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Propagation of flood waves on the N'ziriver (Bandama, Côte d'Ivoire)

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Abstract
Floods are random natural phenomena with often disastrous consequences. To the recurrence of these events, the understanding and monitoring of flood propagation mechanisms along the main rivers of Côte d'Ivoire become a way of watershed management and flood prevention. The aim of this study is to know the evolution of the flood waves along the N'zi, the main tributary of the Bandama River, which every year is subjected to flood sometimes exceptional. The highlight of rainfall and flow relationship shows that N'zi floods are mainly generated by precipitation and that the watershed's response is immediate. The spatial heterogeneity of the rains and their intensity variation disrupt the evolution of the waves which is done either by amplification or by attenuation. The determination of the physical parameters of the bed and the propagation parameters of the flood point by the analysis of the hydrographs revealed the attenuating nature of the floods especially around Bocanda: 50% on the M'bahiakro-Bocanda section and 83% between Bocanda and Dimbokro. The weakness of the slope, the sinuosities and the roughness of the bed contribute greatly to the attenuation of the flood waves with a low celerity (0.6 m/s).

1. Introduction
Over the course of the 21st century, the nature has undergone significant changes linked to climate change, which will become more acute according to the season and the geographical environment [1]. Changes in the distribution of rainfall could increase the intensity and frequency of certain phenomena such as floods and flooding in some regions of the world. Given the unpredictable nature of their occurrence, these phenomena pose a threat to the neighbouring populations. The implementation of protective measures against these phenomena remains a major concern for contemporary hydrologists who are developing models to prevent floods and inundation risks [2-5].

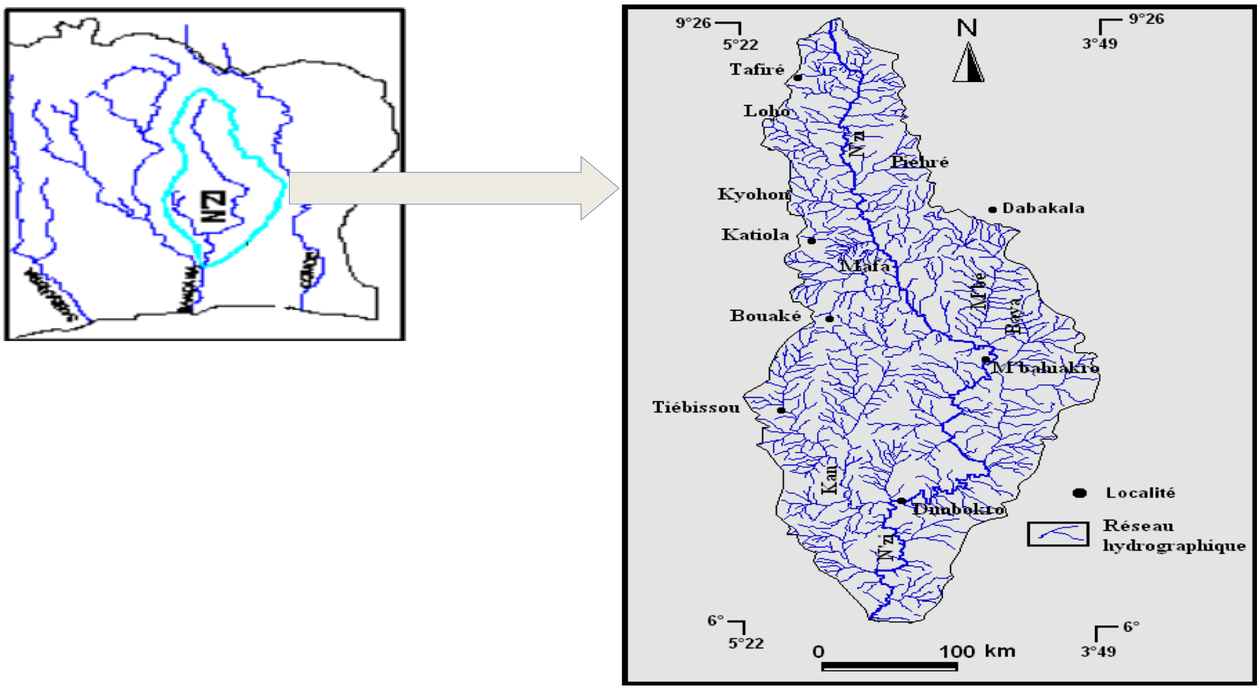
In Côte d'Ivoire, no study has ever covered this topic, yet it is very important in the policy of settlement [6]. As a result, the mechanisms of propagation of flood waves along the main Ivorian rivers are unknown and there is no monitoring of the evolution of floods which consequences are often disastrous. Thus, this article entitled "Propagation of flood waves along a river: the case of the N'zi river" is a first of its kind in the process of understanding floods in Côte d'Ivoire.

The main objective of this work is to follow the evolution of flood waves along the N'zi River. Specifically, it will first of all explain the functioning of the N'zi watershed during floods, then to determine parameters related to the propagation of flood waves and to explain the influence of the hydraulic characteristics of the sections on the process of flood wave propagation. This study aims at contributing to the understanding of flood phenomena and the dynamics of flood waves on the N'zi River. Although not a model, this study was based on methods of hydrographs analysis at different hydrometric stations.

2. Presentation of the study area
The study area is the N'zi watershed, which is a sub-catchment of the Bandama River. It covers an area of 35000 km² and lies between longitudes 3 ° 49 'and 5 ° 22' West and latitudes 6 ° and 9 ° 26 ' North. The main stem of River N'zi is 725 km long and takes its source in the north, in the region of Ferkéssedougou at an altitude of 400 m. Its flows into the Bandama at Tiassalé at less than 100 m altitude.

The N'zi hydrographic network is very dense as shown in figure 1.

Figure 1: N'zi watershed and hydrographic network.



