Frequency analysis of the evolution of hydropluviometric maxima in the Volta watershed at the Oti-Pendjari outlets

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Abstract: In recent years, hydroclimatic disasters have become increasingly recurrent and weaken environmental and human systems. The objective of this study is to conduct a frequency analysis of rainfall and hydrometric maxima in the Volta watershed at the Oti and Pendjari outlets. The annual maximum values in 24 hours of rainfall and extracted flows have undergone a series of work including a global statistical assessment; statistical hypothesis tests followed by a graphical and numerical evaluation (AIC, BIC) and quantile estimates for the return periods of 2 years, 5 years, 10 years, 15 years, 20 years and 30 years. The statistical tests include independence and stationarity tests; the extreme adjustment laws used are those of GEV (three parameters), Gumbel (two parameters) and Weibull (two parameters). The results show that out of the 21 stations, the maximum sampling size of the maximum annual daily rainfall is 40 years (most stations) and minimum 28 years (only the Porga station). The maximum value of the extremes recorded so far is 226 mm and a minimum of 19.4 mm at the Bakoissi station. The average of the maximum annual rainfall in 24 hours of all the stations in the basin is 74.35 mm, thus indicating a well-watered area at the advent of extreme rainfall. It also shows high asymmetry and flattening coefficients across the data from the Natitingou station and low at the Tanguiéta station, demonstrating a variability of extremes in the Oti-Pendjari watershed. It is briefly apparent that 18 of the 21 stations have data that follow the Gumbel law, while stations such as Fada Ngourma and Natitingou follow that of GEV and Tanguieta that of Weibull. The estimation of the quantiles at the different return periods is 173 mm (maximum) for a return period of 50 years at Barkoissi and 61.5 mm (minimum) at Porga.

Keywords: Oti-Pendjari watershed, frequency analysis, annual maximum in 24h

Introduction

West Africa is facing serious problems of increasingly recurring floods in a context of persistent climate variability/change (Mul et al., 2015). In recent years, hydrometeorological disasters have become increasingly recurrent and are weakening environmental and human systems (IPCC, 2007) in both urban and rural areas.

This increase in extreme hydroclimatic phenomena does not spare the Volta watershed, where they were the subject of the project entitled "Integrating flood and drought management and early warning for adaptation to climate change in the Volta Basin", funded by WMO in 2022. However, the Oti-Pendjari watershed covers 9.82% of the Volta basin area. This situation is reflected in the occurrence of extreme hydro-rain events in recent years (Koungbanane et al., 2020) which are becoming increasingly increasing and aggravating and are seen as potential consequences of climate change in the region (Komi et al., 2016).

Flood events are observed both at the scale of the countries' internal watersheds and transboundary watersheds, as is the case in the Oti-Pendjari watershed shared between Togolese territory (45%) and Beninese territory (12.1%). The objective of this study is to carry out a frequency analysis of the rainfall and hydrometric maxima in the Volta watershed at the Oti and Pendjari outlets.

Presentation of study area

The Oti-Pendjari watershed is located in the large Volta River basin and drains part of the transboundary countries (Burkina Faso, Benin, Togo and Ghana). It entirely covers the savannah and Kara regions, 1/3 of the central region, barely 1/5 of the plateau region and a small portion of the maritime region over an area of 26,700 km2, or approximately 45.0% of the surface area of the territory of Togo; (Gordonet al., 2013; Koungbanane et al., 2020) and 12.1% of the surface area of the Beninese territory. Its surface area is 75,385.96 km² and extends from north to south over 07.54° and 12.20° north latitude and -0°3' and 0°50' east longitude (Figure 1). The Oti-Pendjari watershed is an integral part of the tropical climate domain where the movement of the Intertropical Front (ITF) explains the alternation of the rainy season and the dry season (Addra, 1978; Koungbanane et al., 2020). Thus, it is covered with the Sudanese tropical climate characterized by a dry season (November to March or even April) and a rainy season (May to October) which varies between 700 and 1300 mm annually. On the other hand, August is the wettest month with more than 150 mm. The temperature varies from 31°C to 43.5°C or 37.5°C over the period 1981-2020.

The Oti-Pendjari watershed is part of the vast Oti-Pendjari plain. This plain is a very large centered gutter that crosses it in a North-East-South-West direction and receives in the East the rivers coming from the pre-Atakorian inselbergs and in the West those coming from the Dapaong and Bombouaka plateaus (Baritse, 1998). This plain, which floods during the rainy season, is formed of a succession of low plateaus slightly inclined towards the thalwegs which they dominate by about 20 to 30 m (Poss, 1996).

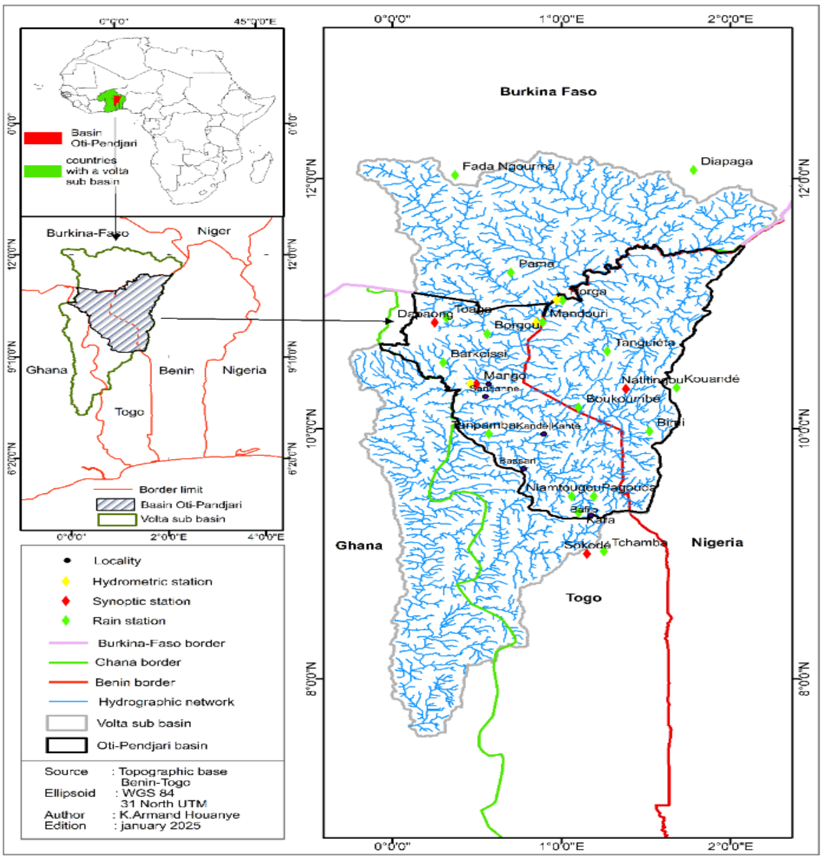


Figure 1: Location of study area

Data and methods

Rainfall data from 1981 to 2020 from twenty-one climatological stations were used to create the rainfall field of the basin studied. It is also necessary to note the temperature data from the synoptic stations of the basin which were used to develop the potential evapotranspiration (PET) data. In addition, the hydrometric data from Porga in Benin, Mandouri and Mango in Togo covering the period 1981-2020 were used, as well as GIS data such as DTMs, shapefiles, etc.

