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Title of Paper: Trends in West African floods: A comparative analysis with rainfall and vegetation indices.

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The several comments made are gratefully acknowledged and the interactive discussion process was particularily interesting (see Table 1R for a synthesis of the discussion process).

Table 1R: Summary of interactive comments on the paper.

Review or comments received	Authors	Short description – key points	Response sent by the authors
RC C2829 on 24 Jul 2015	Anonymous Referee	Referee comments	AC C3009, 06 Aug 2015. (In English)
SC C3383, 28 Aug 2015	Daniel Sighomnou	Short Comment in French. Issues concerning the representativity of the dataset and homogeneity of the record periods	
SC C3501, 09 Sep 2015	Ansoumana BODIAN	Short comment in French. Issues concerning mainly some of the flow data used that present numbers of missing values and/or non validated values	SC C3509, 09 Sep 2015. (In French)
SC C3503, 09 Sep 2015	Daniel Sighomnou	Short comment in English. The author stressed the importance to clarify the origin and quality of flow data used	SC C3527, 09 Sep 2015. (In English)
SC C3534, 09 Sep 2015	Ansoumana BODIAN	Short comment in French. The authors suggest to remove the catchments presenting numerous missing values and/or the catchments for which data are suspected to present large uncertainties	
RC C3816, 23 Sep 2015	Anonymous Referee	Referee comments	

We will modify the manuscript in response to the main criticism. The main changes that we plan to make are listed hereafter:

- The title will be modified to better reflect the content of the manuscript,
- More details on the data used will be given and the three catchments presenting either too much missing values or low quality control were removed. Note that this does not modify deeply the main results and conclusion of the paper.

By complying with the suggestions made during the interactive discussion process, we believe that the manuscript has been clarified and improved.

Interactive comment on "Trends in West African floods: a comparative analysis with rainfall and vegetation indices" by B. N. Nka et al.

Since 28 August 2015, our submitted paper "**Trends in West African floods: a comparative analysis with rainfall and vegetation indices"** have registered two reviews from the nominated referees (RC C2829 and RC C3816) and four short comments (SC C3383, SC C3501, SC C3503 and SC C3534) made by Daniel SIGHOMNOU and Ansoumana BODIAN. A response to the review from the first referee was posted during the interactive discussion process (AC C3009). The short comments posted mainly questionned the status of the data used, given that flow time series in the region present generally large amount of missing values particularly for the data from Senegal and Gambia. Some responses to these short comments were posted during the interactive discussion process (SC C3509 and SC C3527) but since some responses were in French (for the comments sent in French), we decided to clarify the data issue in this finale response. Finally, a supplement referree sent a detailed review about all aspects of the paper and address also the data quality issue.

In this letter, we provide a response to the comments and reviews that were not sent during the interactive discussion process. We will first answer the first comment of Daniel Sighomnou (SC C3383). After that, we will respond to the short comment made by Ansoumana Bodian (SC C3534). This response is more general and intends to address also the previous discussion brought by Ansoumana Bodian and Daniel Sighomnou on flow data origins and quality. Finally, we will present our responses to the review of the anonymous supplement referee (RC C3816).

All the responses are in English while some previous short comments were in French. We hope that this mix of the two languages will not confuse the readers and we suggest to HESS that the short comments in French sent by Daniel Sighomnou and Asoumana Bodian be translated to ensure a broader audience.

I. RESPONSE TO THE SHORT COMMENTS BY DANIEL SIGHOMNOU (SC C3383).

Comments of the reviewer

D. SIGHOMNOU
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La lecture de l'article appelle de notre part les commentaires suivants :

1) Alors que le titre de l'article laisse sous-entendre l'analyse de la tendance des crues en Afrique de l'Ouest, dans son ensemble, les bassins versants étudiés couvrent une zone relativement limitée de cette région. En particulier la zone d'étude de la région Sahélienne concerne trois bassins versants voisins d'un même pays, le Burkina Faso. D'autre part, la longueur des chroniques de données étudiées n'est pas homogène et le nombre de bassins disposant de longues chroniques de données couvrant à la fois la période humide d'avant 1970 et celle sèche d'après 1970 est limité à deux. Les conclusions de l'étude mériteraient par conséquent d'être confirmées par de nouvelles études sur d'autres bassins de la région, comme cela est d'ailleurs souligné dans le papier. Il serait par conséquent plus prudent, pour ce qui concerne le titre de l'étude, de parler d'une contribution à l'analyse de la tendance des crues en Afrique de l'Ouest.