Because of its elongated geographical configuration, the N'zi watershed is representative of the major climate groups in Côte d'Ivoire [7]. In the north, there is the tropical transitional regime (Sudanese climate). The tropical humid regime (Baouléan climate) is characteristic of the central part of the watershed. The South of the watershed is illustrated by a subequatorial regime (Attiéan climate). The average monthly maximum rain in the Sudanese climate is about 170 mm during the months of April and September against an average maximum of 300 mm during the month of June in the Baoule climate. In the Attian climate the maximum average rain is around 250 mm in the same month of June. The N'zi watershed is characterized by medium desaturated ferralitic soils (north) and highly desaturated ferralitic soils (Center and South) [8]. Indeed, these elements (vegetation, landscape, types of soil, etc.) constitute the physical conditions of the flow.
The main stem of the N'zi River has five (5) large hydrometric stations which allow the estimation of daily flows based on water level surveys. They are, from North to South: Fętekro, M'bahiakro, Bocanda, Dimbokro and N'zianouan (Figure 2).

3. Materials and methods

3.1.Material

The material used to achieve the objectives consists of:

- the topographical map of the study area at a scale of 1/500000 (South-East leaf);
- daily rainfall data from 1990 to 1992;
- data on daily flows from 1990 to 1993;
- the Map info software for the digitization of the maps and the determination of certain parameters characteristic of the basin.

3.2.Methods

The methods used for this study are first of all the analysis of the hydrographs carried out at the different hydrometric stations for the determination of the annual floods and the mechanisms of propagation of the flood waves. Then the superposition of hyetograms and hydrographs made it possible to highlight the rain/flow relationship. Similarly, physical parameters of the identified sections have been determined. These are mainly:

- the length (L);
- the distance of the sections as the crow flies (d), determined from the map scanned on Map info;
- the sinuosity index which quantifies the degree of sinuosity of the river was determined by the "classical" formula (1) used by [9]:

$$Is = \frac{L}{d} (1)$$

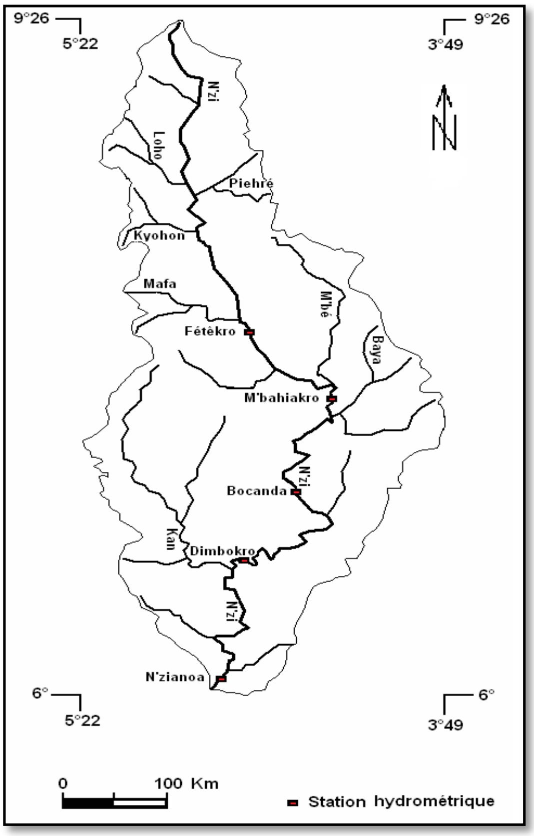


Figure 2: Hydrometric stations on N'zi.

The conventional formula for determining the slope of a section is given by the following equation (2):

$$I = \frac{(Z_{TNam} - Z_{TNav})}{L} (2)$$

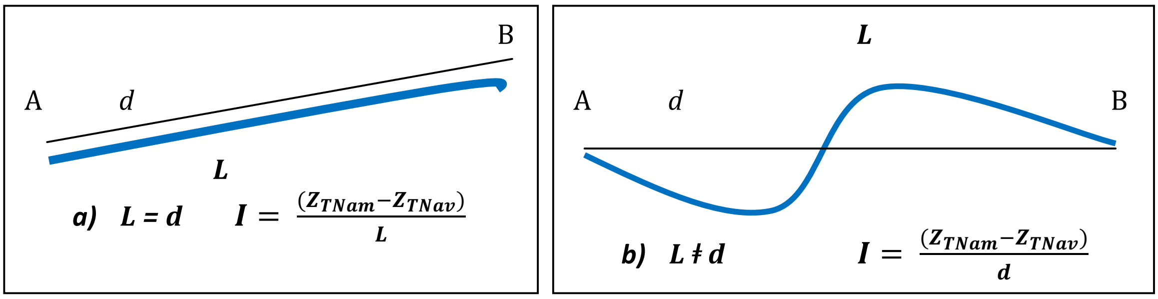


Figure 3: Determination of the slope of a section: (a) Linear section; (b) Sinious section.

By definition, the slope of a section is the ratio of the altitude difference of the ends A and B by the length (L) (Figure 3a). For a river section with ends A and B, the determination of the slope with the length (L) of the considered section is not always verified. Indeed, the hydraulic path followed by the water which is the length (L) of the section of the stream is not always a straight line but often describes a curve with several concavities. As a consequence, the slope could be redefined as the ratio of the altitude difference between the ends A and B of the section considered by the distance (d) (Figure 3b). Thus, therefore, equation (2) becomes equation (3):

$$I = \frac{(Z_{TNam} - Z_{TNav})}{d} \qquad (3)$$

In the case of our study the bed of the river is very sinuous on all the sections chosen. The length (L) of the considered section is different from the distance as the crow flies (d) between the ends of the section, due to many sinuosities of the river. It is therefore equation (3) that allowed us to calculate the slopes of the different sections.Finally, two parameters of propagation of the flow peaks have been defined. These are:

- the duration of translation of the flood point given by the expression:

$$\boldsymbol{\Delta t = (t_{Av} - t_{Am}) * 24 * 3600 (insecond)} \qquad (4)$$

- the celerity or the average speed of propagation of the flood waves established by the following relation:

$$\boldsymbol{c = \frac{L}{\Delta t}} \qquad (5)$$

4. Results and discussion

4.1. Some feature of the N'zi bed

The length of the watercourse on a section, the distance between the stations defining a section, the altitude of the different stations, the sinuosity index and the average slopes of the sections are given in table 1.