The tools used for the visualization and statistical processing of hydroclimatological and GIS data are Excel and R language while QGIS for mapping and HYFAN-PLUS for the Application of Extreme Laws for frequency analysis. The method used for spatializing rainfall fields is that of Thiessen, which is a technique frequently used to estimate the spatial distribution of precipitation from the network of 21 rainfall stations distributed over the Oti-Pendjari watershed. It consisted of assigning weights to each station according to the area it represents on the total surface area of 75,385.96 km² studied (Figure 2). Thus, the basin was divided into polygons (Thiessen or Voronoi polygons), where each polygon surrounds a rainfall station. Each polygon represents the area for which the station in the center is considered representative of precipitation. For the spatialization of precipitation, it was necessary to locate the rainfall stations and construct the Thiessen polygons. Once the polygons have been constructed, it is necessary to calculate the area of each polygon in relation to the total area of the watershed. Thus, the weight assigned to each station is the ratio between the area of its polygon and the total area. The precipitation recorded by each station is then multiplied by this weight.

$$P_{bassin} = \sum_{i=1}^{n} P_i . W_i$$

Where:

- P_{bassin} the average precipitation of the watershed.
- P_i precipitation measured at station i.
- W_i weight of station i, defined by the area of its polygon relative to the total area of the basin.

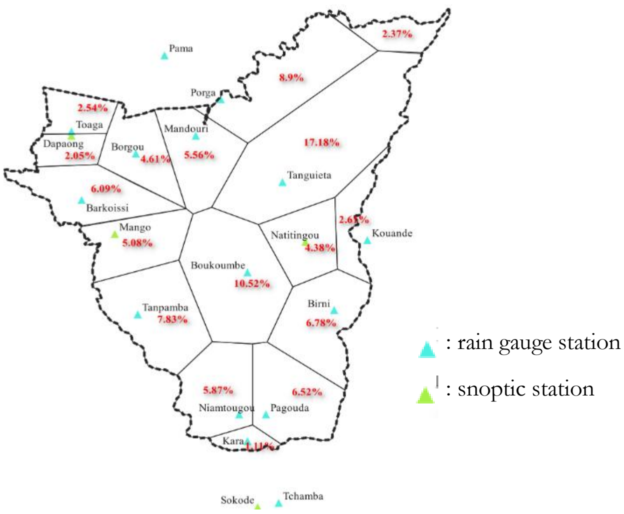


Figure 2: Weights associated with station rainfall using the Thiessen method

After constructing the polygons and calculating the associated weights, as shown in Figure 2, the Thiessen method was used to estimate the average rainfall over the entire watershed for each observation period. Thus, for each year from 1981 to 2020, the rainfall measured at each station is weighted according to the polygons and summed to give an overall estimate, which is the rainfall field.

The study of the basin's hydro-rainfall variability from 1981 to 2020 is based on the average rainfall and hydrological share and the determination of the standardized rainfall index (SPI) and the standardized discharge index (SDI). The rainfall/discharge relationship is added to show the influence of rainfall on surface runoff in the basin.

Frequency analysis on annual daily maxima (precipitation, flow rates) following the extreme laws: GEV (Generalized Extreme Value), Gumbel, Weibull and return periods was carried out.

GEV	Gumbel	Weibull
$f(x)=\frac{1}{\alpha}\left[1-\frac{k}{\alpha}(x-u)\right]^{\frac{1}{k}-1}\exp\left\{-\left[1-\frac{k}{\alpha}(x-u)\right]^{1/k}\right\}$	$f(x)=\frac{1}{\alpha}exp\left[-\frac{x-u}{\alpha}-exp\left(-\frac{x-u}{\alpha}\right)\right]$	$f(x)=\frac{c}{\alpha}\left(\frac{x}{\alpha}\right)^{c-1}\exp\left[-\left(\frac{x}{\alpha}\right)^{c}\right]$

Frequency analysis is used, in particular, to estimate the magnitude of the temporal event Tx to which a return period T is associated (quantile of return period T or probability of exceedance p). The estimate T of the value of the quantile is obtained by fitting a probability law F (x; θ) to a sample of n observations where θ represents the vector of parameters associated with the probability distribution F. To estimate this probability of occurrence of the hydrometeorological event in the Oti-Pendjari watershed, we have a series of flow rates and rainfall series over a period of 1981-2020. It also made it possible to predict the probability of extreme events (maxima), such as very heavy rainfall or major floods, which occur rarely but have significant impacts, which also made it possible to estimate the return periods or exceedance frequencies for these events. Finally, it has enabled a better understanding of the variability of precipitation and flow rates, which is essential for integrated water resources management. La relation entre la probabilité au non dépassement et la période de retour est donnée par la formule The relationship between the probability of non-exceedance and the return period is given by the formula : $T=\frac{1}{1-q}$ and the return time T of an event is defined as the inverse of the frequency of occurrence of the event, i.e.:

$$T=\frac{1}{1-F(x)}$$

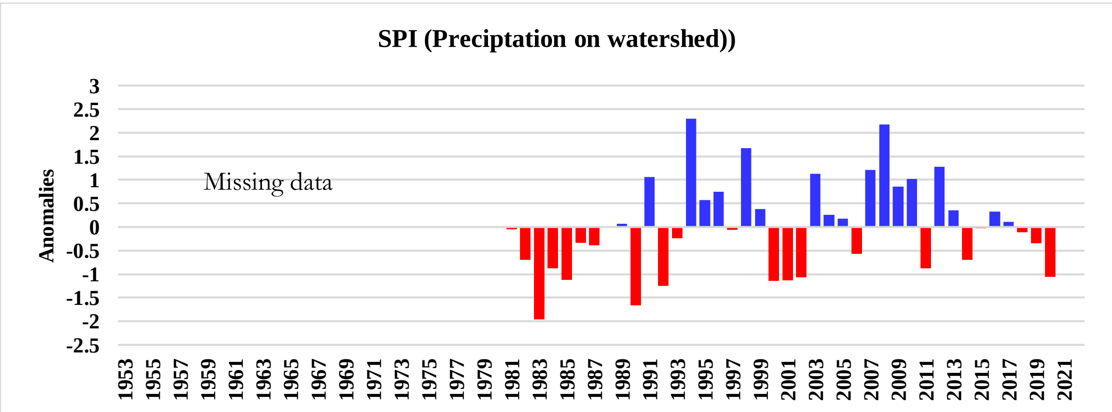
.

