PEER-REVIEWED ARTICLE

Preliminary studies for a modeling approach regarding floods on the Bia River in Aboisso City

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Abstract

Worldwide, flooding caused by the overflow of rivers is a real threat to people and their property. This is why it is so important to have high-quality data and indicators for modelling this phenomenon. The aim of this study is to determine the morphometric characteristics involved in the flooding process in the Bia watershed upstream Aboisso outlet, and to estimate flood flows statistics both in order to get some insight in the overall features of the river watershed and flood behaviour. To do this, the methodological approach adopted initially enables the morphometric parameters of Bia watershed upstream Aboisso to be determined using empirical formulae and a DTM. Secondly, a frequency analysis is carried out, based on sampling the maximum annual flows generated from the series of average daily flows (1950–1983) from Aboisso station. Various probability laws for extreme values (Gumbel, Weibull and VEG) were fitted to the sample. The results show that the Bia watershed upstream Aboisso outlet covers an area of 8,887 km^2, is elongated in shape (K_G: 3.58), a low relief (D_S: 16.05) and a moderate average slope (I_W) estimated at 14.67 %. In addition, the stream which is draining the basin is more than 300 km long, with an average longitudinal slope (I) of 9.6 %. Estimated flood quantiles for return periods T_5, T_{10}, T_{20}, T_{50} and T_{100} are 368 m^3/s, 446 m^3/s, 520 m^3/s, 616 m^3/s and 688 m^3/s respectively.

Keywords

Flooding · morphometric parameters · frequency analysis · Bia · Aboisso

Resumé

À l'échelle du monde, les inondations causées par le débordement des cours d'eau constituent de véritables menaces pour les hommes et leurs biens. C'est pourquoi, disposer de données et d'indicateurs de qualité pour la modélisation de ce phénomène est important. La présente étude a pour objectif de déterminer à l'échelle du bassin versant de la Bia à l'exutoire d'Aboisso, les caractéristiques morphométriques intervenant dans le processus d'inondation et d'estimer les débits de crue. Pour ce faire, l'approche méthodologique adoptée, permet dans un premier temps, à l'aide de formules empiriques et d'un MNT de déterminer les paramètres morphométriques du bassin versant de la Bia à Aboisso. Dans un second temps, une analyse fréquentielle qui s'appuie sur l'échantillonnage des débits maximaux annuels générés à partir de la série des débits moyens journaliers (période 1950–1983) de la station d'Aboisso, est réalisée. Ainsi, différentes lois de probabilité de valeurs extrêmes (Gumbel, de Weibull et de VEG) ont été ajustées à l'échantillon constitué. Les résultats révèlent que le bassin versant de la Bia à l'exutoire d'Aboisso couvre une superficie de 8 887 km2, une forme allongée, un faible relief avec une pente moyenne modérée estimée à 14,67 %. En outre, le cours d'eau drainant le bassin sur plus de 300 km, cumule une pente moyenne longitudinale de 9,6 %. Quant aux quantiles de crue estimés suivant les périodes de retour T_5, T_{10}, T_{20}, T_{50} et T_{100}, ils aboutissent respectivement à 368 m^3/s, 446 m^3/s, 520 m^3/s, 616 m^3/s et 688 m^3/s.

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https://doi.org/10.58440/ihr-29-2-a26

Resumen

En todo el mundo, las inundaciones causadas por el desbordamiento de los ríos constituyen una amenaza real para las personas y sus bienes. De ahí la importancia de disponer de datos e indicadores de calidad para modelizar este fenómeno. El objetivo de este estudio es determinar las características morfométricas que intervienen en el proceso de inundación de la cuenca del Bia, en la desembocadura de Aboisso, y estimar los caudales de crecida. Para ello, el enfoque metodológico adoptado permite, en primer lugar, determinar los parámetros morfométricos de la cuenca del Bia en Aboisso mediante fórmulas empíricas y un MDT. En segundo lugar, se realiza un análisis de frecuencias, basado en el muestreo de los caudales máximos anuales generados a partir de la serie de caudales medios diarios (1950–1983) de la estación de Aboisso. Se ajustaron a la muestra diversas leyes de probabilidad de valores extremos (Gumbel, Weibull y VEG). Los resultados muestran que la cuenca del Bia en la desembocadura de Aboisso tiene una superficie de 8.887 km2, es alargada, presenta un relieve escaso y una pendiente media moderada estimada en el 14,67 %. Además, el curso de agua drena más de 300 km de la cuenca, con una pendiente longitudinal media del 9,6 %. Los cuantiles de crecida estimados para los periodos de retorno T_5, T_{10}, T_{20}, T_{50} y T_{100} son 368 m^3/s, 446 m^3/s, 520 m^3/s, 616 m^3/s y 688 m^3/s respectivamente.