Table 1: Characteristics of the bed of theN'Zi on the considered section.

Characteristics / **Sections**	**Spot height of Stations**		**Distance in a straight line sections**	**Length of sections**	**Index of winding sections**	**Slope**
	Z_{TNam} (m)	**Z_{TNav} (m)**	**d (m)**	**L (m)**	**Is**	**I (m/m)**
Fêtèkro - M'bahiakro	186.6	112.4	56 500	88 000	1.56	0.001313
M'bahiakro - Bocanda	112.4	92	47 000	105 500	2.24	0.000434
Bocanda - Dimbokro	92	80	50 000	176 000	3.52	0.000240
Dimbokro - N'zianouan	80	29	71 000	161 500	2.27	0.000718

Overall, the slopes of the sections are gentle. The morphology of the N'zi bed has a meandriform style. Indeed, the N'zi bed has the strongest slope on the Fętekro-M'bahiakro stretch with an average value of 0.001313 m / m, ie 0.13%. This section, which has a lower sinuosity index (Is = 1.56), has a meandriform fluvial style. The Bocanda-Dimbokro section, on the other hand, has the lowest slope value of 0.00024 m / m, ie 0.02%, and the largest sinuosity index (Is) is 3.52. This index gives it a very meandering profile, similar to the sections of M'bahiakro - Bocanda and Dimbokro - N'zianouan whose islands are between 2 and 3.
The longest of the sections is that of Bocanda-Dimbokro with 176 km following the winding bed and the shortest is that of Fetèkro-M'bahiakro with 88 km of bed less winding.

4.2. Rain-flow relationship

The rainfall/flow relationship revealed by the graphs in Figure 4 shows that floods are mainly generated by rainfalls. During the great rainy season which runs from March to mid-July, despite the intensity and frequency of the rains, they do not generate high amplitude floods. During this same period, precipitations of more than 60 mm give only flows with high amplitudes of around 40 m^3/s. This can be seen on all the graphs at Fętekro, M'bahiakro, Dimbokro and N'zianouan stations (Figure 4). However, during the small rainy season which runs from mid-September to mid-November on these graphs, these rainfalls of lower intensity than those of the great rainy season give high amplitude flows. Two exceptional peaks in flows are then observed at this time of the year. Like in 1992, the rainfall/flow relationship of 1991 and 1993 also shows two remarkable peaks in flows.Thus, observing the correlation of peaks in flows at the different hydrometric stations, two important annual floods are retained and will be analysed (Table 2).

Table 2: Floods periods studied.

Years	1991		1992		1993	
Floods	**1st flood**	**2nd flood**	**1st flood**	**2nd flood**	**1st flood**	**2nd flood**
Periods	**From 05 to 18 July**	**From 07 to 18 September**	**From03 to 16 October**	**From 09 to 20 November**	**From 06 to 10 September**	**From10 to 17 October**