Results and discussion

Hydropluviometric variability in the Oti-Pendjari watershed

Figure 2 illustrates the hydropluviometric variability in the Oti-Pendjari watershed highlighting the standardized rainfall indices and flow rates at the Mandouri and Porga hydrometric stations, the period 1981-2020 is the one calibrated for our study. However, note too much missing data for the Mandouri station and some also for the Porga station, less striking than the previous one.

The analysis of Figure 3 shows an alternation of dry and wet seasons. The more pronounced dry seasons in the 1980s confirm the numerous studies carried out by researchers such as (Fontaine, 1986; Fontaine, 1990; Boko, 1988; Mahé, 1992; Mahé, 1995; Ouedraogo et al., 2001; Vissin, 2007; Amoussou, 2010).



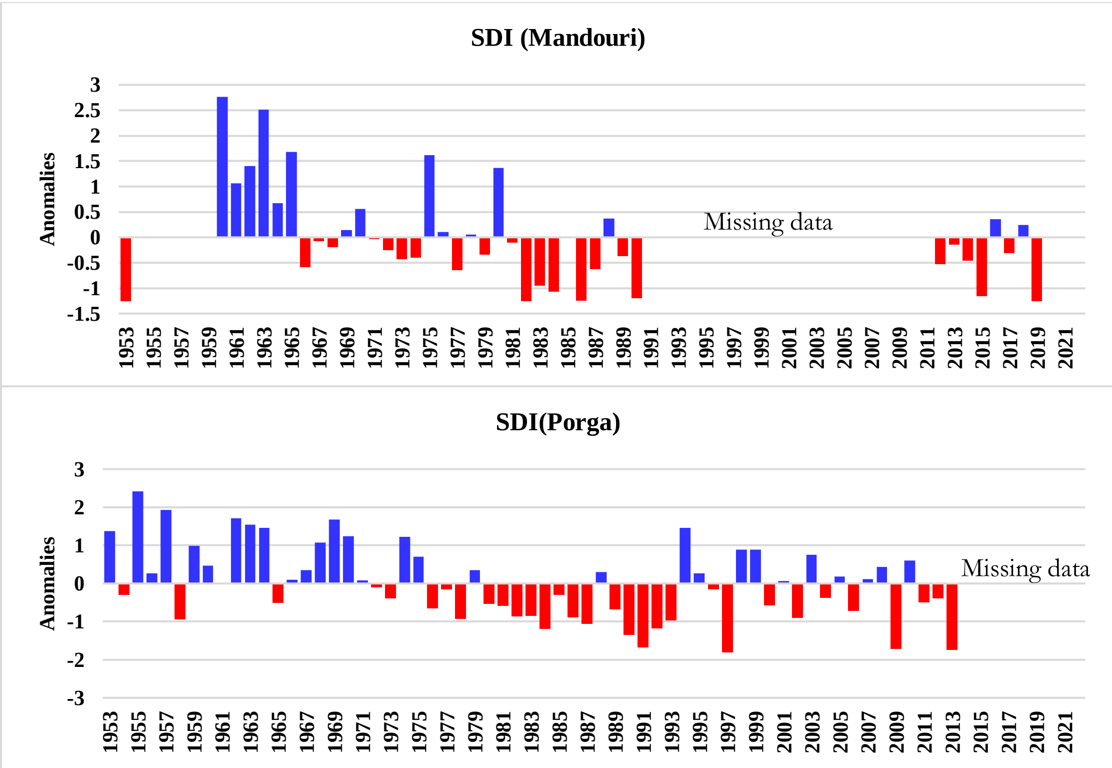


Figure 3: Hydropluviometric variability in the Oti-Pendjari watershed from 1981-2020.

Dry years follow wet years, whether in terms of rainfall or runoff. Thus, dry years of precipitation correspond to years with a deficit in flow. The wet rainfall years of both 1990 and 2000 correspond to excess flow, showing the close link between rainfall/flow, illustrated in Figure 4.

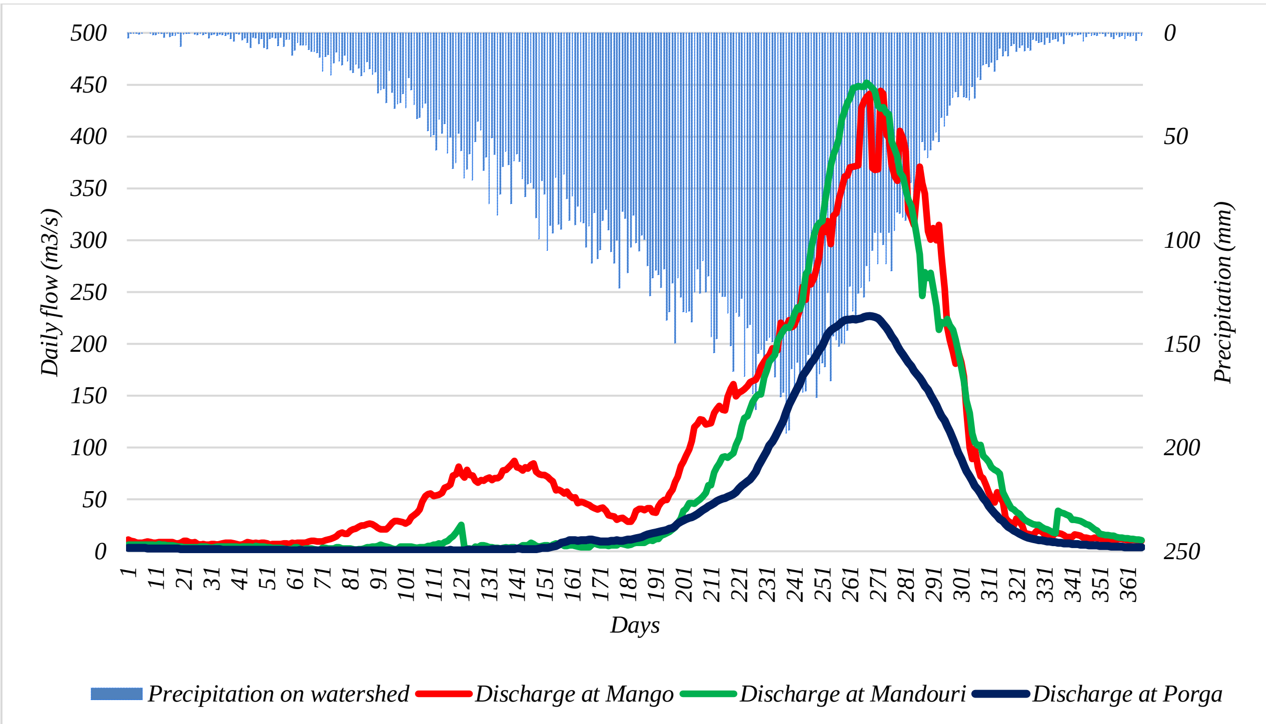


Figure 4: Relationship between watershed rainfall and surface runoff at three hydrometric stations (Porga, Mango and Mandouri) from 1981 to 2020.