2) Bien que toutes les références bibliographiques citées soient pertinentes au regard du sujet traité, on ne citera jamais toutes les études réalisées dans la région sur ce sujet. On peut par conséquent se contenter de la présentation des publications majeures dans les références bibliographiques afin d'en limiter le nombre. Cette remarque n'est cependant pas rédhibitoire si le très grand nombre des références citées ne pose pas de problème pour l'édition.

Conclusion et suggestions

Bien rédigé et très bien menée, du point de vue de la rigueur et de la cohérence scientifique, l'étude est d'un intérêt certain pour le développement. Elle répond aux préoccupations des acteurs de développement et représente une contribution au progrès scientifique, notamment pour ce qui concerne les développements récents de l'hydrologie de la région d'étude et mériterait d'être acceptée pour publication. La prise en compte des observations présentées ci-dessus ajouterait cependant un plus à la consistance de l'information/leçon qu'on en tire.

Response to the short comments (SC C3383) by Daniel Sighomnou

Thank you for these comments. The comments of the reviewer Daniel Sighomnou pointed out that

1) The title of the paper is misleading since the sample of data used in this study is not large enough to be representative of the hydrological behavior of the entire West African region, and the distribution of the studied catchments in the different climatic zones of the region is not homogeneous. According to this, he suggests that the title of the paper should better reflect a contribution, rather than an exhaustive regional analysis. We fully agree with this comment. We believe that the new title proposed for the revised manuscript « ***Trends of floods in West Africa: Analysis based on 11 catchments of the region*** » better reflects the content of the paper.
2) In the second comment, the reviewer highlights the fact that there is a large number of references used for the paper but conclude that this is not prohibitive to the publication of the paper if the large number of bibliographic references of the paper is not an issue for the editor. We decided to keep all the previously cited references and let the editorial board decide wether this section needs to be shortened.

II. RESPONSE TO THE COMMENTS SC3501, SC3503 AND SC C3534 BY ANSOUMANA BODIAN AND DANIEL SIGHOMNOU.

Comments of the reviewers

A. BODIAN (SC C3501)

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La méthodologie de l'étude consiste à constituer un échantillon de valeur maximum et supérieur à un seuil sur la base des chroniques journalières. Dans ce cas les lacunes dans les chroniques journalières peuvent biaisées les résultats. Donc, il serait bon que les auteurs donnent plus d'éclaircissements sur la nature et l'origine des données, car je connais bien les stations et je sais qu'il y a beaucoup plus de lacunes que celles mentionnés dans le tableau 1. En effet, à ma connaissance, les données observées ne sont pas aussi complètes à l'échelle journalière sur la période 1970-2000. Dans mes travaux de thèse j'ai utilisées les données de la station de Sokotoro et de Bébélé mais c'est des données très lacunaires particulièrement pour la station de Bébélé. Les données du bassin du fleuve Gambie sont aussi lacunaires particulièrement pour lastation de Niokolokoba qui ne présente que 4 années hydrologiques complètes sur la période 1970-2000. Même la station de Kédougou qui semble être la mieux suivie et qui est la station principale du fleuve Gambie présente sur la période 1970-2000 au moins quatre années hydrologiques incomplètes. Donc, est-ce des données reconstituées où réellement observées?

D. SIGHOMNOU (SC C3503)

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The authors state in the paper that all the data used in the study have been subject to quality control before being included in the study. On this basis, the comments we made in our analysis and conclusions arising consider that there is no doubt on this point. Mr. BODIAN who used data from some stations of the study in his own work says that the series are very lacunar at the same stations, which is very common in this region.

If there is a single doubt about the quality of data used in the study, all findings are subject to questioning. The question therefore needs to be clarified by the authors.