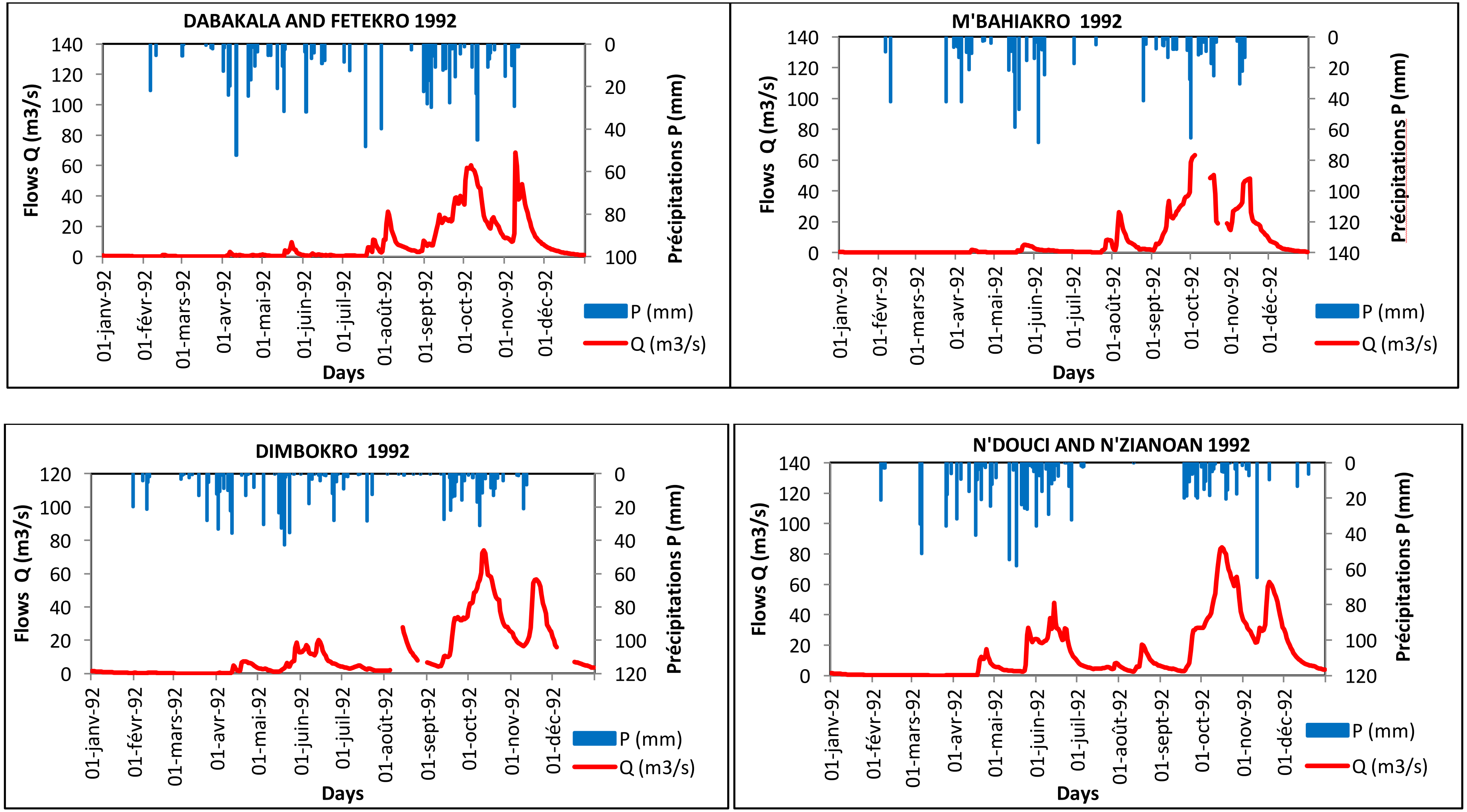


Figure 4: Demonstration of the rainfall-flow relationship in 1992 in Fętekro, M'bahiakro, Dimbokro and N'zianouan.

4-3 Analysis of the studied floods

With the exception of the first annual flood of 1991, which occurred from July 5 to 18, almost all the floods studied were observed during the short rainy season. The first flood is the most important of the two annual floods identified. It is characterized by a high amplitude compared to the second one, according to the data in table 3, at each hydrometric station.

Table 3: Flood amplitude at each hydrometric station

Years	1991		1992		1993	
Floods	**1st flood**	**2nd flood**	**1st flood**	**2nd flood**	**1st flood**	**2nd flood**
Stations	**Amplitudes of floods (in m^3/s)**					
Fêtèkro	**364**	**126**	**61.5**	**68.4**	**162**	**87.3**
M'bahiakro	**259**	**116**	**68**	**48**	**150**	**110**
Bocanda	**208**	**142**	**72.9**	**61.2**	**137**	**110**
Dimbokro	**157**	**139**	**74**	**56.3**	**123**	**106**
N'zianouan	**330**	**143**	**84.4**	**61.4**	**111**	**129**

4.3.1. Analysis of the first annual flood

The first annual flood is propagated entirely either by attenuation illustrated by the gradual regression of the curves of Fętekro to Dimbokro (flood of July 1991) and sometimes up to N'zianouan (flood of September 1993), or by amplification observable by ancestry of the peak flows (October 1992 flood). It should be noted, however, that the flows are exceptionally high at the N'zianouan station (Figure 5).