Figure 4 shows that the maximum flow occurs after the optimum precipitation showing that the flows are made by the precipitated water blades. Similarly, the evolution of the hydrological behavior in the basin shows that the Porga station upstream of the other two, reaches its peak faster which is more spread out and less pronounced than the others. On the other hand, the Mandouri station which is halfway between Porga upstream and Mango downstream, reaches its peak slightly earlier with a value of 449.02 m3/s against 448.24 m3/s for Mango. This water gap between upstream and downstream confirms the fact that this Oti basin is part of the largest plain of the Oti-Pendjari basin. Which corroborates the results of (Koungbanane et al., 2020). It is a zone of water spreading generating this gain observed at the Mango outlet compared to Mandouri.

Variability of rainfall indicators associated with quantiles in the Oti-Pendjari watershed

The analysis of the annual 24-hour rainfall maxima made it possible to describe the average rainfall abatement whose cumulative rainfall can induce flooding in the watershed. The maximum flow rates confirm the effects of these precipitation abatement. Thus, Figure 5 illustrates the evolution of the quantiles of the annual daily rainfall maxima of the basin.

It emerges from the analysis of Figure 5 that the rainfall heights associated with the 95th and 99th percentiles which are respectively indicators of extremely rainy events, very heavy rain and heavy rain, which vary from one day to another and from one year to another over the period 1981-2020. The 99th percentiles (32.14 mm), which is very close to the maximum (33.28 mm) shows the importance of the 99th percentiles in flooding. This confirms the very wet periods in the basin where rainfall is higher than average (22.48 mm). Less wet years are more recorded in the 2010s.

Figure 6 presented the 95th and 99th percentiles of the average maximum daily flows of the basin from 1981-2020. From the analysis, it appears that the 95th and 99th percentiles of the flows which are respectively 753.92 m3/s and 936.55 m3/s are very close to the maximum annual flow in 24 hours (951.85 m3/s). These values are consistent with the rainfall quantile data. In comparison, it appears that the dry periods of rain (2010), where the maximum precipitated water blades are lower than the basin average, while these same periods record high maximum flows higher than the basin flow average (331.8 m3/s), showing that the flow does not only depend on precipitation, but also on the dynamics of land occupation.

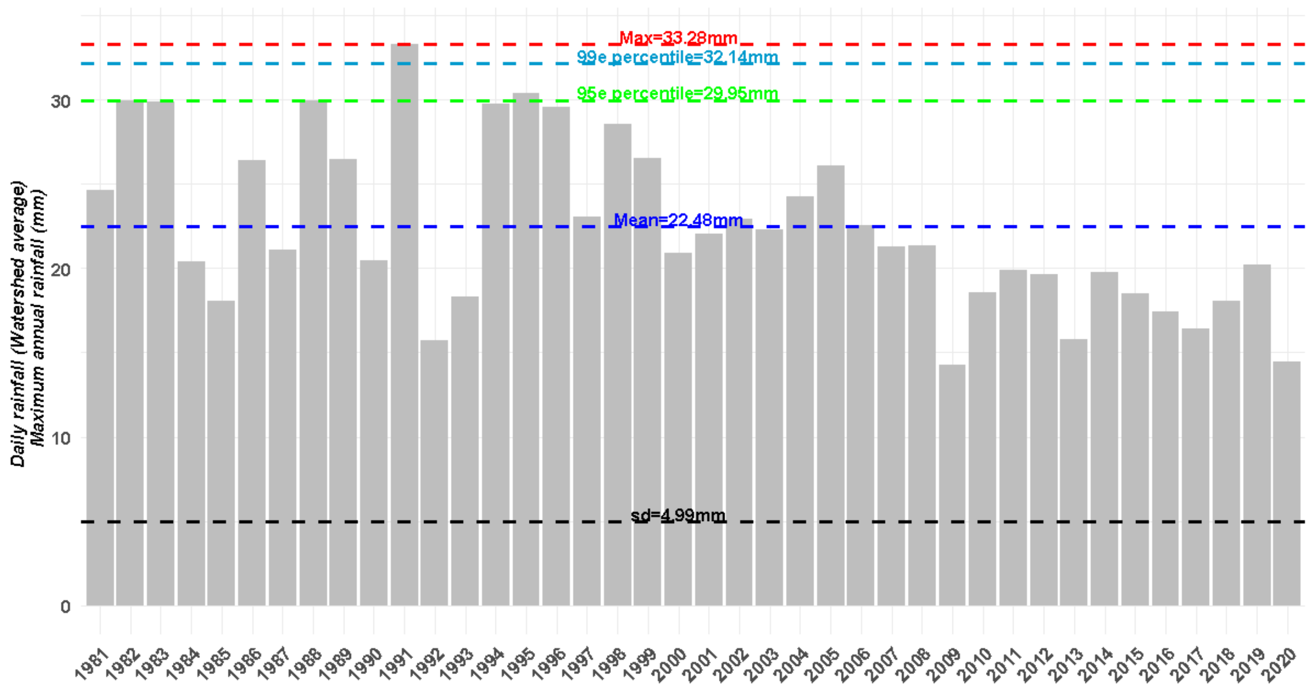


Figure 5: Rainfall indicators associated with the 95th and 99th percentiles in the Oti-Pendjari watershed from 1981-2020

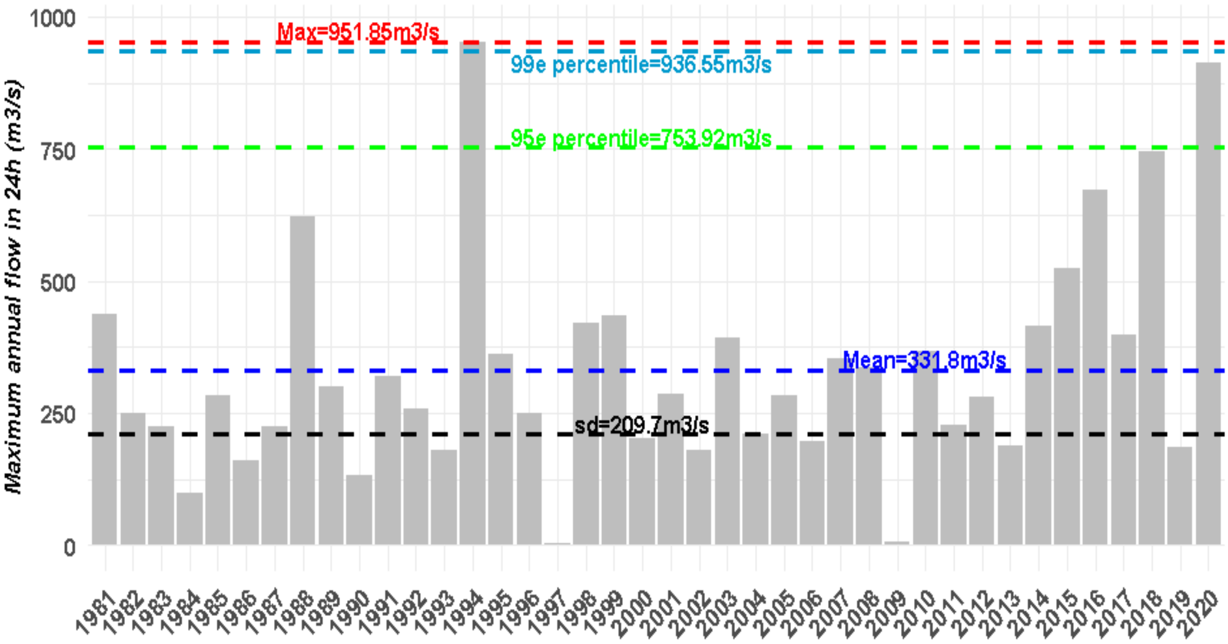


Figure 6: Average hydrometric indicators associated with the 95th and 99th percentiles in the Oti-Pendjari watershed from 1981-2020

