its return period $T = h \times N$ (h = 365) in the case of annual maximum), is defined by:

$$p - 1/T \tag{3}$$

The estimation of the return level is obtained by inverting the distribution function of the GEV distribution $H_{\mu,\sigma,\xi}$ and substitute the parameters $\mu, \sigma \wedge \xi$ with their maximums likelihood estimators. The estimator of the return level (RL) can be directly constructed by this method:

$$RL_T = \mu - \sigma/\xi \left[1 - \left\{-\log(1 - 1/T)\right\}^{-\xi}\right] \tag{4}$$

In the non-stationary setting the parameters μ and σ can depend linearly on time t.

$$RL_T = \mu(t) - \sigma(t)/\xi \left[1 - \left\{-\log(1 - 1/t)\right\}^{-\xi}\right] \tag{5}$$

2.2.5. Likelihood Ratio Test (Deviance Test)

The likelihood ratio test will be used to see to which distribution (fréchet, Gumbel, Weibull) our maxima belong in order to properly estimate the parameters of the model chosen for each station. The statistic of this test is defined by:

$$D = -2\log\left(L_{H_0}/L_{H_1}\right) \tag{6}$$

where L_{H_0} and L_{H_1} are respectively the likelihood functions of the Gumbel distribution and the GEV distribution calculated for the parameter values estimated with the maximum likelihood method. This ratio follows a chi-square distribution with 1 degree of freedom [12] used to accept H_0 (maximum rainfalls are from a Gumbel distribution) or reject H_1 (maximum rainfalls are from a GEV distribution with $\xi \neq 0$).

We reject the H_0 hypothesis when the calculated statistic is greater than the quantile of ***Chi-squared with one degree of freedom***: if $\xi < 0$, we can conclude that we have a Weibull distribution and if $\xi > 0$, **we** have the Fréchet distribution. When the statistic is less than the quantile of ***Chi-squared with one degree of freedom***, the hypothesis H_0 is accepted: the observations are then distributed according to a Gumbel distribution. In our study, the p-values are calculated (95% confidence) with the hypothesis H_0 the observations come from a Gumbel distribution.

2.2.6. Trend and Return Level Analysis

First, for trend analysis, it will be based on the sign of μ_1 or σ_1, if it is positive so the trend is increasing and decreasing, if it is negative and to check the significance of the trends using the likelihood ratio test. For example, if the maxima of rainfalls for a given station follows a non-stationary Gumbel model, to know the significance of its trend, we test from a stationary Gumbel model.

Then, to have a more general vision of the evolution of the extreme rainfalls and to make a comparison of all the stations under study, we will calculate the relative value of the evolution of the parameters $\mu(t)$ and $\sigma(t)$ as follows:

$$V = \mu(2005) - \mu(1951)/\mu(1951) \tag{7}$$

And

$$V_1 = \sigma(2005) - \sigma(1951)/\sigma(1951) \tag{8}$$

A relative change of −40% implies that at the end of the period, the parameter ($\mu(t)$ or $\sigma(t)$) was 40% lower than at the beginning of the period. This very interesting approach was used by [5] to characterize long-term changes in annual maximum snow depth and snowfall.

Finally, since the return levels are also time dependent, the same approach will be used to analyze the N = 20-year and N = 30-year return levels. A key issue is the importance of using time-dependent return levels, so the N = 20-year and N = 30-year return levels estimated by Stationary GEV and Nonstationary GEV will be compared.

3. Results

3.1. Trend Detection

Figure 2 shows the spatial distribution of the results of Kendall's test performed on the daily rainfall data for each station. This statistical test determines whether the trend is significant or not.

Indeed, out of the **27** stations under study, 24 show a ***significant trend***, **23** of which show a significant negative trend and one (01) station (**Nioro**) which shows a significant positive trend. On the other hand, the **Bakel**, **Kédougou** and **Kaffrine** stations do not show a trend.