A. BODIAN (SC C3534)

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Je comprends la difficultés d'avoir des chroniques de données complètes. Mais au cas où les données ont été reconstituées, il serait préférable de présenter d'abord les données de base avec les pourcentages de lacunes pour chaque station. Ensuite, il serait intéressant de présenter la méthodologie utilisée pour reconstituer les valeurs manquantes. Je pense aussi qu'au delà d'un certain pourcentage de lacune, il serait préférable de ne pas retenir la station pour l'étude. Je pense notamment aux stations de Bébélé (fleuve Sénégal) et Niokolokoba (Gambie) qui ont des pourcentage de lacunes trop élevés. Je suis conscient que ça fait quelques bassins de moins dans ton échantillon de bassins mais aussi dans le contexte d'une étude qui se veut régionale, mais cela permet d'éviter d'avoir des résultats biaisés en appliquant vos tests de rupture et de tendance

Response to the comments

Ansoumana BODIAN pointed out the fact that original data used in this study present numerous missing values. In addition Daniel Sighomnou pointed out the need to provide more details on the database used for this study. In his comment, Ansoumana BODIAN refers specifically to the times series of the Senegal and Gambia rivers tributaries. Thus, our response focus on these specific catchments.

In reply to these questions, we stated in the paper the difficulty to find good quality-controled data in the region . The time series used in the study were collected from research institutions of the region, specifically the IRD-Dakar (team of “Institut de Recherche pour le Développement” settled in Dakar) and the OMVS (Organisation pour la Mise en Valeur du fleuve Sénégal).

The flow time series of Fadougou, Sokoroto and Bebele were obtained from the Hydraccess database which is managed by OMVS. These data have been verified and homogenized by the OMVS and a IRD team for their use in the ‘Actualisation de la monographie hydrologique du fleuve Sénégal’ project (Bader and Cauchy, 2013).

Time series of Kedougou, Missira, Diaguiri and Niokolokoba were collected from the database of IRD-Dakar team. These data have been collected and processed prior to the realization of the project ‘Etude du schéma hydraulique du fleuve Gambie‘, in 1998 by Sogreah, Hydroconsult International and SCET Tunisie (SOGREAH Ingenieri et al., 1998). The data have then been criticized and homogenized for the period 1971 - 1998. These time series were updated until 2002 by IRD-Dakar.

The process of quality controls and homogenization of the time series presented below includes the reconstitution of the observed and existing data in the study period, and filling gaps for some parts of the time series where data do not exist. Data used for reconstruction of time series were collected differently, the first type of data are water level measured directly on gauging stations of the catchments, and the second type is derived from automatic water level recorders. In the other hand, the gaps were fulfilled using mathematic models (propagation model, regression model etc..). According to the information that we have from the data manager on the catchment time series, the large part of the time series consists of reconstruction made on the time series (using observed water level data), consequently these data can be consider as observed data. Only the few missing values from these measurements were filled by modelling.

We believe that in some data base of the region, the time series used here are not routinely updated, and this can lead to differences between the database versions. At our sense, the time series used in this study have been seriously critisized, and constructed rigorously; some of the methodolgy used are well explain in the two reports mentioned above. However, as we stated in the paper, some uncertainties are inherent to the use of the data of West African region, since these data are always imperfect. In this respect, we agree with the fact that some caution need to be taken in when interprating the results.

III. RESPONSE TO THE COMMENTS OF REVIEW 4 BY THE SUPPLEMENT REFEREE 2

1. Does the paper address relevant scientific questions within the scope of HESS?

This paper fully addresses one of the mean hydrological questions of the African Sahel, the hydrological Sahelian paradox and its spatial and temporal extension and significance. It addresses an important scientific issue to be clarified in the CC context and the deep environmental and Human changes observed in Sub Saharan countries: the respective role of natural and anthropic actions in the water cycle evolution.

2. Does the paper present novel concepts, ideas, tools, or data?

The paper does not present special novelties; however it attempts to answer a scientific dilemma by robust and recognized methods and using partly original data sets; ideas and tools are original in his context, although some works of Mahé et al (Mahé et al., 2011 and Mahé et al., 2013; no cited) investigated previously the spatial extension of hydrological behaviours through West Africa.

- Mahé, G., Lienou, G., Bamba, F., Paturel, J-E., Adeaga, O., Descroix, **L.,** Mariko, A., Olivry, J-C., Sangaré, S., Ogilvie, A., Clanet, J-C., 2011. Le fleuve Niger et le changement climatique au cours des 100 dernières années. *Hydro-climatology variability and change (Proceedings of symposium held during IUGG 2011, Melbourne, Australia);* IAHS pub. n° 344, 131-137.