1 Introduction

The study of extreme events is one of the major issues in most African countries with large river basins (Panthou, 2013). This issue requires specific approaches and technologies for the purpose of reducing the vulnerability of social systems to natural hazards. Based on this observation, the use of hydraulic simulation models has increased in recent years, particularly in the context of risk studies (Werren & Lasri, 2014; Abidi et al., 2019). These models have allowed significant steps forward in flood management, both for forecasting and for prevention and crisis management (Tanguy, 2012). The results of the hydraulic models used are heavily reliable on the quality of the data provided. These data are generally presented in different forms (topographic, geometric, hydraulic and hydrological). Moreover, Layan et al. (2012) consider that hydrological studies are one of the foundations on which any hydraulic modeling of rivers must be built in order to predict floods and manage hydrological risks in a floodplain. In this context, preliminary studies are necessary to determine some characteristics and indicators related to the physical, hydrological and hydraulic functioning of the watershed of interest. In the specific case of the Bia watershed in Aboisso, few studies addressing these aspects exist and when they do, these studies are very often limited to the Ayamé outlet (EDF, 1955; Meledje, 2015) or further upstream to Bianouan (Fadika et al., 2019). This study would like to address these shortcomings. This will be achieved by determining the morphometric characteristics of Bia watershed upstream Aboisso outlet and estimating the flood flows on the basis of quantiles according to different return periods, namely T_5, T_{10}, T_{20}, T_{50} and T_{100}.

2 Materials and Methods

2.1 Study area

Aboisso is both a district and the capital of the Sud-Comoé region. It is located in the southeast of Côte d'Ivoire between latitudes 5.43° N and 5.52° N and longitudes -3.34° W and -3.17° W. The city's hydrography is dominated by the Bia, a transboundary river that originates in Ghana at an altitude of about 300 meters. The watershed of the Bia at its outlet in Aboisso lies between latitudes 5°27' N and 7°23' N and longitudes -3°24' W and - 2°31' W (Fig. 1) and is bounded to the west by the Comoé basin and to the east by the Tanoé basin. In addition, the river flows through the town of Aboisso, separating it into two banks before beginning its final journey to the Aby lagoon (320 km from its source). From a climatic point of view, the rainfall analysis of the basin distinguishes two zones: the humid tropical zone in the north with a single rainy season and further south, a subequatorial zone with two distinct rainy seasons (Meledje, 2015). As for the relief, the watershed generally corresponds to a low relief except in some areas in Ghana where it culminates at elevation not exceeding 650 m (EDF, 1955).

2.2 Data

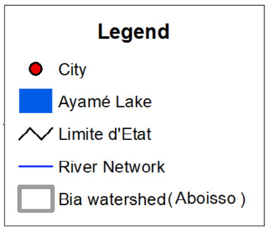
Two types of data are used in this research:

1. Hydrometrical data on annual maximum flows. Those data are derived from the time series of daily average flows recorded on the Bia River at Aboisso hydrometric stations (1950–1983) and Bianouan (1981–2005).
2. Cartographic data namely, a Digital Terrain Model (DTM) describing the morphology and topography area study. This DTM which is used to delineate the watershed of interest is derived from a global ASTER V4 image with a spatial resolution of 30 m × 30 m[1].

3 Methods

The approach used in this research is twofold. The first one is related to the determination of morphometric watershed parameters and takes advantage of the use of empirical formulas and Geographic Information Systems (GIS). The second one is dedicated to the frequency analysis of hydrometrical variables

[1] Downloaded from https://earthexplorer.usgs.gov/ (accessed 20 Sep. 2023).



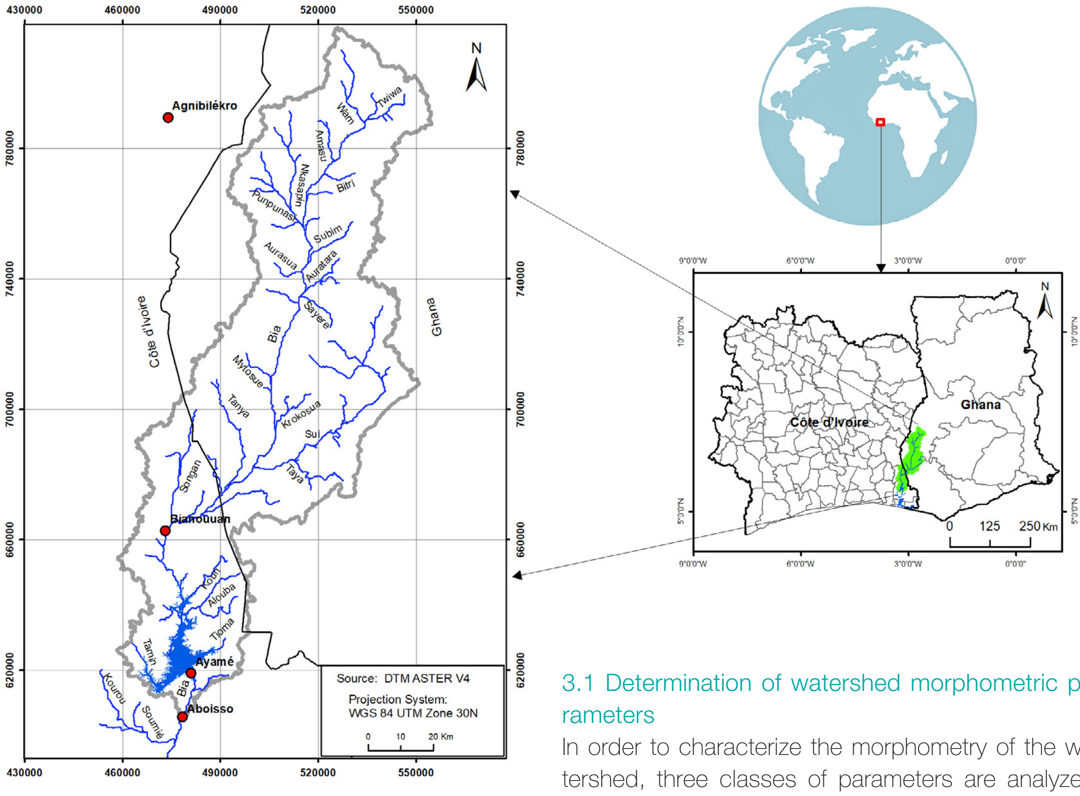


Fig. 1 Geographical location of Bia watershed upstream Aboisso.