The results of these analyses will help on model selection of the model to be used for fitting the annual maxima. An Stationary GEV (SGEV) model for

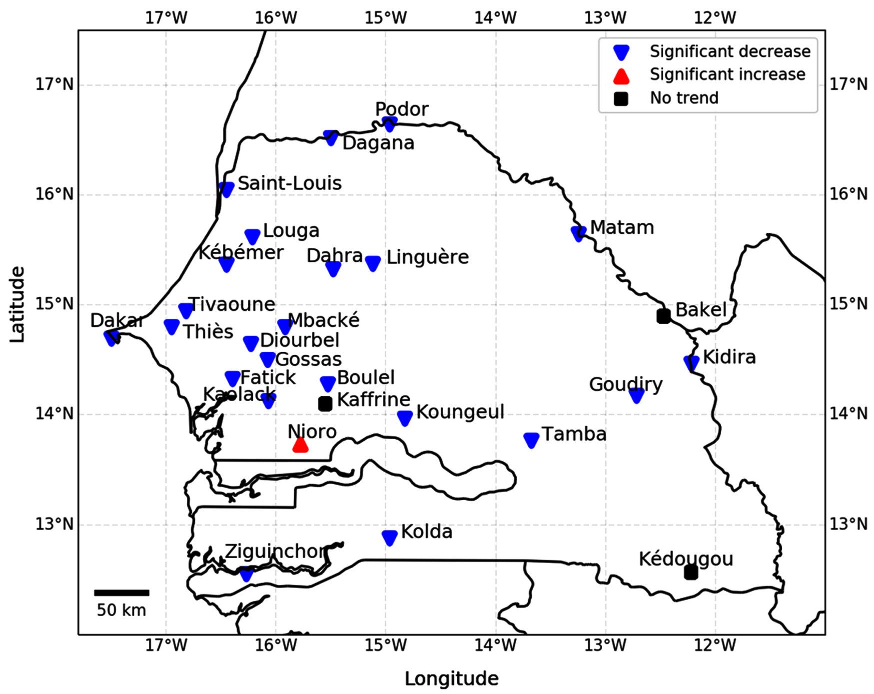

Figure 2. Significance of trends (using the Mann Kendall test with 95% confidence) on daily data.

stations with no trend and an Nonstationary GEV (NSGEV) model for stations where a trend has been identified.

3.2. Selected Model with AIC Criterions

Figure 3 shows the model chosen for each station with the AIC criterion for parameter estimation. The analysis shows us that the annual maxima can be modeled by either **Model 2** or **Model 3**, we can also notice that no station is modeled by **Model 4**. This shows that statistically testing the time dependence with a single parametric model will provide much more robust results than with two parameters in our study area. The NSGEV model selected for each station will therefore be further investigated throughout this paper.

3.3. Likelihood Ratio Test

The GEV model includes the following three distributions: **Gumbel**, **Fréchet**, and **Weibull**. The likelihood ratio test is used to choose which of these distributions is adapted to estimate the parameters (μ, σ, and ξ) for the chosen model for each station. The *p*-values calculated from this test (95% confidence level) for these **27** stations with the assumption H_0, the observations are from a Gumbel distribution showed that only two stations (Table 3) will be modeled by a **Fréchet** distribution ($\xi > 0$).

3.4. Analysis of the Evolution of Rainfall Extremes

The analysis of trends in location or scale parameters shows a diverse picture.

Table 3. Choice of a distribution for parameter estimation (μ, σ, and ξ).

Station	*p*-value	choice of distriution
Dakar	0.89	Gumbel
Thiès	0.94	Gumbel
Tivaouane	0.15	Gumbel
Diourbel	0.75	Gumbel
Fatick	0.97	Gumbel
Gossas	0.19	Gumbel
Mbacké	0.62	Gumbel
Kaffrine	0.7	Gumbel
Kaolack	0.44	Gumbel
Nioro	0.08	Gumbel
Boulel	0.86	Gumbel
Louga	0.89	Gumbel
Linguére	0.77	Gumbel
Kébémer	0.43	Gumbel
Dahra	0.72	Gumbel
Matam	0.89	Gumbel
Podor	0.91	Gumbel
Saint-Louis	0.15	Gumbel
Dagana	0.5	Gumbel
Goudiry	0.71	Gumbel
Kidira	0.005*	Frechet
Kolda	0.00041*	Frechet
Koungheul	0.16	Gumbel
Tamba	0.39	Gumbel
Ziguinchor	0.08	Gumbel
Kédougou	0.87	Gumbel
Bakel	0.89	Gumbel