Similarly, this increase in flow rates in an environment where rainfall is in a basin with a high evaporative demand could not be explained by a strong degradation of the vegetation cover as reported by Mahé et al., (2000) in the Bani basin and (Amoussou, 2010) in the Mono basin located between Togo and Benin.

Amoussou et al., (2015) and Totin et al., (2016), added that the last decades have been plagued by a slight recovery in rainfall and the recurrence of floods have caused a lot of damage to human, socioeconomic and environmental levels. From this point of view and in light of the results of this analysis, the 95th and 99th can be the subject of indicators for analyzing hydroclimatic events followed by flooding in the study area. In addition, to better appreciate the effects of precipitation on the hydrology of the Oti-Pendjari watershed at the outlets of the Porga, Mandouri and Mango hydrometric stations, a frequency analysis was carried out.

Frequency analysis of hydropluviometric maxima in the Oti-Pendjari basin

This frequency analysis of the annual maxima in 24 hours in the Oti-Pendjari watershed will make it possible to study the frequency and intensity of extreme hydropluviometric events such as floods and heavy rains. This allows flood prevention and planning of hydraulic infrastructures in the context of integrated flood risk management (IFRM).

Figure 7 illustrates the annual maxima of regionalized rainfall and flow rates of the three hydrometric stations (Porga, Mandouri and Mango) in 24 hours in the Oti-Pendjari watershed. The analysis shows an evolution of the rainfall maxima in 24 hours consistent with those of the flow maxima of the three stations, confirming the crucial role of precipitated water sheets in surface flows. However, the slight differences could be attributed to the dynamics of surface states and different uses. But, let us note that the Oti sub-basin is more watered than the Pendjari sub-basin as shown in Figure 8, which illustrates the spatio-temporal evolution of rainfall in the basin. This rainfall in the Oti sub-basin added to the flow upstream, explains the higher flows recorded at the Mango outlet, an area regularly flooded during high waters.

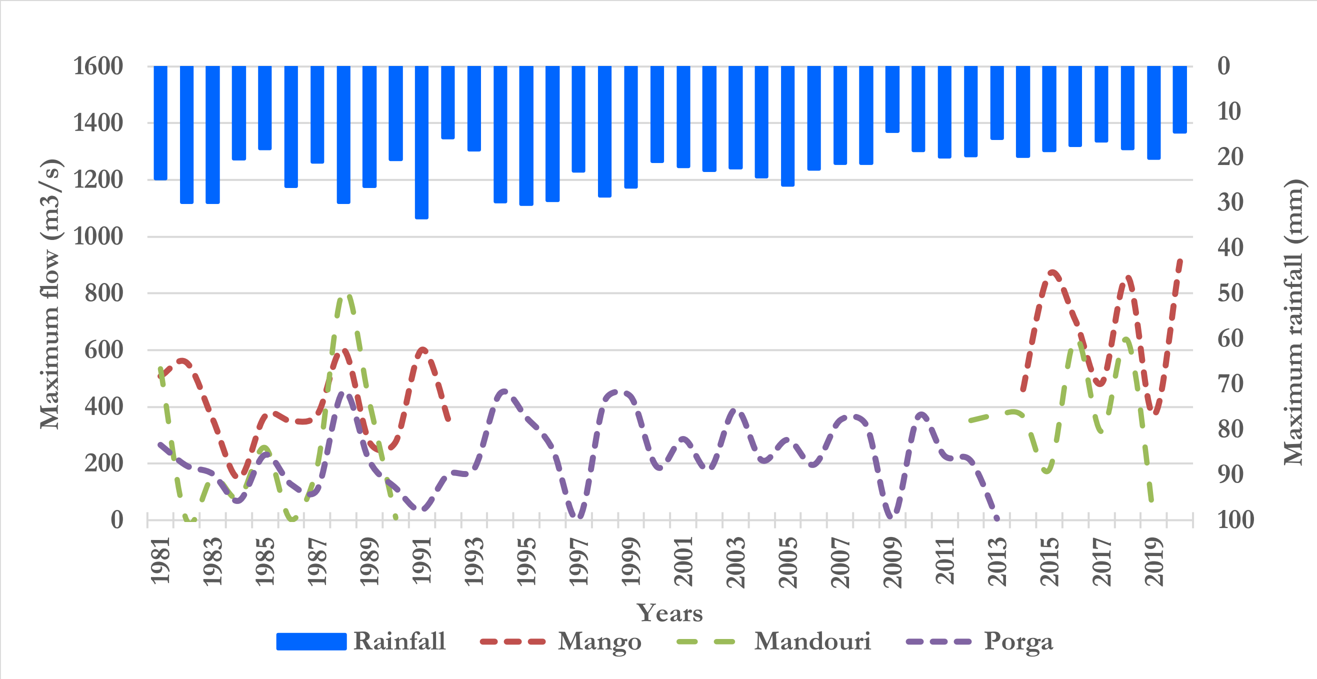


Figure 7: Trends in annual daily maximum rainfall and discharge in the Oti-Pendjari watershed from 1981-2020