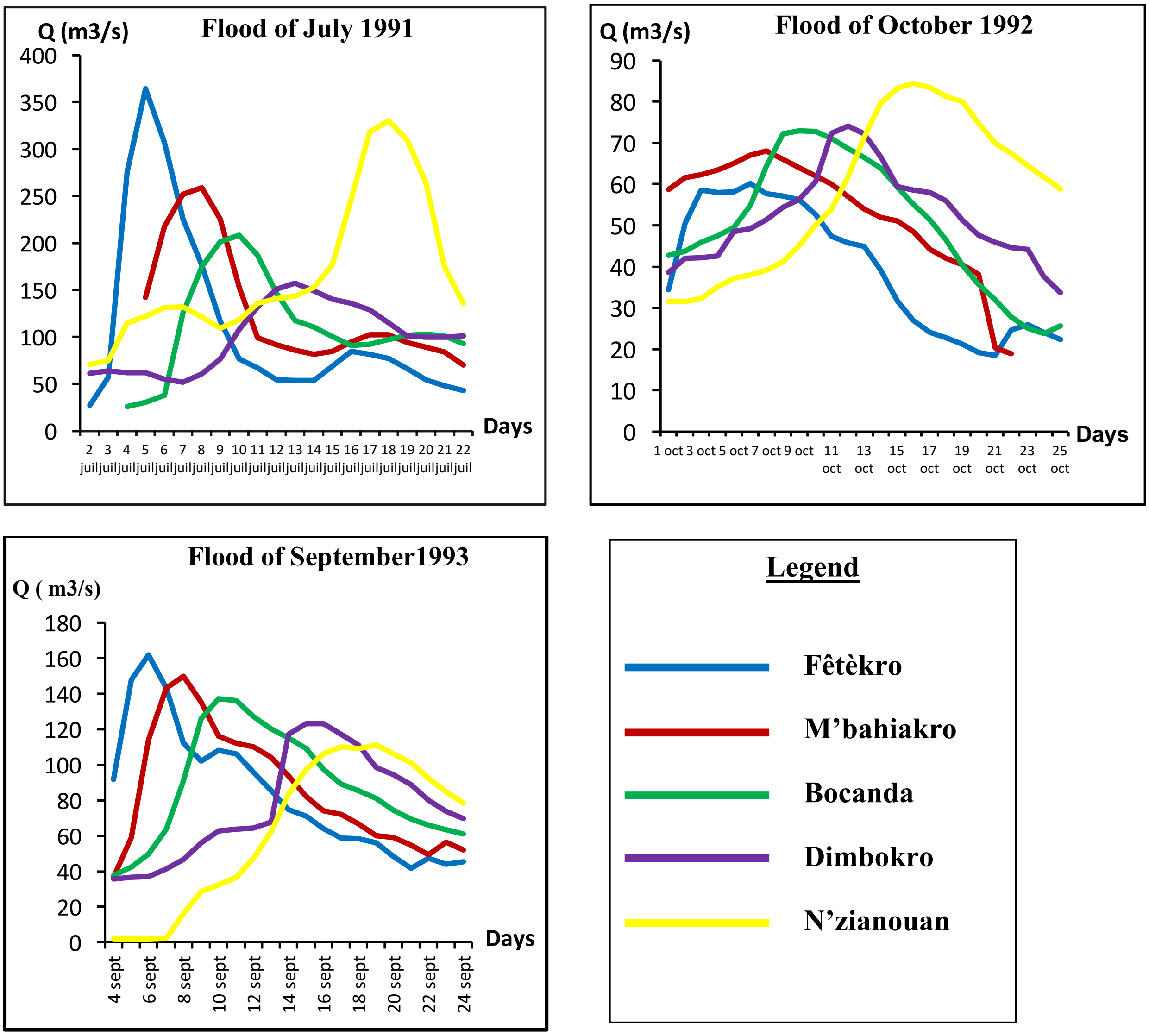


Figure 5: First annual N'zi flood observed from 1991 to 1993

4.3.2. Analysis of the second annual flood

The second annual flood of N'zi is propagated by an alternation of the two mechanisms of propagation (attenuation-amplification), which is manifested by a jerky appearance of the curves (Figure 6). In 1991 and 1992, the flood observed at Fętekro fades as it arrives at M'bahiakro and from there it grows to Bocanda. At the start of Boncanda, it continues to Dimbokro to amplify again in N'zianouan. In October 1993 the flood begins with an amplification of Fętekro in M'bahiakro followed by attenuation on the following section and so on until N'zianouan where a flood still attenuated but still dominant.

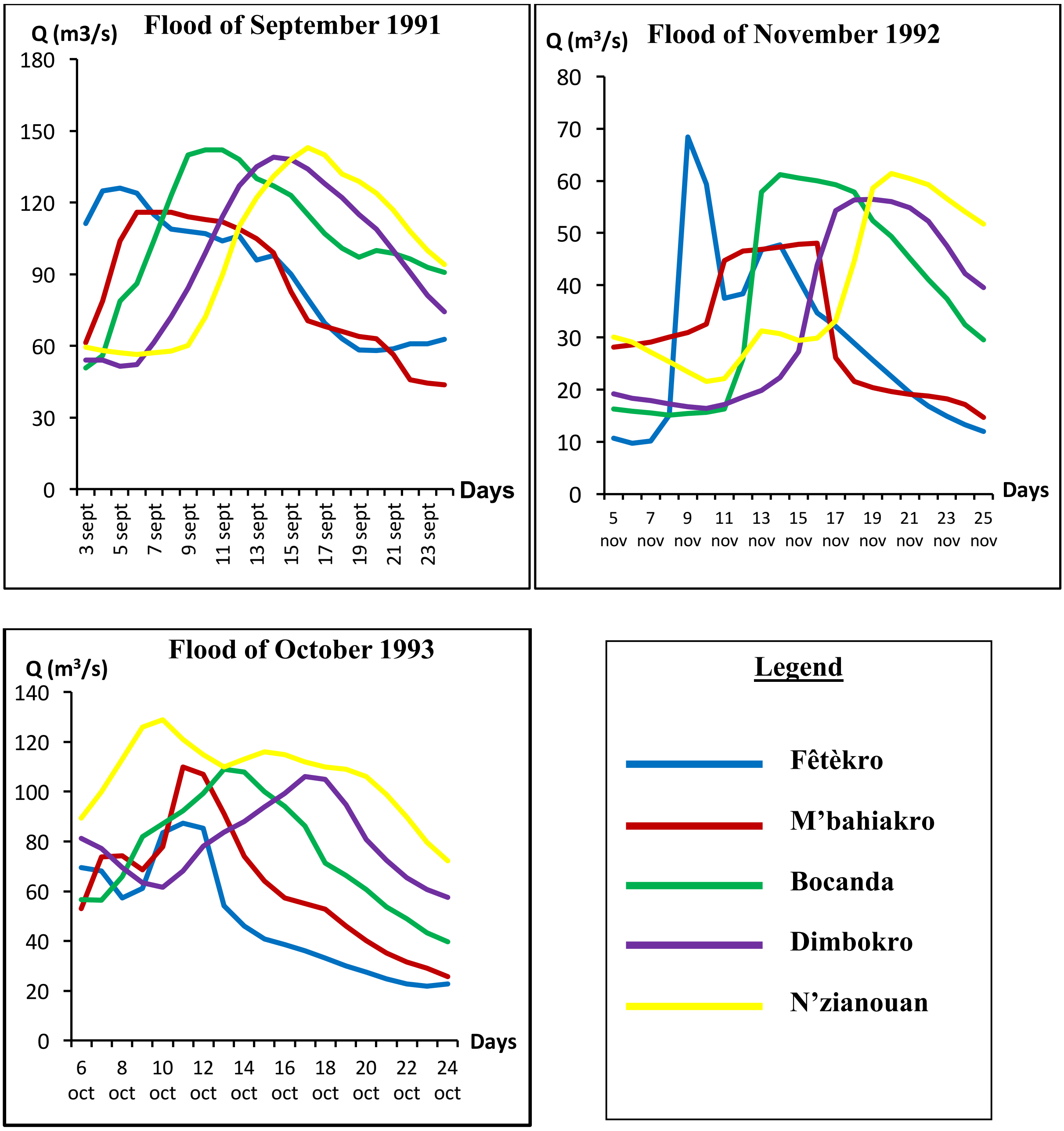


Figure 6: Second annual N'zi flood observed from 1991 to 1993

4.4.Duration and speed of the flood waves of the N'zi

4.4.1.Duration and speed of attenuated flood waves

The propagation time of the flood peaks and the speed of the waves vary from one section to another. These two parameters are related and depend on the hydraulic characteristics of the bed but also on the intensity of the generated floods. Table 4 gives information on the duration of translation of the peaks and on the average speed of translation of the flood waves that attenuate along the sections considered on the N'zi.

The floods which propagate with attenuation take 1 to 3 days to traverse the 88 km long Fętekro-M'bahiakro section with a speed of about 2 km/h, ie 0.55 m/s. Between M'bahiakro and Bocanda, the attenuated floods have a short and constant duration of translation which is 2 days. By implication the resulting celerity is also constant and slightly higher compared to the others (2.2 km/h or 0.61 m/s), despite the fact that these floods are generated at different dates and by rainfalls of different intensities. Flood waves propagate faster on this section than those between Fętekro-M'bahiakro (Table 4).