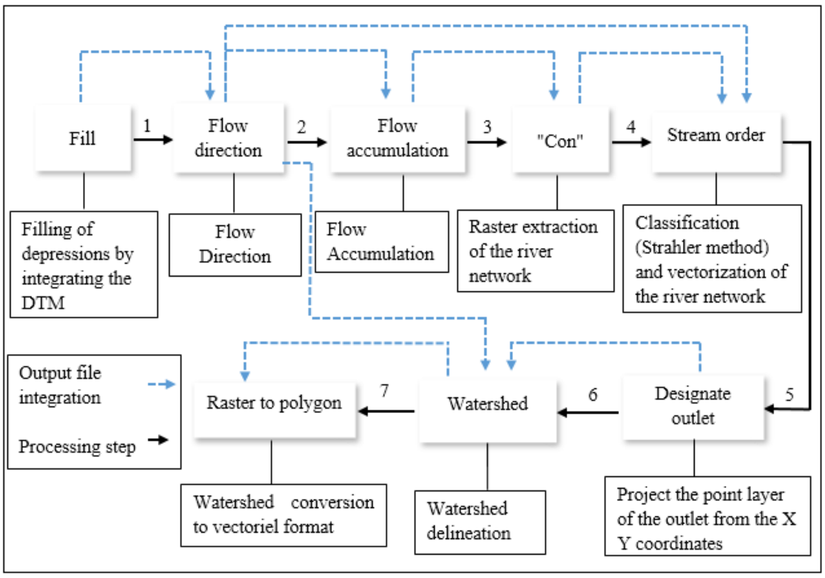


Fig. 2 Watershed delineation process using ArcGIS spatial analysis tools; inspired by (Saidi, 2013).

(Hydrological Frequency Analysis; El Adlouni & Bobee, 2014). It is inspired by several works (Yahiaoui, 1997; Kouider, 2003; Avahounlin et al., 2013; Meddi & Sadeuk, 2014) and also used the implementation made in the Hyfran software.

3.1 Determination of watershed morphometric parameters

In order to characterize the morphometry of the watershed, three classes of parameters are analyzed: geometry, topography and hydromorphometric aspects.

3.1.1 Geometry

In terms of geometry, the focus is lead on parameters to characterize the delineation and shape of the watershed:

Delineation

The watershed is the area where precipitation is received and where rivers are fed, so the amount of water which is flowing to the river will depend on the watershed area. In this study, watershed area (*A*) and its perimeter (*P*) are delineated from the DTM and integrated in a GIS (Fig. 2).

Shape

The shape of the basin influences the shape of the hydrograph. Among the morphological index to characterize its shape, the Gravelius compactness index (K_G) and the equivalent rectangle were selected (Konin et al., 2021). K_G is defined as the ratio of watershed perimeter to the circle perimeter with the same area. The closer this coefficient is to 1, the more quasi-circular shape, the basin will take and conversely will tend towards a more elongated shape. The K_G, is expressed as follows:

$$K_G = \frac{P}{2\sqrt{\pi A}} = 0.28 \times \frac{P}{\sqrt{A}} \qquad (1)$$

https://doi.org/10.58440/ihr-29-2-a26

Furthermore, the equivalent rectangle is defined as the rectangle of length (**L**) and width (**l**) that has the same area (**A**) and perimeter (**P**) as the watershed (Eqs. 2 and 3)

$$\begin{cases} 2 \times (L \times l) = P \\ L \times l = A \end{cases} \tag{2}$$

$$L = \frac{P + \sqrt{P^2 - 16A}}{4} \quad ; \quad l = \frac{P - \sqrt{P^2 - 16A}}{4} \tag{3}$$

3.1.2 Topography

In this section, various parameters are analyzed which describe hypsometrical and slope characteristics:

Hypsometry

The hypsometric curve stands for the distribution of watershed area according to the elevation. Its plot allows a direct reading of the characteristic elevation such as the maximum (H_{max}), minimum (H_{min}) and average (H_{avg}) elevation. As for the vertical drop (*D*), it can be deduced from the hypsometric curve through the relationship between the $H_{5\%}$ and $H_{95\%}$ (Eq. 4):

$$D = H_{5\%} - H_{95\%} \tag{4}$$

Slopes

There are several indices that allow to characterize watershed slopes, make comparisons between basins and make basins classifications. We have the global slope index, the specific gradient and the average watershed slope.

Global slope index

The global slope index (I_G), is determined as follows (Eq. 5):

$$I_G = \frac{D}{L} \tag{5}$$

Specific gradient

The specific gradient (D_S) is given by Eq. 6:

$$D_S = I_G \times \sqrt{A} = \frac{D}{L}\sqrt{L \times l} = D \times \sqrt{\frac{l}{L}} \tag{6}$$

with

D: vertical drop in [m]; I_G: global slope index

L: equivalent rectangle length in [m]; **l**: equivalent rectangle width in [m]

D_S: specific gradient in [m]; *A*: watershed area in [m]

It gives rise to a classification of the ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer) independent of basin areas (Table 1; Roche, 1963).