Indeed, of the 24 stations studied with the non-stationary GEV model, 5 stations show an increasing trend (Table 4). On the other hand, for the other stations, we notice a decreasing trend.

Figure 4 shows an example of the evolution of the trends in extremes for the stations of **Louga** (increase in the scale parameter) and **Thies** (decrease in the location parameter). On the other hand, the stations of **Bakel**, **Kaffrine** and **Kédougou** show no trend in either the location or scale parameter.

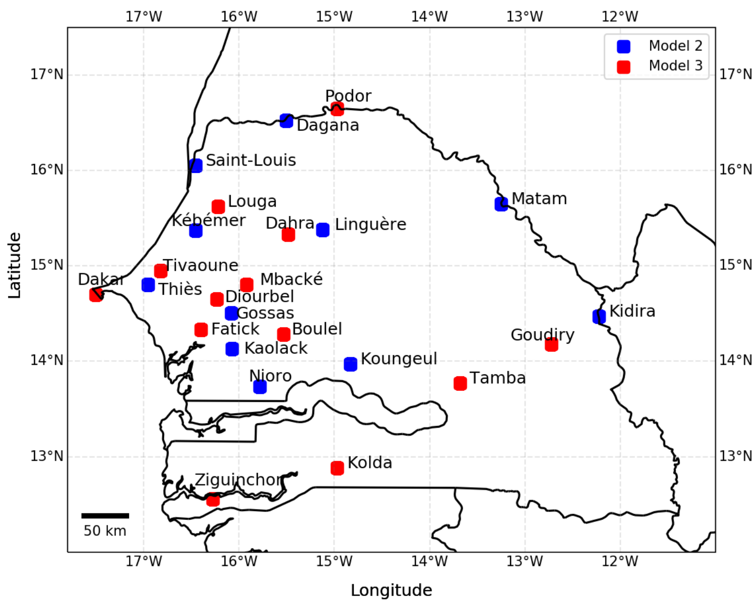

Figure 3. Model selection for each station showing a trend.