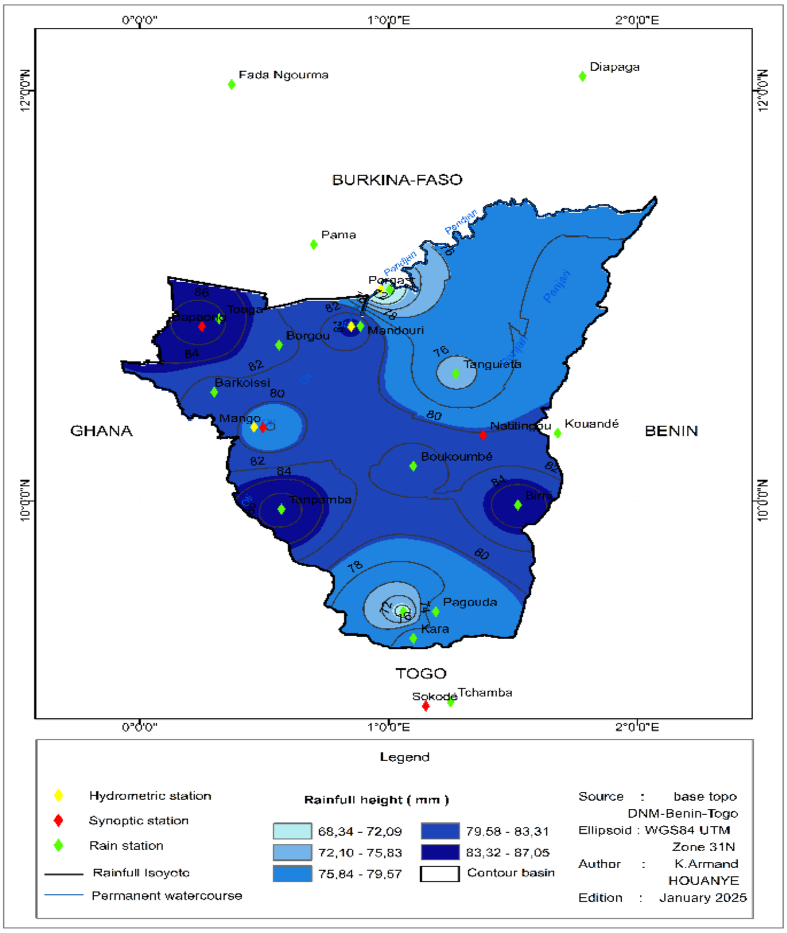


Figure 8: Spatialization of annual 24-hour rainfall maxima in the Oti-Pendjari watershed from 1981-2020

Hydropluviometric frequency analysis

Figure 9 illustrates the frequency of occurrence of precipitated water blades from the daily maximums observed in the Oti-Pendjari watershed from 1981 to 2020.

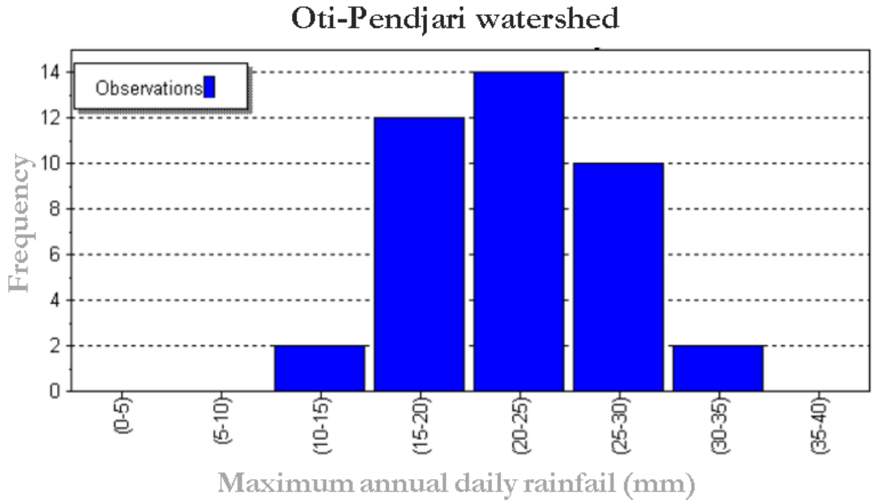


Figure 9: Frequency of occurrence of 24h annual maximum rainfall in the Oti-Pendjari watershed from 1981-2020.

The analysis shows that the highest daily maximum rainfall heights are 30 to 35 mm and appear in the series with a frequency of occurrence of 5%, slightly higher than that found by Koungbanane et al., (2020), who had worked only on the Oti sub-basin. On the other hand, the lowest rainfall (10-15 mm) is recorded twice in the series, or 5% of the rainfall events. Water heights between 20-30 mm which water the Oti-Pendjari basin more, appeared 90% in the series of events.

La Figure 10 présente la fréquence d'apparition des débits maximaux annuels journaliers observés aux exutoires de Porga, Mandouri et Mango dans le bassin-versant Oti-Pendjari de 1981 à 2020.

De l'analyse de la Figure 10, il ressort que les débits maximaux annuels en 24 heures dans le bassin aux trois exutoires varient de 0 à 696 m^3/s à Porga, de 0 à 896 m^3/s à Mandouri et à 2000 m^3/s à Mango. Les débits faibles sont enregistrés une fois à Porga et à Mandouri, soit 2,5 % et 3 fois à Mango soit 7,5 %. Les très forts débits maximaux sont apparus une seule fois dans la série à l'exutoire de Porga (696 m^3/s) et de Mango (2000 m^3/s) contre 6 fois à Mandouri (896 m^3/s). Ces débits maximaux ont une fréquence d'apparition respective 2,5 %, 15 % et 2,5 %. La fréquence d'apparition sur la plus élevée sur la série des trois stations correspond aux débits variants entre 1750 à 2000 m^3/s en aval du bassin-versant à l'exutoire de Mango.

Figure 10 shows the frequency of occurrence of the maximum annual daily flows observed at the Porga, Mandouri and Mango outlets in the Oti-Pendjari watershed from 1981 to 2020.

From the analysis of Figure 10, it appears that the maximum annual flows in 24 hours in the basin at the three outlets vary from 0 to 696 m3/s at Porga, from 0 to 896 m3/s at Mandouri and 2000 m3/s at Mango. Low flows are recorded once at Porga and Mandouri, i.e. 2.5% and 3 times at Mango, i.e. 7.5%. The very high maximum flows appeared only once in the series at the outlet of Porga (696 m3/s) and Mango (2000 m3/s) against 6 times at Mandouri (896 m3/s). These maximum flows have a frequency of occurrence of 2.5%, 15% and 2.5% respectively. The frequency of occurrence at the highest on the series of the three stations corresponds to the flows varying between 1750 to 2000 m3/s downstream of the watershed at the outlet of Mango.

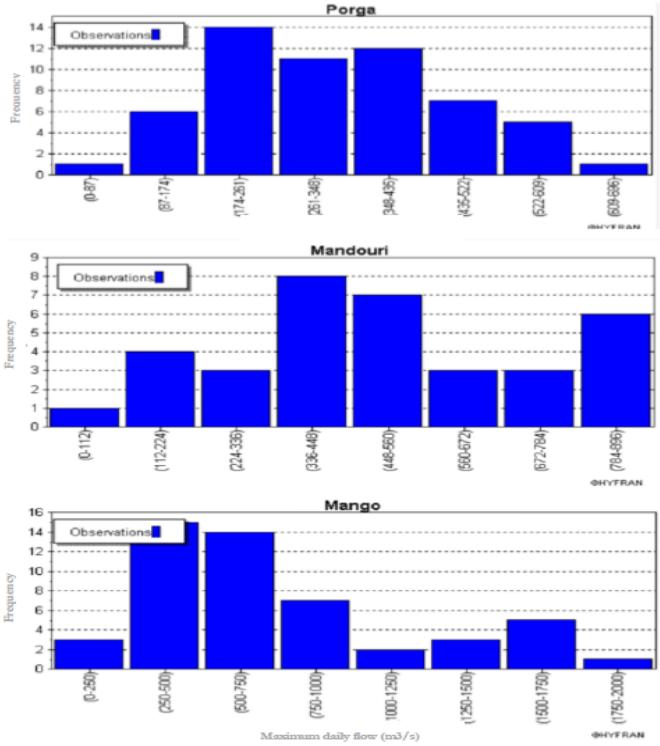


Figure 10: Frequency of occurrence of maximum annual flows in 24 hours at the Porga, Mandouri and Mango outlets in the Oti-Pendjari watershed from 1981-2020.