Average slope of watershed

The DTM and the ArcGIS software-processing tool (Slope) were used to estimate the average slope of watershed (I_W; Saidi, 2013).

Table 1 Average relief as a function of D_S.

Reference	Interval	Relief type
R1	$D_S \le 10$ m	Very low relief
R2	10 m $< D_S \le$ 25 m	Low relief
R3	25 m $< D_S \le$ 50 m	Fairly low relief
R4	50 m $< D_S \le$ 100 m	Moderate relief
R5	100 m $< D_S \le$ 250 m	Fairly strong relief
R6	250 m $< D_S \le$ 500 m	Strong relief
R7	$D_S >$ 500 m	Very strong relief

3.1.3 Hydromorphometric aspects

Average slope of the main stream

The average slope of the main stream (longitudinal slope of the main stream) determines the speed with which water reaches to basin outlet and therefore concentration time. This variable influences the maximum flow observed. This slope is determined by the longitudinal stream profile or its tributaries after removing 20 % of the upper part and 20 % of the lower part of the profile (Eq. 7):

$$I = \frac{\Delta H}{L} \tag{7}$$

with

I: Average slope of the main stream [m/km].

L: length of stream section concerned in [km].

ΔH: difference in elevation between the furthest point (20 % of profile) and the watershed outlet (20 % of profile) in [m].

Time of concentration

This is the time required for a water particle to flow from the most hydrologically distant feature of the watershed to the outlet. In this study, T_C was estimated using the old Giandotti formula (Touaïbia, 2004, Eq. 8).

$$T_C = \frac{4\sqrt{A} + 1.5L_{ep}}{0.8\sqrt{H_{avg} - H_{min}}} \tag{8}$$

with

T_C: time of concentration in [hours]

L_{ep}: length of the main stream in [km]

A: watershed area in [km²]

H_{avg}: average elevation of watershed in [m]

H_{min}: minimum elevation of watershed in [m]

3.2 Estimating flood flows of certain magnitudes

The study of peak flows provides information on the trigger flows for flood and flooding in the watershed (Kouassi, 2014b). Several methods for determining flood flows of certain magnitudes are existing (empir-

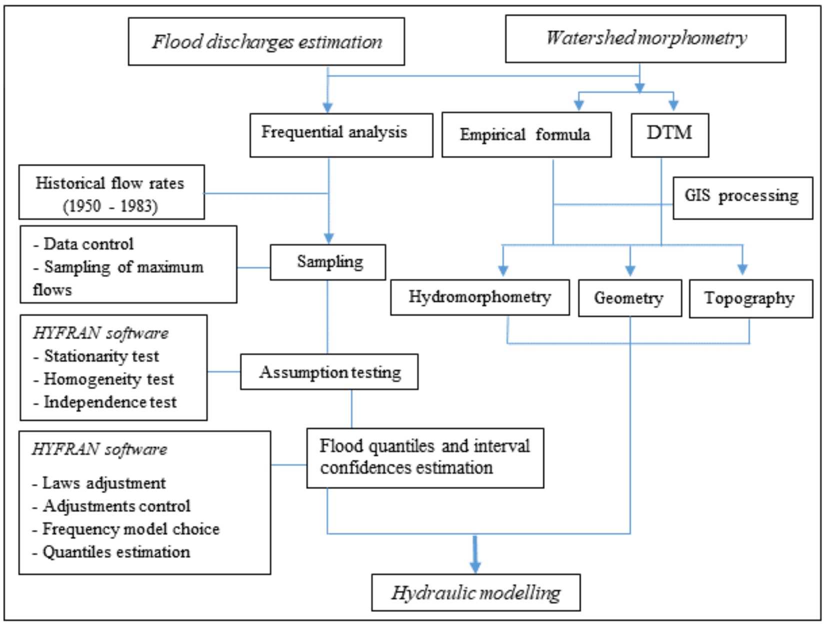


Fig.3 Methodological approach summary.

ic, probabilistic and statistic). For the current study, statistic methods through applying frequency analysis from historical flow data of Bia River in Aboisso station are adopted (period 1950–1983).

This approach requires the use of:

1. A sampling resulting in the selection of the maximum values of each year in the series of daily average flows of Aboisso station (Meddi & Sadeuk, 2014; Hachemi, 2017).
2. Hypothesis tests to judge the quality of the sample (Yahiaoui, 2012) mainly involving the Wald-Wolfowitz independence test, Kendal stationarity and Wilcoxon homogeneity test (Kouider, 2003; Yahiaoui, 2012; Kouassi et al., 2014a; Koungbanane et al., 2020).
3. The choice of a frequency analysis model to predict the probability of occurrence flood event from the flow distribution function F(Q) or the probability density P(Q).
4. The choice of a statistical model following the Gumbel, VEG (General Extreme Value) and Weibull laws (Kouider, 2003).
5. A control of the fit and validation of statistical model through the χ^2 adequacy test and the Akaike information criteria (AIC; Akaike, 1974) and Bayesian information criteria (BIC; Schwarz, 1978).