Table 4: Duration and speed of attenuated flood waves

SECTIONS OF N'ZI	**Dates of the attenuated floods**	**Delay of propagation**		**Celerity**		**Averagecelerity per section**
		in day	in hour (jr x 24)	in km/h	in m/s (km/h/3,6)	
Fêtèkro - M'bahiakro (88 km)	5-8 juil. 1991	3	**72**	1.222	**0,340**	**1.986 km/h or 0.552 m/s**
	5-6 sept. 1991	1	**24**	3.667	**1,019**	
	9-11 nov. 1992	3	**72**	1.222	**0.340**	
	6-8 sept. 1993	2	**48**	1.833	**0.509**	
M'bahiakro - Bocanda (105.5 km)	8-10 juil. 1991	2	**48**	2.198	**0.611**	**2.198 km/h or 0.611 m/s**
	8-10 sept 1993	2	**48**	2.198	**0.611**	
	11-13 oct. 1993	2	**48**	2.198	**0.611**	
Bocanda - Dimbokro (176 km)	10-13 juil. 1991	3	**72**	2.444	**0.679**	**1.882 km/h or 0.523 m/s**
	10-14 sept. 1991	4	**96**	1.833	**0.509**	
	14-18 nov. 1992	4	**96**	1.833	**0.509**	
	10-15 sept 1993	5	**120**	1.467	**0.407**	
	13-17 oct. 1993	4	**96**	1.833	**0.509**	
Dimbokro - N'zianouan (161.5 km)	14-17 sept 1993	3	**72**	2.243	**0.623**	**2.243 km/h or 0.623 m/s**

The translation of the flood waves takes place slowly overall with a general mean attenuation velocity around 0.6 m/s. The floods then spend more time on the sections before becoming less severe: 2 to 3 days for the majority of the sections and 3 to 5 days for the longest Bocanda-Dimbokro stretch.

4.4.2. Duration and speed of amplified flood waves

As for the amplified floods, the speed of the waves and the duration of translation of the flow tip also vary from one section to another (Table 5). In spite of this variation, the mean time of amplification of the floods on all the sections is 3 days. However, the average speed of amplification remains very low, less than 1 m/s for most amplified floods (M'bahiakro-Bocanda, Bocanda-Dimbokro and Dimbokro-N'zianouan sections).

Figure 7 shows the sector diagrams of the mechanisms of propagation of the flood waves (attenuation and amplification) on the various sections. Indeed, along the Fętekro-M'bahiakro section, 67% of the floods propagate with mitigation and 33% are amplified. Unlike the previous section, the M'bahiakro-Bocanda section is distinguished by attenuated floods rather than amplified floods: 50% mitigation versus 50% amplification. The 176 km Bocanda-Dimbokro section has 83% flood mitigation, while on the Dimbokro-N'zianouan section the majority of floods are amplified by 83%.

4.5. Discussion

After the long dry period from mid-November to mid-March, the desaturated ferralitic soils covering the N'zi watershed [10]are prepared for heavy infiltration of rainwater for the recharge of groundwater during the great rainy season from mid-March to mid-July. This could further explain the lack of high amplitude floods during this rainy season. In addition to this hypothesis, we should consider the large water requirements of the neighbouring populations, who store large volumes of water in the retention basins for irrigation and pastoral purposes in the dry season [11]. In fact, Bandama in general and N'zi in particular, have many agropastoral dams in their northern part which is the most unfavourable zone on the hydroclimatic level. These dams thus affect the normal hydrological behaviour of the watershed [10].

Table 5: Time and celerity of amplified floodwaves

Sections of N'zi	Dates of amplifiedfloods	Delay of propagation		Celerity		Averagecelerity per section
		in day	in hour (jr x 24)	in km/h	in m/s (km/h/3.6)	
Fêtèkro - M'bahiakro (88 km)	10-11 oct. 1993	1	**24**	3.667	**1.019**	**3.667 km/h or 1.02 m/s**
	6-7 oct. 1992	1	**24**	3.667	**1.019**	
M'bahiakro - Bocanda (105.5 km)	6-10 sept 1991	4	**96**	1.099	**0.305**	**1.832 km/h or 0.51 m/s**
	7-9 oct. 1992	2	**48**	2.198	**0.611**	
	12-14 nov. 1992	2	**48**	2.198	**0.611**	
Bocanda - Dimbokro (176 km)	9-12 oct. 1992	3	**72**	2.444	**0.679**	**2.444 km/h or 0.68 m/s**
Dimbokro - N'zianouan (161.5 km)	13-18 juil. 1991	5	**120**	1.346	**0.374**	**2.624 km/h or 0.73 m/s**
	14-16 sept. 1991	2	**48**	3.365	**0.935**	
	12-16 oct. 1992	4	**96**	1.682	**0.467**	
	18-20 nov. 1992	2	**48**	3.365	**0.935**	
	17-19 oct. 1993	2	**48**	3.365	**0.935**	