Graphic adjustment of maximum rainfall and maximum flow in 24 hours

Figure 11 illustrates a graphical adjustment of the maximum daily rainfall series by the best distribution laws over the period 1981-2020 in the Oti-Pendjari watershed.

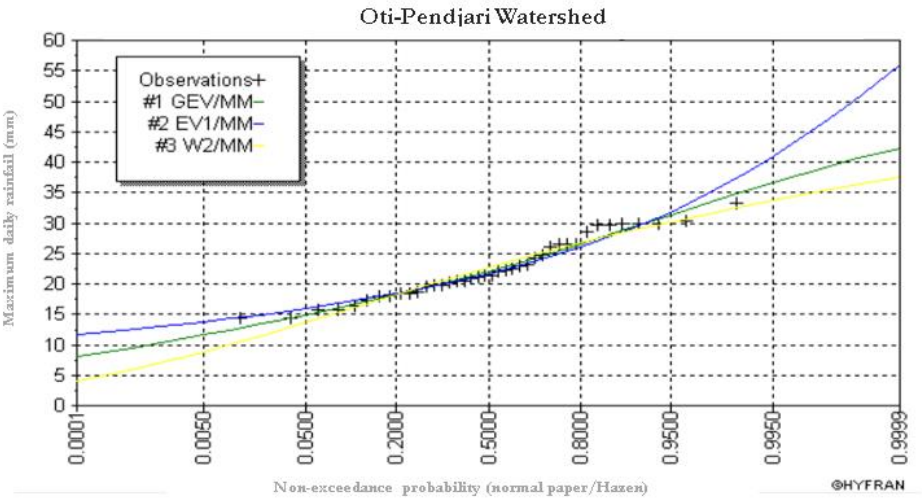


Figure 11: Graphical adjustment of daily maxima using Gumbel law

It is clear from the analysis of this Figure 11 that the adjustment of the maximum daily rainfall of the basin closely follows the suitable model in a confidence interval with a probability of not exceeding 95%. The best fitting law with the maximum likelihood at best the extreme values recorded with the rainfall field is the Gumbel law, which shows a minimization of the AIC and BIC criteria as shown in Table 1.

Table 1: Adjustment of maximum rainfall with laws (method of moments)

Adjustment laws	BIC	AIC
Gumbel	747,16	743,34
Weibull	747,23	743,40
GEV	752,29	746,56

It emerges from the analysis of this Table 1 that the maximum daily rainfalls are independent, homogeneous and stationary in the Oti-Pendjari watershed and well adjusted with the best Gumbel law, slightly better than the Weibull law. Figure 12 illustrates a graphical adjustment of the series of maximum 24-hour flows by the distribution laws over the period 1981-2020 at the Porga, Mandouri and Mango outlets in the Oti-Pendjari watershed.

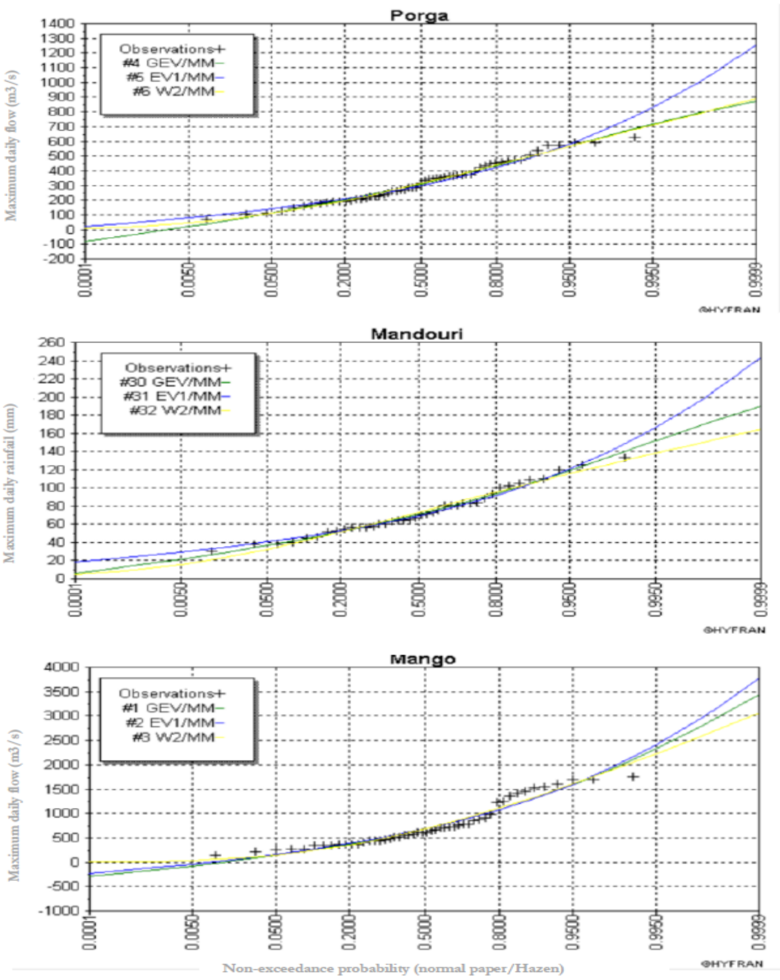


Figure 12: Graphical adjustment of maximum flows with the distribution laws (Gumbel, Weibull and GEV) at the Porga, Mandouri and Mango outlets in the Oti-Pendjari watershed from 1981-2020

From the analysis of Figure 12, it appears that the adjustment of the maximum daily flows of the basin evolves appropriately in a confidence interval with a probability of not exceeding 95% or even 99%. The best adjustment laws observed with the maximum likelihood of the extreme values recorded at Porga, Mandouri and Mango are the Weibull and Gumbel laws. Thus, the Weibull law best adjusts the maximum daily flows at the Porga and Mandouri hydrometric stations while the Gumbel law best adjusts the extreme values of the flows at the Mango station. Table 2 which best presents the adjustment laws, which minimize the AIC and BIC criteria, which confirms the choice of the Weibull and Gumbel laws.