In overall, the best law being identified, the flood quantiles as well as the associated confidence intervals were estimated using the Hyfran software (El Adlouni & Bobee, 2014) calculating the different return periods. Fig. 3 stands for an overall summary of the methodological approach adopted in this study.

4 Results and discussion

4.1 Determination of the watershed morphometric parameters

The morphometric analysis reveals that at the Aboisso outlet, the Bia watershed has a geometric area of approximately 8,887 km² for an estimated perimeter of 1,205 km (Table 2).

Gravelius compactness index (K_G) of 3.58 reflects an elongated basin with a northeast-southwest orientation (oblique). This elongated shape will strongly influence

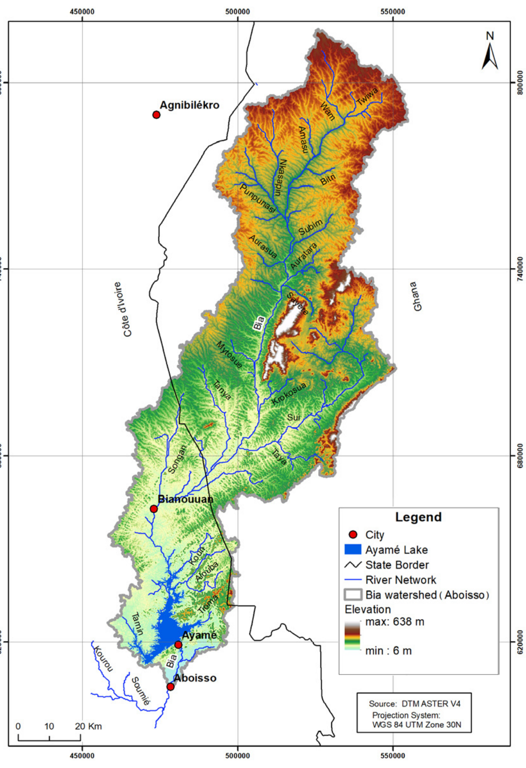


Fig 4 Elevation spatial distribution of Bia watershed upstream Aboisso.

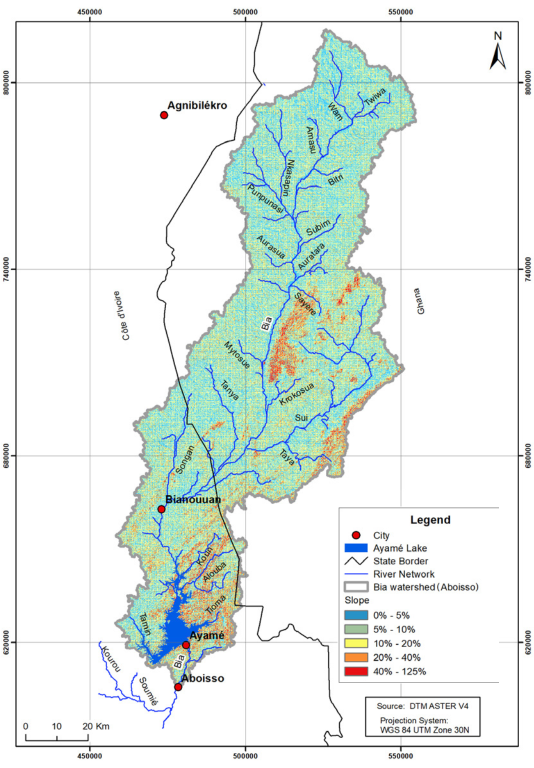


Fig 5 Slope spatial distribution of Bia watershed upstream Aboisso.

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Table 2 Morphometric characteristics of Bia watershed upstream Aboisso.

		Features	Units	Values
Geometry	Delimitation	Area (*A*)	km²	8887
		Perimeter (*P*)	km	1205
	Shape	Length (*L*)	km	587.37
		Width (*l*)	km	15.13
		Gravelius compactness index (K_G)		3.58
Topography	Hypsometry	Maximum elevation (H_{max})	m	638
		Minimum elevation (H_{min})	m	6
		Median elevation ($H_{50\%}$)	m	200
		Average elevation (H_{avg})	m	222
		Elevation 5 % ($H_{5\%}$)	m	450
		Elevation 95 % ($H_{95\%}$)	m	100
		Vertical drop (*D*)	m	350
	Slope	Specific gradient (D_S)	m	16.05
		Global slope index (I_G)	m/km	0.60
			%	14.67
Hydromorphometric aspects		Average slope of the main stream (*I*)	m/km	0.96
		length of stream section concerned (*L*)	km	298
		Difference between elevation (ΔH)	m	285
		Time of concentration (T_C)	h	45
		Length of main stream (L_{ep})	km	300

the overall flow, especially the watershed answer time. Thus, with a time of concentration of 45 h, for the same rainfall, less peak flows will be recorded at the outlet due to the longer time of water routing. Topographically, the basin elevations vary between 6 m and 638 m (Fig. 4) with a predominance of higher elevations in the basin northern regions. Also, the specific gradient value (D_S: 16.05 m), allows to classify Bia watershed relief in a general way in low reliefs class. Moreover, the watershed has a moderate average slope (I_W) of 14.67 % (Fig. 5). It is recognized that such slopes slow down area runoff, thus giving water enough time to infiltrate into the soil. In addition, in line with the hydromorphometric aspect, the stream draining the basin over more than 300 km has an average slope (*I*) of about 0.96 m/km (or 9.6 %). This last slope conditions not only the speed of water in the channel but also the speed of flood wave and draft of the river. These slope data are essential variables for the calibration of hydraulic models for flood simulation.