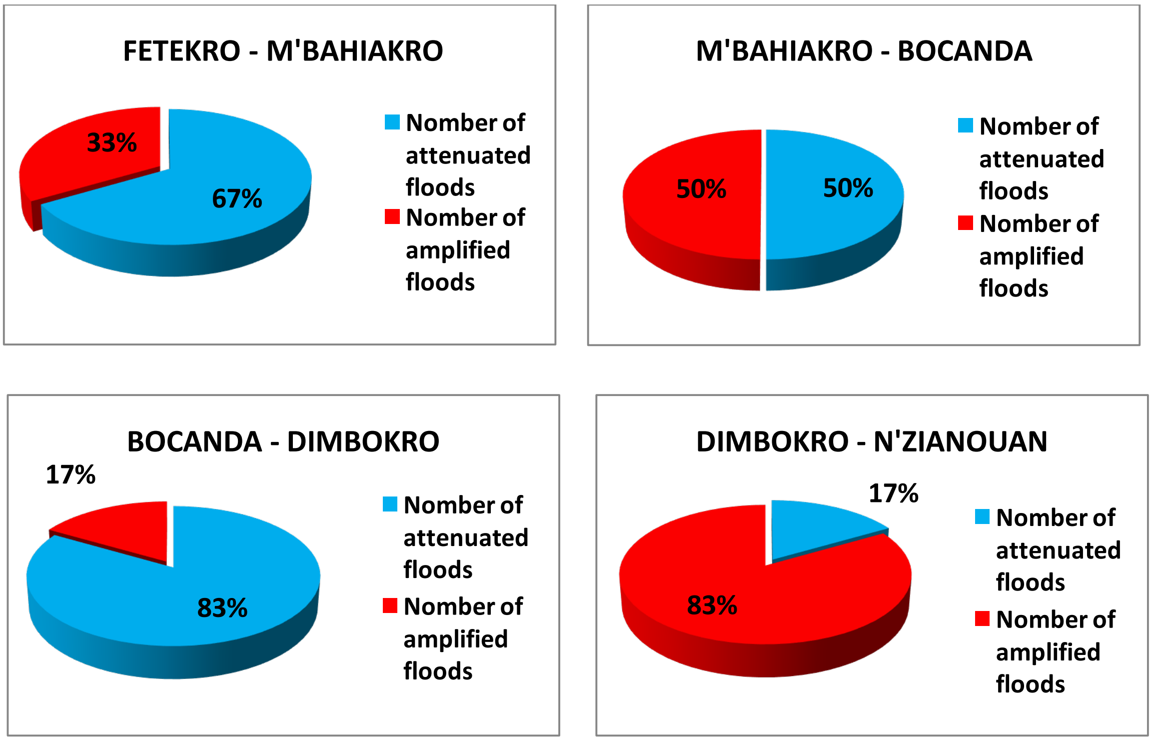


Figure 7: Percentage of mitigation and amplification of N'zi floods

The transition between the rainy season and the short rainy season is relatively short-lived (1 and a half months to 2 months) and the atmosphere remains humid at this time. As a result, during the short rainy season from September to November, soils are always inundated with with water, retention ponds and all natural depressions are filled. There is therefore an increase in the coefficient of runoff which results in floods of high amplitude (flow around 80 m^3/s).
The flows of the N'zi flood would thus depend on the initial water status of the soils and the climate regime. According to [12], initial conditions of low soil humidity result in lower flood amplitude than that generated under high humidity conditions. It is possible to observe, in this small rainy season, floods of high amplitude generated by rains of low intensity but of long duration of abatement. To this end, a few rare rain events, more upstream of the N'zi watershed, could generate exceptional floods downstream and even amplify the floods identified at the Fętekro station. These events seem to be frequent on the N'zi and often surprise populations with the extraordinary rise of water in the bed.

Generally the first annual flood is not subjected to major disturbances and spreads homogeneously from Fętekro to Dimbokro. However, when the watershed receives intense rain or a succession of rains upstread, the generated flood propagates with mitigation from Fętekro to Dimbokro. The fact that 80% of the Dimbokro-N'zianouan section is located in the well-watered equatorial transition climate (Attiéan climate) favours the frequent flood disturbances with amplified waves characterized by high amplitude and exceptional peaks in flows. But when homogeneous rains fall over the entire N'zi watershed or when a series of local rains fall from upstream to downstream the watershed, the flood generated is disturbed during its journey and therefore it propagates by amplification from Fętekro to N'zianouan.
As for the second annual flood of the N'zi, it propagates by an alternation of the two mechanisms of translation: mitigation-amplification. This phenomenon could be justified by the spatial heterogeneity and the very high intensity of precipitations. Indeed, the rains of the small rainy season are often localized but very intense and last in time. Our results are in line with those of [13] who consider that the intensity, duration and spatial extension of rains are decisive factors for the flood flow.
The speed of the flood wave along the N'zi main stream, and somehow on its tributaries, is highly variable. For the same section, this speed varies from one flood to another depending on the intensity and frequency of precipitations. It also varies according to hydrometeorological conditions and sometimes to the action of local residents who may or may not derive more or less considerable quantities of water [14].
However, the weakness of the average slope of the flow, the hydraulic radius, the sinuosities of the bed, the roughness of the banks and the bottom, then the enlargement of the bed in some places considerably contribute to the reduction of the velocity of the flood waves. The sinuosities and curves of the N'zi bed lengthen the flow path on sections of short distance as the crow flies. In addition, according to [15]thesinuosities increase the friction forces so specific load losses play an important role in the attenuation and the reduction of the speed of the floods. This results in the flooding of large areas because the water load, which cannot be evacuated quickly in the minor bed, occupies the major bed. Under these conditions there is certainly attenuation of the flood waves but the recession takes place slowly over several days. The impact of this situation is the flooding of cultivated and cultivable areas, the inability of people to freely conduct their agricultural business and the delay of certain activities to be carried out in the vicinity of the bed.
The bed of N'zi, of meandriform morphology, is rough and cluttered with an irregular shape and a gentle slope on the M'bahiakro-Bocanda section. The depth of the minor bed gradually increases on this section. Particularly in Bocanda the bed of the N'zi seems deeper than on the other sections (6.27 m) and is in the form of a basin. For this purpose, there would be a strong water current on the M'bahiakro-Bocanda section due to the depth of the bed at Bocanda. Water flows are rapid on this section, resulting in a relatively high value of the speed of peak flows (0.61 m/s). One could even observe a slight reduction of the duration values of the flood waves translation and as a matter of fact an increase of the average celerity of the floods if the time scale was hourly. The daily time-scale would prove very inefficient in delivering all information relating to flash floods.
Thus, it is observed that on the Bocanda-Dimbokrosction, the progression of the flood waves takes a little more longer than on the other sections. This would probably be due to the length of the section because it is the longest of the sections. But this slowdown could also be linked to low slope value and sharp rise of water caused by the slightly greater depth of the bed at Bocanda which would result in the waters stagnation. The high flood mitigation rate (83%) on this section could be justified by the simultaneous occurrence of other factors such as the significant specific load losses associated with the numerous sinuosities, the crossing works, the existence of major fractures in the substratum under the river [16], the enlargement of the bed on some section, as [15] noticed, the larger the bed, the stronger the mitigation. As a whole, the celerity of flood waves on the N'zi River is low and floods evolve according to a daily time-scale [6]. The existence of important structures and water withdrawals for domestic use in the N'zi-crossed towns also considerably contribute to the limitation of flood flows and their mitigation [17].
The regular mitigation of floods at Fętekro (Dimbokro) may possibly provide a minimum of security around the bed of N'zi during the rainy seasons. But, considering the random and unpredictable nature of flood occurrence, this is not a total security guaranty.
However, the Dimbokro-N'zianouan section witnesses a high rate of flood amplification (83%). This could be due to the prevalence of the Attiéan climate, but also to the lack of important agropastoralinsfrastructures, contrary to the upstream N'zi watershed [10].
The high rate of flood amplification on this section reflects a real insecurity for which preventive measures will have to be taken during the rainy seasons. This would include, for example, the delimitation of a protective area around the bed, frequent alerts to the population and, especially after rains, and sensitization.