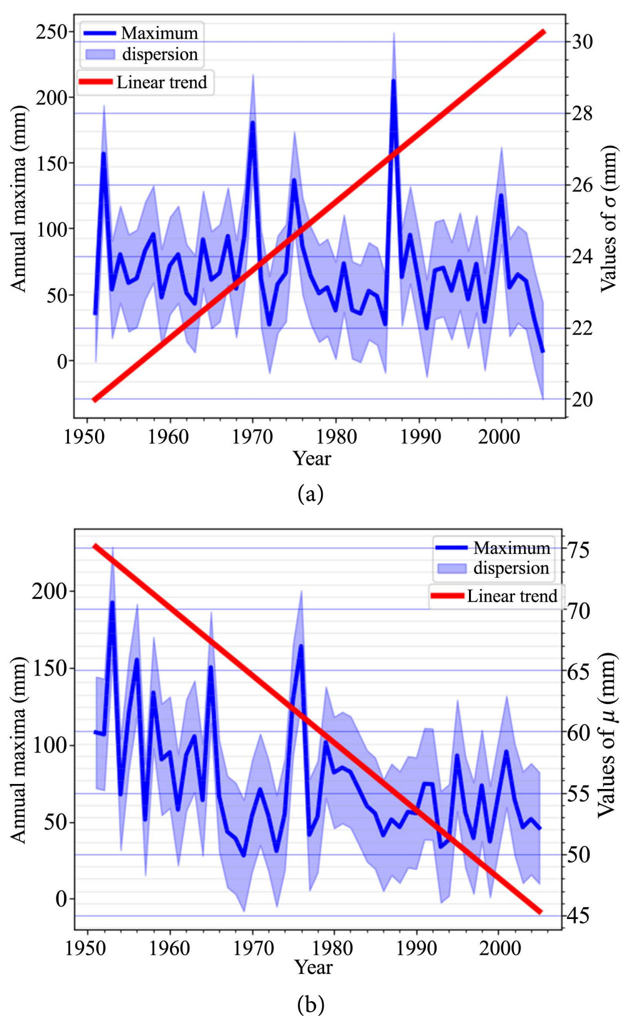

Figure 4. Evolution of trends I the stations: Louga (a); Thiès (b).

Table 4. Estimation of the parameters $\mu(t)$, $\sigma(t)$ and ξ for some stations, 0* represents the value of the shape (ξ) parameter of the gumbel distribution significantly null.

Stations	Location (μ)	Scale (σ)	Shape (ξ)	μ_1	σ_1	Equation
Dakar	53.32	26.13	0*	-	−0.019	$\sigma(t) = 26.13 - 0.019t$
Thiès	75.6	24.18	0*	−0.55	-	$\mu(t) = 75.6 - 0.55t$
Tivaoune	54.76	19.8	0*	-	+0.19	$\sigma(t) = 19.8 + 0.19t$
Kaolack	67.39	22.27	0*	−0.14	-	$\mu(t) = 67.39 - 0.14t$
Nioro	62	23	0*	+0.19	-	$\mu(t) = 62 + 0.19t$
Kaffrine	56.98	16.95	0*	-	-	-
Bakel	55.18	18.64	0*	-	-	-
Ziguinchor	84.16	31.05	0*	-	−0.094	$\sigma(t) = 31.05 - 0.094t$
Kédougou	68.91	21.03	0*	-	-	-
Louga	60.3	15.53	0*	+0.05	-	$\mu(t) = 15.53 + 0.05t$
Linguère	44.92	19.78	0*	+0.055	-	$\mu(t) = 44.92 + 0.055t$
Kébémer	44.75	21.46	0*	+0.14	-	$\mu(t) = 44.75 + 0.14t$
Kolda	83.989	34.569	0.35	-	+0.052	$\sigma(t) = 34.569 + 0.052t$
Kidira	77.075	23.65	0.297	−0.358	-	$\mu(t) = 77.075 - 0.358t$

To quantify this increase or decrease in the trends of the location and scale parameters, their relative values were calculated. Indeed, for the **11** stations showing a trend in location (Figure 5(a)), the results reveal that 8 of the **11** stations have negative relative values (decreasing trend). This decrease is more important at the station of **Thies** with a decrease of about **−39%** of the magnitude of the extremes which is lower than that of the beginning of the period (1951). On the other hand, the other stations show an increasing trend (positive relative value). This increase is more marked at the station of **Kébémer** with an increase of +16% higher than that of the beginning of the year (1951). However, the calculation of *p*-value (not shown) shows that these trends are significant only for 2 stations (**Thies** and **Kidira**). For a trend in the scale parameter, two (**02**) of the **13** stations show an increasing trend (**Tivaouane** and **Louga**) in the frequency of extreme rainfalls, more marked at the **Tivaouane** station with **+51%** higher than at the beginning of the year 1951 (Figure 5(b)). However, for the other stations, the results show a downward trend. These trends are not significant for all **13** stations.

The return level decreases from ***286 mm*** to ***236 mm***, a relative change of about **−17%.** The **20**-year and **30**-year return levels (not shown) decrease linearly with time with a narrower confidence band for this station. This decrease applies well to all stations except five (**Kébémer, Linguère, Louga, Nioro** and **Tivaouane**).