4.2 Estimation of flood flows

4.2.1 Sampling and hypothesis testing

Using the Hyfran software (El Adlouni & Bobee, 2014), the sample was subjected to several hypothesis tests. Out of the three tests considered (Table 3), the independence and stationarity tests were validated at a threshold of 5 %, as opposed to an acceptance threshold of 1 % for the homogeneity test.

These results (Table 3) establish that the series of annual maximum values of daily flows (Fig. 6) consists of independent, homogeneous and stationary values. Therefore, the sample of annual maximum flows from Aboisso station easily meets the conditions for the application of the frequency analysis.

Table 3 Hypothesis test and acceptance threshold.

Tests	Authors	Acceptance level
Independence	Wald-Wolfowitz	5 %
Stationarity	Kendal	5 %
Homogeneity	Wilcoxon	1 %

Table 4 Parameters of the probability laws (u, α and k).

Probability law	u (mm)	α (mm)	k
VEG	208.80	95.74	0.16
Gumbel	213.63	103.23	–
Weibull	–	313	2.39

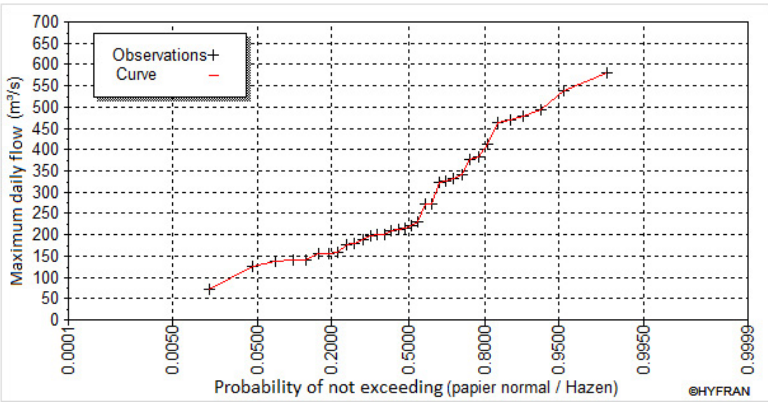

Fig 6 Empirical probabilities of annual maximum flows evolution at the Aboisso station over period 1950–1983.

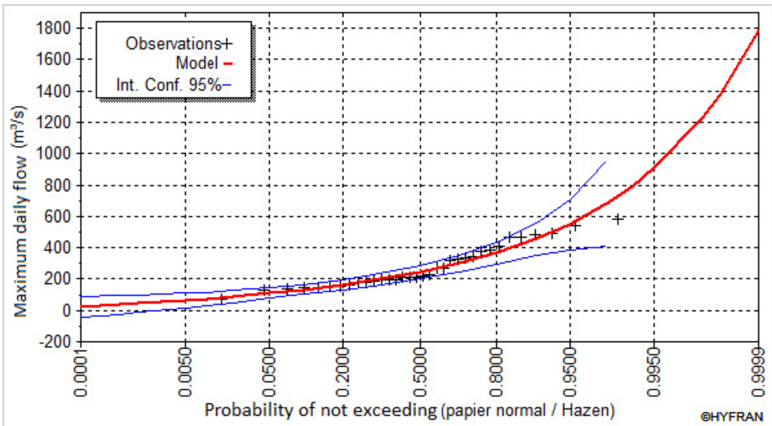

Fig 7 Adjustment of the sample of annual maximum flows at Aboisso to VEG law.

4.2.2 Fitting to probability laws

The Hazen frequency analysis model was used to describe the evolution of the empirical probabilities of the annual maximum flows of Aboisso hydrometric station over period 1950–1983 (Fig. 6). Also, the parameters of position (u), scale (α) and shape (k), of different distributions were evaluated according to the maximum likelihood and presented in Table 4.

In addition, the fit of the different laws (VEG, Gumbel and Weibull) to the annual maximum flow series (Figs. 7, 8 and 9) was numerically evaluated using the Chi-square test of adequacy (Table 5).

This test verified the significance of empirical frequency differences between the sample data and the fits.

Thus, the results reveal that, for both Gumbel and VEG law fits, the calculated $\chi^2 \leq \chi^2$ tabulated (Table 5). So, these fits are considered satisfactory and therefore the H_0 hypothesis is accepted at the 5 % significant level.

With regard to the Weibull distribution fit, we find that calculated $\chi^2 \geq$ tabulated χ^2 (Table 5). In this case, the H_0 hypothesis is rejected at the 5 % significant level, but accepted at the 1 % significance level. Therefore, the fit is satisfactory at the 1 % significant level.

4.2.3 Choice of the analysis model and estimation of flood quantiles

The different laws selected all fit, more or less, to the sample of annual maximum flows at significant levels of 1 % to 5 %. It is therefore appropriate to subject these fits to comparison criteria in order to deduce the most reliable and best suited to describe the flow values for extrapolation in this study. From the graphical comparison (Fig. 10), it can be seen that the Gumbel's law fit is framed by the VEG and Weibull law fits.