Conclusion

Two exceptional floods are generated each year on the N'zi River, usually during the short rainy season, between September and November. These floods are strongly mitigated from Fetèkro to Dimbokro, particularly around Bocanda: 50% of flood is mitigated on the M'bahiakro-Bocanda section and 83% between Bocanda and Dimbokro. They are however very disturbed between Dimbokro and N'zianouan with 83% amplification. The physical parameters of the sections greatly contribute to the slowdown of the flood waves along the N'zi River, with an average speed of 0.6 m/s. The floods thus take long to cross the different sections over the N'zi basin and spread, which is due to the duration of flood waves mitigation (2 to 4 days). This increases the risk of flooding of cultivation areas during the short rainy season. This study is therefore part of the prevention of these risks of flooding and can participate in the decision-making in the policy of sustainable management of the N'zi watershed.

References

1. Ouranos, Élaborer un plan d'adaptation aux changements climatiques. *Guide destiné au milieu municipal québécois Montréal (Québec),* (2010) 48.
2. P. Javelle, Caractérisation du régime des crues : le modèle débit-durée-fréquence convergent. Approche locale et régionale. *Thèse de doctorat, Institut National Polytechnique de Grenoble, France*, (2001) 238.
3. T. Ouarda, C. Girard, G. Cavadias and B. Bobee, Regional flood frequency estimation with canonical correlation analysis. *J. Hydrol.* (2001)157-173.
4. V.Kendrovski, F.Matthies, G.Cerkez, M. Dragosavac, D. Dimitrijevic, M.Rancic, E. Paunovic, O. Schmoll, and B.Menne, ManagingHealthRisksduring the Balkans Floods. *American Journal of Climate Change,* 6 (2017) 597-606.
5. M. Lang, C. Perret, E. Renouf and E. Sauquet, Incertitude sur les débits de crue. *Houille Blanche,* 6 : (2006) 33-41.
6. V. B. Estupina, Vers une modélisation hydrologique adaptée à la prévision opérationnelle des crues éclair. Application à de petits bassins versants du sud de la France. *Thèse de doctorat, Institut National Polytechnique de Toulouse,* (2004) 254.
7. B.T.A. Goula, I. Savane, B. Konan, V. Fadika, G. B. Kouadio, Impact de la variabilité climatique sur les ressources hydriques des bassins de N'zo et N'zi en Côte d'Ivoire (Afrique tropicale humide). *Vertigo- la revue électronique en sciences de l'environnement, n°1,* (2006) 1-12.
8. A. M. Kouassi, Caractérisation d'une modification éventuelle de la relation pluie-débit et ses impacts sur les ressources en eau en Afrique de l'Ouest : cas du bassin versant du N'zi (Bandama) en Côte d'Ivoire. *Thèse de doctorat, Université de Cocody Abidjan (Côte d'Ivoire),* (2007) 234.
9. J. R. Malavoi and J. P. Bravard, Eléments d'hydromorphologie fluviale. *ONEMA, Collection : Comprendre pour agir,* (2010) 228.
10. A.M. Kouassi, K.F. Kouamé, M.B. Saley, and J. Biemi, Application du modèle de Maillet à l'étude des impacts des changements climatiques sur les ressources en eau en Afrique de l'ouest : cas du bassin versant du N'zi-Bandama (Côte d'Ivoire). *J. Asian Sci. Res.* 3(2) : (2013) 214-228.
11. C. Lévêque, C. Dejoux and A. Iltis, Limnologie du fleuve Bandama, Côte d'Ivoire. O.R.S.T.O.M., Hydrobiologie, 24 rue Bayard, 75008 Paris, France. *Dr W. Junk Publishers, The Hague. Printed in The Netherlands. Hydrobiologia 100,* (1983) 113-141.
12. A. Lequien, Analyse et évaluation des crues extrêmes par modélisation hydrologique spatialisée : cas du bassin versant du Vidourle. *DEA Sciences de l'Eau dans l'Environnement Continental, Université Montpellier II (France),* (2003) 67.
13. C. Cosandey and M. Robinson, Hydrologie continentale.*Revue Géographique de l'Est ;* Armand Colin, Paris, (2000) vol. 42 / 4 | 368.
14. M. E. Saïdi, Genèse et propagation des crues en milieu sub-aride : exemple de l'Oued Souss (Maroc). *Bull. Assoc. Géogr.* Paris, (1994) 94-110.
15. Goutx, Hydraulique des cours d'eau : la théorie et sa mise en pratique.*Centre d'Etudes Techniques Maritimes et Fluviales, Groupe d'Hydraulique Fluviale (Cetmef),* (2001) 62.
16. Anonyme, Annuaire hydrologique de Côte d'Ivoire.*Ministère des travaux publics et des transports, direction centrale de l'hydraulique,* (1979) 234.
17. S. Bahiré, Monographie sur le N'zi.*Direction de l'Hydraulique Humaine,* (1986)184.

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