- Mahé, G., Lienou, G., Descroix, L**.**, Bamba, F., Paturel, J.E., Laraque, A., Meddi, M., Moukolo, N., Hbaieb, H., Adeaga, O., Dieulin, C., Kotti, F., Khomsi, K., 2013. The rivers of Africa: witness of climate change and human impact on the environnement. *Hydrological Processes* 27, 2105–2114, DOI. 10.1002/hyp.9813).

The main problem of this paper lies in the quality of the data set; or more precisely the status of part of the data set; as it was highlighted by my colleagues Daniel Sighomnou (WMO) and Ansoumana Bodian (St Louis University, Senegal) during the discussion process, it is necessary to describe more precisely the status, quality and lacks in the data set. Particularly, you have to remove the sentence (page 5087) "all these data have been subject to quality control before being included in the study" and provide a table giving the number of lacks in the series, making a special status to the stations with a lot of lacks which were fulfilled by reconstituted data; this also can be the opportunity to test your proposed methodology as a reanalysis of a data set, with, and then without the reconstituted data (specially for the NiokoloKoba and the Bebele stations). There are few documented basins, thus it is important to try to use all the available data sets; however it is worth to verify its significance and accuracy.

Response to the comment 2

Thank you for this insightful comment. In adition, the comment made in the summary of the review advising in quote:

« Adding a table indicating the real status of new provided data, some of them being processed in order to fulfilled missing data; you must check that the statistical results and scientific assumptions are not influenced by the fact that some data were re constituted (ex removing the 3 more concerned stations: Niokolo Koba, Diaguiri and Bebele); it should be interesting to compare the regional treatment with and without considering these three stations; in this ways, your last section (4-2) where you only use the basins of Burkina Faso is a good way to avoid some problems resulting of the data quality »

Gives precisely suggestion about the recommendations of the reviewer.

It should be noted that the number of missing years presented in Table 1 of the last version of the paper represent in fact the number of years where we were not able to determine a maximum annual discharge value. Since the annual maximum value occurs systematically during the rainy season, annual time series might present less numerous missing values if the data exist for the rainy season and vice-versa. However, we fully agree with the comments made by the reviewer on the need to clarify both the quality of the data and the possible missing maximum discharge that have been filled by the data providers.

On the basis of the comments made by the reviewer and the short comments posted by A. Bodian and D. Sighomnou (**SC C3383, 28 Aug 2015, and SC C3534, 09 Sep 2015)** and after discussions with the data providers, we propose in the new version of the paper to

- Remove the three concerned time series Niokolokoba, Diaguiri, and Bebele from the analysis. This decision is supported by the fact that the calibration of rating curves on these catchments was particularly unstable.

- Keep the sentence “all these data have been subject to quality control before being included in the study” of page 5087, since the less reliable time series will be removed.
- In the Table 1 of the paper, specifically in the column “Missing years”, we will specify the number of maximum discharge that have been filled (recomputed by either modified rating curves or hydraulic modeling) for each of the remaining time series Fadougou, Kedougou, Missira and Sokoroto. And this will also be specified in the legend of the Table.

We present here some reanalysis that have been made with the set of time series remaining, when the three cathcments (Niokolokoba, Diaguiri and Bebele) are removed. Table 2R is the corrected version of the Table 1 (page 5016 of the latest version of the paper) that we will replace in the paper, in this table, filled maximum discharge of catchments Fadougou, Kedougou, Missira and Sokoroto are presented on column seven. We can observe that except the time series of Fadougou and Sokoroto, the maximum discharges of the two remaining times series are observed (i.e. obtain from water level measurement and associated quality-controled rating curves).

Tableau 2R: General information on the 11 catchments, the flow and rainfall data sets used for the study. Annual rainfall is computed over the 1960–1999 period. Value of missing years recorded for the catchments Fadougou, Sokoroto, Missira and Kedougou represent the number of filled maximum discharge for these catchments.