This finding more or less indicates the ability of the Gumbel law to best fit the series of maximum sampled flows. In practice, the best fitting law is the one with the highest posterior probability P(Mi/x) and the lowest Bayesian Information Criteria (BIC) and Akaike Information Criteria (AIC). Thus, according to the results of the numerical comparison (Table 6), the Gumbel law with the values of BIC and AIC being respectively 429.97 and 426.91 are lower than those of the VEG and Weibull laws. The same observation is made for the posterior probability (P(Mi/x)) whose value associated with the Gumbel distribution (51.75) is higher than that of the other distributions. Finally, the graphical and numerical comparison criteria tested agree on the fact that Gumbel's law remains the law that best fits the sample of annual maximum flows at the Aboisso hydrometric station.

Consequently, the estimation of the flood quantiles from the subsequent Gumbel law adjustment is performed according to the return periods of T_5, T_{10}, T_{20}, T_{50} and T_{100} years. Thus, for these return periods, the results of the respective quantiles (Table 7) vary between 368 m³/s (T_5) and 688 m³/s (T_{100}) and

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it is these quantiles which will be used not only as input data (initial conditions) of the hydraulic models of simulation of the extreme floods but also for the estimation of the probable spatial extents. Moreover, they will also be used for the dimensioning of hydraulic structures such as bridges, spillways of dams and the heights of protection dykes.

4.3 Discussion

4.3.1 Morphometric parameters of the watershed

The determination of morphometric parameters has made it possible to highlight a certain number of parameters influencing the flows at outlet. The Bia basin in Aboisso has an elongated shape (K_G: 3.58), a moderate average slope (I_W: 14.67 %) and a generally low relief. This elongated shape of the basin, which favors the slowing of storm water runoff from the watershed to the outlet, is in agreement with the results of the study by Konin et al. (2021) on the San Pedro River basin. Also, in the study of the simulation of the hydrological behavior of the Agneby watershed, Goula et al. (2009), determined that the average slope of the watershed was on the order of 12.5 % with an equally elongated shape. These shape and slope characteristics appear to be typical of small coastal river basins in Côte d'Ivoire.

4.3.2 Flood flow statistics

Due to the availability of hydrometric data over the study area for a 34-year period only for this study a method of frequency analysis is chosen which is favoured to use by several authors (Meddi & Sadeuk, 2014; Kouassi et al., 2018a) for the estimation of extreme hydropluviometric variables when the constraint of having at least 30 years of data available is met.The present analysis tested three laws (VEG, Gumbel and Weibul), however, given the results of the Chi-square goodness-of-fit test and the information criteria (AIC and BIC), the Gumbel model appears to be the most suitable for fitting our data. This model is particularly robust when it comes to the adjustment of extreme values of hydrometrical variables. Indeed, Kouassi et al. (2018a), after studying the ability of several laws to adjust the maximum annual rainfall at the Port-Bouët station, recommend the use of the Gumbel distribution for hydraulic design projects in the city of Abidjan. Furthermore, based on the studies of Goula et al. (2010) and Soro (2011), Gumbel's law seems particularly adapted to humid tropical regions. However, it should be noted that there is no universal model, each model is adapted to certain types of climates or watersheds with a well-determined interest (Hachemi, 2017). Thus, the study by Kodja (2018) aimed at characterizing the indicators related to extreme hydroclimatic events in the Ouémé watershed at the Bonou outlet indicated that in terms of fitting maximum daily flows, the VEG law was more suitable in Sudanian area. Also, in the Algerian context, Mouas & Souag (2016) tested the effectiveness of seven distribution models to fit instantaneous max-

Table 5 χ^2 adequacy test applied to probability laws.

Features	VEG	Gumbel	Weibull
Sample size (n)	34	34	34
p-value	0.3903	0.1918	0.0276
Degree of freedom (μ)	4	5	5
Number of classes (C)	8	8	8
Significant level	95 %	95 %	95 %
χ^2 calculated	4.12	7.41	12.59
χ^2 tabulated	9.49	11.07	11.07

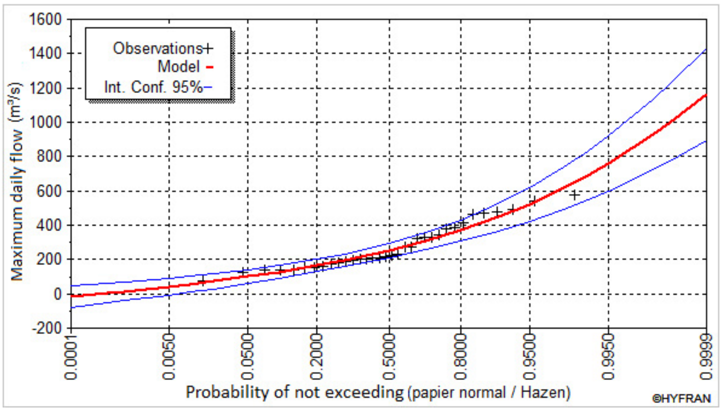

Fig 8 Adjustment of the sample of annual maximum flows at Aboisso to Gumbel law.