Table 2: Adjustment of maximum daily flows with the three laws used (method of moments)

Laws	BIC	AIC
Porga station		
Weibull	**727,648**	**723,562**
Gumbel	730,642	726,556
GEV	732,559	726,429
Mandouri station		
Weibull	**482,921**	**479,81**
Gumbel	488,127	485,016
GEV	486,865	482,199
Mango station		
Weibull	747,225	743,401
Gumbel	**747,159**	**743,335**
GEV	752,293	746,557

Return period

Fitting the maximum daily rainfall and discharge to the statistical tests gave an estimate of the quantiles for return periods of (2, 5, 10, 20, 30 years). To assess the uncertainties associated with the estimates, confidence intervals are used as shown in Table 3.

Table 3: Estimation of characteristic flows and confidence intervals using GEV and Gumbel laws

	Best law & parameters		**Return period (T)**	**30yrs**	**20yrs**	**10yrs**	**5yrs**	**2yrs**
Porga	Weibull	α=362.845	Quantile at T	595	565	508	440	313
			Standard deviation	33	30.4	26.3	22.7	19.4
		c =2.47833	Confidence interval (95%)	530 - 659	505 - 625	456 - 560	395 - 484	275 - 351
Mandouri	Weibull	α= 557.035	Quantile at T	939	890	795	682	476
		c= 2.34276	Standard deviation	55	51	45.4	42.1	41.7
			Confidence interval (95%)	832 - 1050	790 - 990	706 - 884	600 - 765	395 - 558
Mango	Gumbel	μ= 548.795	Quantile at T	1740	1590	1340	1070	677
		α =350.706	Standard deviation	188	168	133	98.3	58.4
			Confidence interval (95%)	1370 - 2100	1260 - 1920	1080 - 1600	882 - 1270	563 - 792
Maximum daily precipitation on BV	Gumbel	μ= 20.23	Quantile at T	33.4	31.8	29	26.1	21.7
		α =3.89	Standard deviation	2.33	2.08	1.65	1.22	0.724
			Confidence interval (95%)	28.8 - 38.0	27.7 - 35.9	25.8 - 32.2	23.7 - 28.5	20.2 - 23.0

The analysis of Table 3 indicates that the rainfall quantiles have a better fit in the study area with the Gumbel law. Indeed, the maximum rainfall in 24 hours corresponding to heavy rain events (90th percentile) have an occurrence of 2 years, 5 years, 10 years with a rainfall height ranging from 21.7 ± 0.724 mm to 29 ± 1.65 mm. As for very heavy rain events (95th percentile) and extremely heavy rain events (99th percentile), they have respectively a recurrence of 20 years for and 30 and + and correspond in this order to 31.8 ± 2.08 mm and 33.4 ± 2.33 mm of maximum rainfall in 24 hours. Pursuing the same objectives, (Houessou, 2016) had already reported this frequency for heavy, very heavy and extremely heavy rainfall events in the Mono watershed in Athiémé, southwest Benin (Kodja, 2018) for the Ouémé basin. Similar results were obtained in the Niger basin in Benin (Koumassi et al., 2014). However, the concentration of rainfall quantiles (heavy, very heavy and extremely heavy) is largely a contributor to extreme rainfall events, including floods, which are not without consequences for the dynamics of the basin and the socio-economic life of the populations living there (Amoussou et al., 2015; Kodja, 2018).

For the maximum daily flows, they vary from one law to another and from one station to another. It appears that the quantiles vary from 313 ±19.4m3/s to 1740 ±188m3/s. The quantiles of high flood flows have a periodicity of 2 years to 10 years with maxima ranging from 313 ±19.4m3/s to 508 ± 26.3 m3/s in Porga; from 476 ± 41.7m3/s to 795 ± 45.4m3/s in Mandouri against 677 ± 58.4m3/s to 1340 ± 133m3/s in Mango. The quantiles of very high and extremely high flood flows occur respectively every 20 years and 30 years and +. Thus, the very high flood flows are 565 ± 30.4 m3/s in Porga, 890 ± 51 m3/s in Mandouri and 1590 ± 168 m3/s in Porga. Similarly, the maximum extremely high flood flows in 24 hours in Porga are 595 ± 33 m3/s; in Mandouri they are 939 ± 55 m3/s and in Mango they are 1740 ± 188 m3/s. Moreover, for normal or extreme events with a frequency of ≥ 5 years, or 10 years or 20 years, the flood flows varied respectively from 815 to 1240 m3/s, 997 to 1580 m3/s and 1160 to 1910 m3/s. For exceptional and very exceptional events of rare frequencies (≥ 50 years or = 100 years), the recorded flows were respectively 1360 to 2340 m3/s and 1490 to 2670 m3/s at the Mango outlet.

These results corroborate the results of the work of Koungbanane et al., (2020). These authors find that in Sudanese climatic conditions, the basin receives all the water inputs drained by the river from the upper watershed under the influence of the Atacora chain.

Conclusions

At the end of this research, it should be noted that the Volta watershed at the Oti and Pendjari outlets is faced with variability in rainfall maxima tending to the recurrence of floods in recent decades. These recurring floods in the Volta basin and more precisely in the Oti and Pendjari sub-basins are amplified by the accumulations of daily rainfall maxima with repercussions on societal and environmental issues (deforestation, increasing urbanization and intensive agricultural practices). This observation further confirms the results of research work carried out in watersheds of the same climatic framework including the Niger watershed in Benin by Koumassiet al., (2014), from Pendjari to Porga by Djossou (2020) and on the Oti basin in Mango by Koungbanane et al., (2020). In addition, the results of this research highlight the interannual and decadal variability of precipitation and flow rates, while confirming that the values of the 95th and 99th percentiles not only have a periodicity of 20 years and 50 years but are also close to the observed maxima, thus constituting reliable indicators of very wet periods and associated risks. It should also be noted that on the series of data used, the strong 90th percentile pluviohydrological events have an occurrence of 2 years, 5 years, 10 years and are more regular in the study area. The latter reinforce the results of the work of Houessou (2016) on the Mono watershed in Athiémé, of Kodja (2018) on the Ouémé watershed in Bonou. These observations reinforce the importance of this research, which is the subject of indicators for water resource management and prevention of hydrometeorological disasters (Amoussou et al., 2015).

It should also be noted that according to the frequency analysis, the distribution of hydrological maxima follows specific statistical laws, thus making it possible to estimate return periods and assess flood risks in the Oti-Pendjari basin. The increase in the occurrence of extreme events noted is a warning signal for water resource managers and decision-makers. To this end, it is necessary to strengthen hydrological and rainfall monitoring systems in the basin such as VoltALARM, by integrating low-cost technologies for more reliable and comprehensive data collection. This will ultimately call for intelligent and sustainable integrated management of water resources, based on predictive models and appropriate adaptation measures to address the impacts of climate extremes and environmental degradation.

This first analysis on the Oti-Pendjari basin constitutes a solid scientific basis to guide adaptation policies in the Volta watershed while highlighting the need to continue research to better understand the interactions between climate, human activities and the hydrological regime, in order to minimize risks for populations and ecosystems.

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