Country	Main river	Tributary	Gauging station	Area (km^2)	First and last years for floods	Missing years	Mean annual precipitation (mm)	Number of rain gauges used	First and last years for rainfall
Burkina Faso	Niger	Goudebo	Falagontou	3750	1987/2010	4	410	5	1970/2010
Burkina Faso	Niger	Gorouol	Koriziena	2500	1970/2010	8	371	4	1970/2010
Niger	Niger	Dargol	Kakassi	6950	1959/2009	12	408	6	1970/2010
Burkina Faso	Volta	Mouhoun	Samendeni	4580	1970/2006	0	996	8	1970/2010
Burkina Faso	Volta	Noaho	Bittou	4050	1973/2006	3	804	7	1970/2010
Burkina Faso	Volta	Bambassou	Batie	5485	1971/2004	2	1006	6	1970/2010
Burkina Faso	Volta	Bougouribga	Diebougou	12200	1970/2005	4	956	14	1970/2010
Mali	Senegal	Faleme	Fadougou	9350	1950/2010	23	1073	7	1970/2000
Guinea	Senegal	Bafing	Sokoroto	1750	1970/2010	12	1280	2	1970/2000
Senegal	Gambie	Koulountou	Missira	6200	1970/2000	2	1375	4	1970/2000
Senegal	Gambie	Gambie	Kedougou	8130	1970/2002	0	1262	7	1970/2000

The result of the Mann Kendall test obtain for the time series presented in Table 1R is different from the result presented in the latest version of the paper when the catchments Niokolokoba, Diaguiri and Bebele are removed (see Table 2R which is the new version of Table 5 page 5110 in the latest version of paper). Let us recall that the two estimates coefficients of the Mann Kendall trend test are the correlation coefficient (τ_{MK}) and the *p*-value (α_{MK}). The τ_{MK} gives the direction of the trend detected, and this trend is significant if α_{MK} is lower or equal to the significance level of the test. The significance level has been taken as 10% (0.1) in our study. Obviously, we can observ on Table 2R that there is no more decreasing trend in the set of time series presented at the significance level of 10%. This can be explained by the fact that the catchment Niokolokoba that presented the only decreasing trend in the period 1970-2010 was removed. The same observation is made in the case of nPOT series, were the only cathment showing decreasing trend, Diaguiri was removed.

Table 3R. Results of Mann Kendall trend test on *Q*max and nPOT time series for the 14 shortter time series. "+" for significant positive trend; "–"for significant negative trend; "0" for no significant trend.

Catchments	Area (km^2)	Period	Mann-Kendall Qmax		Conclusion	Mann-Kendall nPOT		Conclusion
			α_{MK}	τ_{MK}		α_{MK}	τ_{MK}	
Falagontou	3750	1987–2010	0	0.46	+	0.04	0.36	+
Koriziena	2500	1970–2010	0.03	0.27	+	0.07	0.25	+
Kakassi	6950	1970–2010	0.01	0.35	+	0.07	0.25	+
Samendeni	4580	1970–2006	0.34	0.11	0	0.77	0.05	0
Bittou	4050	1973–2006	0.66	0.07	0	0.99	0	0
Batie	5485	1971–2004	0.28	0.14	0	1	0	0
Diebougou	12200	1970–2005	0.45	0.1	0	0.19	0.19	0
Fadougou	9350	1970–2010	0.78	−0.04	0	0.52	−0.08	0
Sokoroto	1750	1970–2010	0.67	−0.06	0	0.83	−0.03	0
Missira	6200	1970–2000	1	0	0	0.87	−0.03	0
Kedougou	8130	1970–2002	0.8	0.03	0	0.49	−0.1	0

The changes brought to the dataset might modifiy the results presented in the paper. We present hereafter a comparison of the previous results and the new results obtained with the slightly different dataset. To this aim, we computed the criteria presented in the paper, namely the Success Criterion (SC), the CramerV criterion (Cramer) and the associated p-value (α) for the new set of data (all catchments from Burkina Faso and the four remaining catchments from Senegal). The results presented in Table 5R for the rainfall index and table 7R for the NDVI index show that the scores computed with the modified set of data are different from the score presented in the lattest version of the paper (Table 4R for the rainfall index and Table 6R for NDVI index).