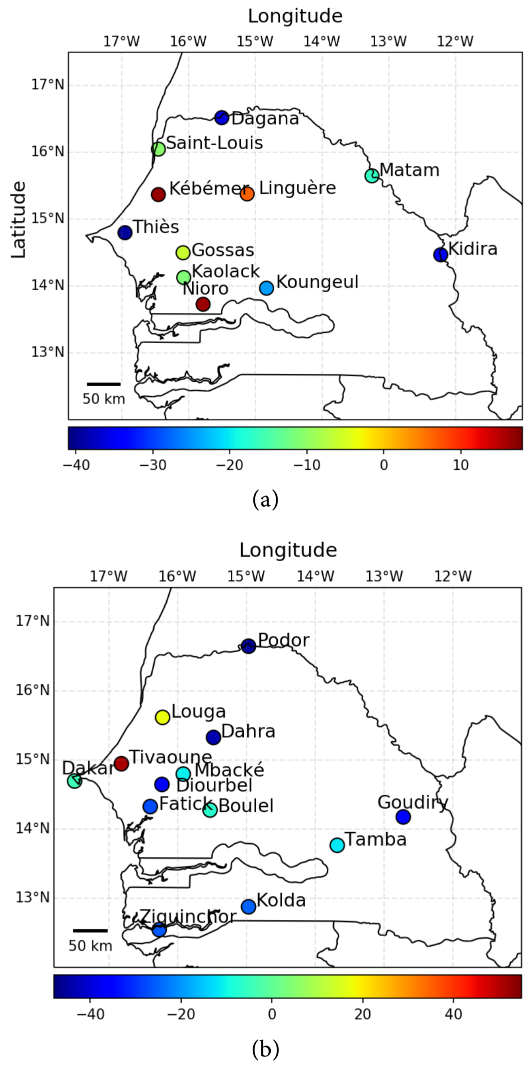

Figure 5. Relative values calculated from parameter trends: location parameter (a); scale parameter (b).

The relative values calculated for the **30**-year return level for the **24** stations show that the magnitude of this decrease or increase differs from station to station (**Figure 6**). For the stations of **Podor** and **Diourbel** this decrease varies respectively by about **−30%** and **−21%** between 1951 and 2005, contrary to the station of **Tivaouane** where we note an increase of more than **27%** compared to the beginning of the year (1951).

Figure 7 shows an example of a linear change in the **30**-year return level at the **Kolda** station.

3.5. Choice of a Non-Stationary Model over a Stationary Model, Impact on Return Levels

In this section, we will compare the relative difference between the return levels calculated from two methods: the return levels obtained with NSGEV (trend in extreme rainfalls) versus SGEV (no trend in extreme rainfalls).

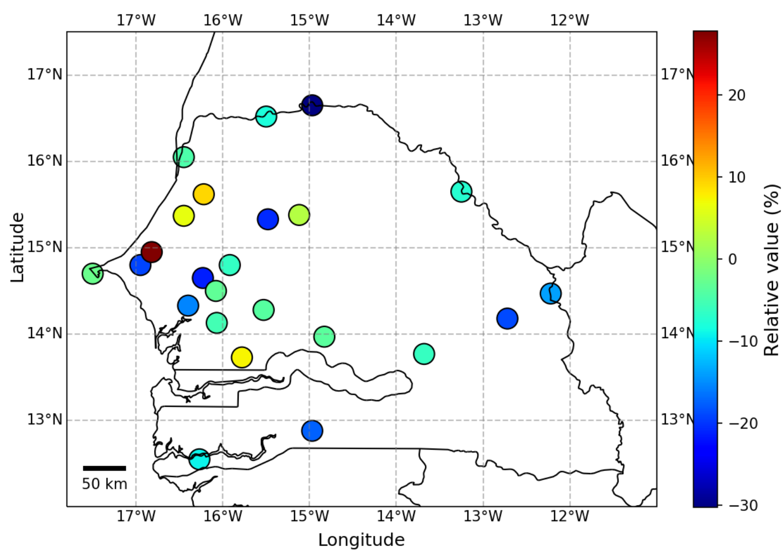

Figure 6. Relative values calculated from the 30-year return level trends for the 24 stations.