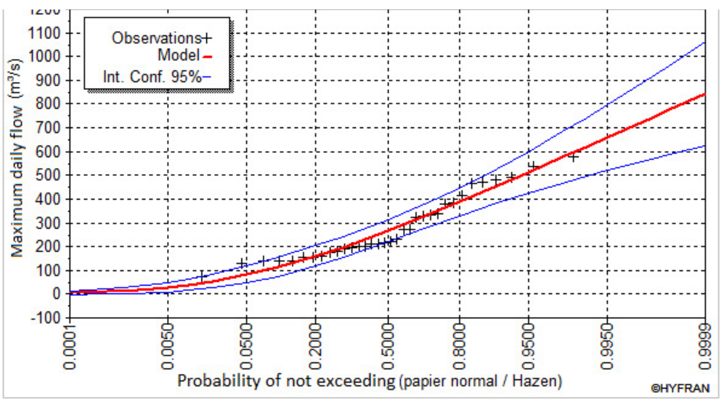

Fig 9 Adjustment of the sample of annual maximum flows at Aboisso to Weibull law.

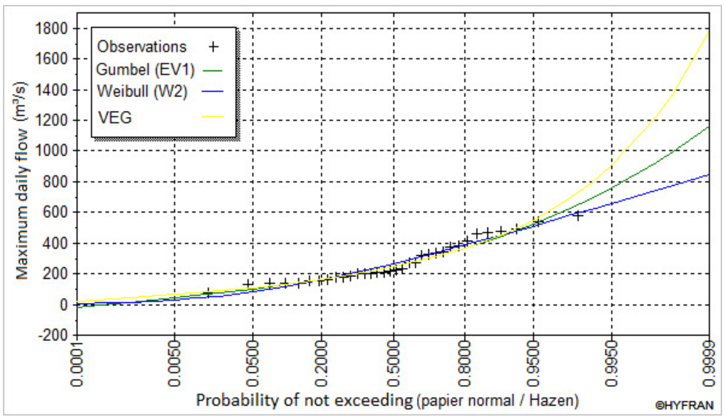

Fig 10 Graphical comparison between the VEG; Gumbel and Weibull laws.

Table 6 Numerical comparison of Gumbel, Weibull and VEG laws.

Laws	Number of setting	Q (m^3/s)	P(Mi)	P(Mi/x)	BIC	AIC
Gumbel	2	688.50	25	51.75	429.97	426.91
Weibull	2	619.16	25	25.30	431.40	428.35
VEG	3	790.41	50	22.95	432.98	428.40

with

P(Mi): a priori probability

P(Mi/x): a posteriori probability

Table 7 Flood quantiles and interval confidences.

Return period T of reference (years)	Fnd (x)	Quantile [m^3/s]	Standard deviation	Confidence interval
100	0.99	688	72.8	[546–831]
50	0.98	616	63.2	[492–740]
20	0.95	520	50.7	[421–620]
10	0.90	446	41.4	[365–527]
5	0.80	368	32.1	[306–431]

imum daily flow data from 28 stations. Based on the comparison criteria (AIC and BIC), they conclude that the Log normal distribution is the most appropriate for the humid region while the exponential distribution is preferred for the semi-arid and arid regions. The use of old hydrometric data (1950–1983) is one of the constraints encountered in this study because it might not reflect todays climatological conditions. In particular, hydrological studies have shown considerable impacts of climate change on runoff in West Africa. These decreases range from 30 % to 50 % or even 60 % in the major rivers (Niger, Senegal, Comoé and Volta rivers) after the 1987–1980 decade recognized in Africa as the period of hydro-rainfall disruptions (Kouakou et al., 2007; Panthou, 2013). Therefore, during the 1950–1983 period, the flows obtained are largely greater than expected today.

Another constraint must be seen in the construction of the Ayamé 1 (1959) and Ayamé 2 (1965) hydroelectric dams in the measurement period of the hydrometric data analysed in this paper. The building of the dam clearly has changed the hydrological and hydraulic conditions of Bia river which might be taken into account when using the statistical results.

Nevertheless, their use does not have a major influence on the long-term objective of this research namely to determine the extent and potential areas of influence of Bia-related flooding in Aboisso city.

5 Conclusion

The aim of this preliminary study was twofold. First, we aimed to determine the morphometric parameters of Bia watershed in Aboisso using a DTM and empirical formulas. Secondly, based on the statistical study of the maximum annual flows, we estimated the flood quantiles according to different return periods. The morphometric analysis reveals the Bia basin at Aboisso outlet has an elongated shape (K_G: 3.58), a low relief (D_S: 16.5) and all for an estimated concentration time of 45 hours. Parameters such as the average slope of watershed (I_W: 14.67 %), the average slope of the main stream (I_W: 9.6 %) being particularly important for the calibration of hydraulic models for flood simulation were determined.

With regard to the statistical study of the flows, it allowed us to identify the Gumbel law as the one that best fits the data, based on the frequency analysis applied to the sample of maximum annual flows. Thus, the associated flood quantiles were estimated to be 368 m^3/s; 446 m^3/s; 520 m^3/s; 616 m^3/s and 688 m^3/s for return periods T_5, T_{10}, T_{20}, T_{50}, and T_{100}, respectively.

Overall, this study offers the opportunity to have precise data and indicators in terms of studies related to hydraulic modelling. In particular, for the simulation of the spatial extent of the flood expansion field, flow velocities and water heights for the mapping of potentially floodable areas or for the dimensioning of hydraulic structures in Aboisso city.

https://doi.org/10.58440/ihr-29-2-a26

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https://doi.org/10.58440/ihr-29-2-a26