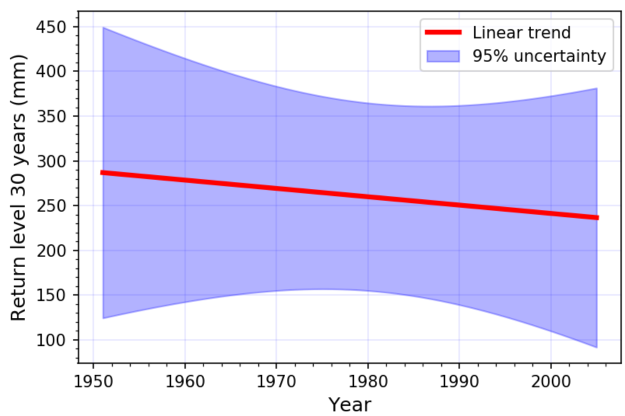

Figure 7. Declining trend of the 30-year return level at the Kolda station with the 95% uncertainty band.

The interest of this comparison is to know what would be the consequence of using NSGEV instead of SGEV for the calculation of return levels which are very important in many areas. For precision we focus on the year 2005 which corresponds to the return to wetter conditions and on the **30**-year return level for NSGEV. The objective is therefore to see if the **30**-year return levels calculated in 2005 for SGEV and NSGEV differ significantly.

The results show a positive difference between the NSGEV and SGEV return levels (Figure 8) for **05** stations (**Kébémer, Linguère, Louga, Nioro, Tivaouane**), more important at the **Tivaouane** station which differs by more than of **11%** (red line). On the other hand, the return levels differ by about less than **13%** for the other stations except **Podor** (**−19%**). These observations are similar to the comparison of the 20-year return level (not shown). Therefore, adopting one or the other method (SGEV or NSGEV) has little importance for the calculation of the return levels on almost all stations.

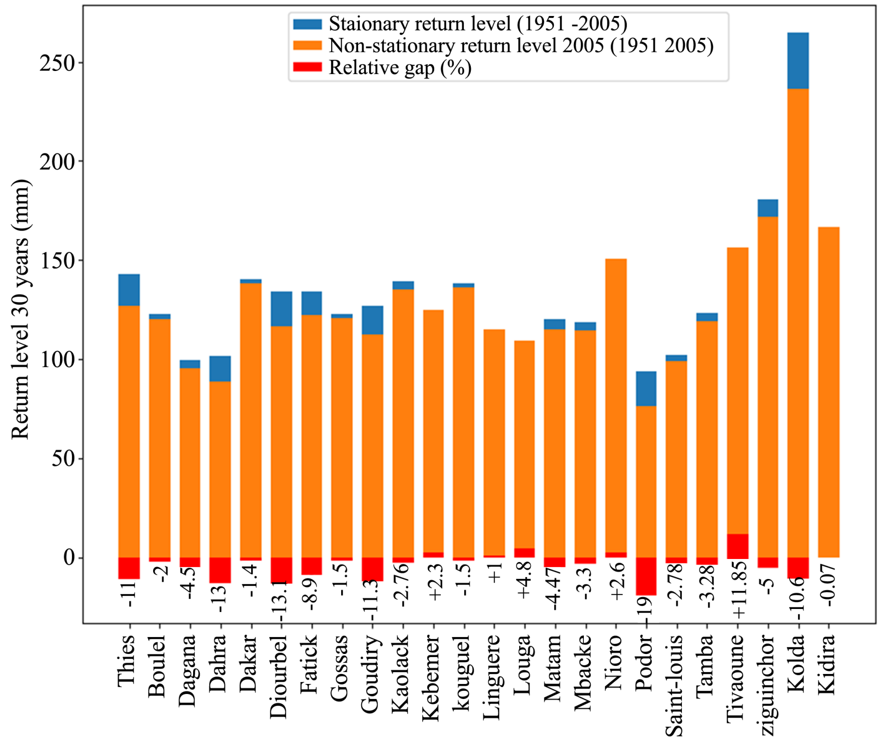

Figure 8. Relative difference in 30-year return level from 1951 to 2005.

4. Discussions

Through the analysis of daily rainfall series over the period 1951-2005 at 27 stations throughout Senegal, the objective of this work was mainly to characterize trends in order to determine the evolution of rainfall extremes. The ***Kendall*** test was performed on our series to verify stationarity. The results showed that for the 27 stations studied, only 3 stations (**Bakel, Kédougou, Kaffrine**) are stationary. On the basis of these results **04** GEV models are used, first to detect trends in the location and scale parameters, then the AIC criterion for the choice of the adequate model for each station and finally, studied the evolution of the extreme rainfalls. The results showed that **11** stations can be modeled by **Model 2** (trend in location parameter) and **13** by **Model 3** (trend in scale parameter). The results of the linear trend and relative value analysis showed a decrease in extreme rainfall at almost all stations. These results are also in agreement with the work of [4], which highlights a downward trend of extreme rainfalls in the Sahelian zone, particularly in Senegal, where we have recorded the most significant decreases. Indeed, during the 1970's, West Africa was hit by a severe drought, which explains the long duration of these dry sequences, leading to a decrease in the intensity and frequency of these extremes at almost all of our stations. To our knowledge, this is the first time that a decreasing trend in the variance (scale parameter) of extreme precipitations has been found in our study area using the extreme value theory. In addition, other works have shown this decrease in extreme rainfalls in West Africa, this is the case of the study of [16] who performed a trend analysis with extreme rainfall indices. The differences obtained by comparing the **30**-year return levels of the NSGEV and SGEV models show that this difference is quite significant for only one **Podor** station (**19%**) out of **24** (estimated with the NSGEV model). From these results, it could be said that it is unnecessary to modify the calculation of the return levels (use of a stationary model). The Block Maxima approach, applied to annual precipitation maximums, can lead to a loss of information (of extreme values), which can make it difficult to identify the significance of trends. To overcome this problem, the frequency exceeding a threshold could be used in other studies. This method was used by [17] to study extreme rainfalls in southeastern South America. The results of this article constituting the proof that climate change could already have an impact on these precipitation extremes as other studies have pointed out by adopting this methodology (non-stationary GEV model); [5] to characterize the long-term changes in annual snow depth showed that half of the stations show significant decreasing trends, or the work of [4] who studied Nonstationarity in series of extreme rainfall, these results showed that for all the zones (West Africa) the most probable rupture is a negative rupture between 1966 and 1970. Furthermore, with the increase of extreme events in recent decades, we could expect an increase in the trends of the parameters of location, scale and return levels, so it would be important to deepen this work in order to study the future evolution of the intensity and frequency of these events in a context of climate change.

5. Conclusions

The characterization of the trends of rainfall extremes with different models of non-stationary extreme values reveals that the linear trends of extremes are decreasing on **19** stations against **05** increasing. However, these trends are only significant for two stations, **Thiès** and **Kidira**. The stations of **Bakel**, **Kédougou** and **Kaffrine** do not show any trend and are stationary, which shows that these three stations are not considerably affected by the droughts of the 1970s and 1980s. In fact, this decrease in extreme rainfalls is mainly caused by the two droughts that hit the country. The NSGEV model proves to be useful for calculations of **20**-year and **30**-year return levels because the most devastating phenomena occur for very large events. Our results show that the trends of the **20**-year and **30**-year return levels have decreased on the major part of the stations, moreover the comparison.

The 30-year return levels estimated by the NSGEV and SGEV seem to differ little significantly except for one Podor station (−19%), so using one or the other method has little influence on the calculation of return levels. However, with climate change disrupting the climate regime with dramatic consequences on socio-economic development and the environment, the NSGEV model could be the most adequate or appropriate for the estimation of return levels. The great unknown that remains now is the future evolution of the intensity and frequency of these events, in a context of climate change for those extensions of this work could be considered. First, make our models much more complex by incorporating non-linear covariates (quadratic model) with much more advanced non-stationary return levels [18]. Second, use simulated data from regional climate models with spatial dependence between extremes.

Conflicts of Interest

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

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