The main diference observed is that the values of the SC scores computed with the new set of data are slightly high than the laters, while the values of Cramer criterion for the new set of data are lower than the later values. However, the results yield to similar interpretations and conclusion. The value of SC criterion between flood time series and the physiographic time series used are higher for Rtot and R5d in the two cases, and the Cramer test does not present significant results in all cases.

Table 4R: SC criterion (+ p-value α) and Cramer criterion values for precipitation index trends compared to Qmax trends and nPOT trends on the set of 14 short-term catchments used in the last version of the paper (page 26).

	Qmax time series			nPOT time series		
	SC	**α**	**Cramer**	**SC**	**α**	**Cramer**
Rtot	0.78	0.14	0.53	0.78	0.14	0.53
R20	0.43	0.36	0.39	0.43	0.36	0.39
Rmax	0.50	0.73	0.21	0.50	0.73	0.21
R95p	0.50	0.59	0.28	0.43	0.48	0.32
Rx5d	0.64	0.11	0.56	0.64	0.11	0.56
SDII	0.29	0.92	0.18	0.29	0.92	0.18

Table 5R: SC criterion and Cramer criterion values for precipitation index trends compared to Qmax trends and nPOT trends on the remaining 11 short-term catchments, when time series of Niokolokoba, Diaguiri and Bebele are not considered.

	Qmax time series			nPOT time series		
	SC	**α**	**Cramer**	**SC**	**α**	**Cramer**
Rtot	0.82	0.59	0.16	0.82	0.59	0.16
R20	0.36	0.63	0.29	0.36	0.63	0.29
Rmax	0.55	1	0	0.55	1	0
R95p	0.55	1	0	0.55	1	0
Rx5d	0.73	0.24	0.35	0.73	0.24	0.35
SDII	0.36	0.63	0.29	0.36	0.63	0.29

Table 6R: SC criterion and Cramer criterion values for the NDVI index trends compared to Qmax trends and nPOT trends for the set of 14 catchments used in the last version of the paper (page 30).

	Qmax time series			nPOT time series		
	SC	**α**	**Cramer**	**SC**	**α**	**Cramer**
NDVI_m	0.21	1	0	0.21	0.80	0.18
NDVI_d	0.50	1	0	0.43	0.17	0.50
NDVI_w	0.43	0.71	0.14	0.36	0.33	0.40

Table 7R: SC criterion and Cramer criterion values for the NDVI index trends compared to Qmax trends and nPOT trends for the set of 11 remaing catchments, when time series of Niokolokoba, Diaguiri and Bebele are not considered.

	Qmax time series			nPOT time series		
	SC	**α**	**Cramer**	**SC**	**α**	**Cramer**
NDVI_m	0.36	0.69	0.12	0.45	1	0
NDVI_d	0.55	1	0	0.55	0.63	0.15
NDVI_w	0.55	1	0	0.45	0.63	0.15

This analysis shows that the results of dependency of trends are not modified if we apply the recommendations of the reviewer.

3. Are substantial conclusions reached?

Yes, the paper, although this is not the first way that Sahelian and Sudanian basins behaviour are opposed, it constitutes an interesting paper using a classical approach in order to investigate the different hydrological functioning in tropical basins.

4. Are the scientific methods and assumptions valid and clearly outlined?

Yes, methodology is consistently used to highlight hydrological functioning and, their spatial and temporal evolution; the paper is clear and easy to read and understand.

5. Are the results sufficient to support the interpretations and conclusions?

At my sense, yes ! I am not sure that 14 basins in the studied statistical set are sufficient to ensure in any case representativity and accuracy, as well statistical justification; but I know that this is very uneasy to gather such a data set in the area; the only concern is the need to better specify the data status, specifically the origin of data, their treatment (if so) their criticism and the number of lacks.

Response to the comment 5

See our response to comment 8.

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?

Yes ! The methods are yet well known and recognized, they constitute a robust scientific protocol; its application in the West African context (opposition between Sahelian and Sudanian areas, Sahelian paradox) proves that the methods is able to be reproduced.

7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution?

There is a good state of the art (in spite of the lack of some recent publications) and the own new original contribution of the authors appears clearly; the providing of new data and overall the limitation of mid size basins allow determine the two main types of hydrological evolution in West Africa.

Response to the comment 7

Thank you for these comments. In adition of the sahelo-sudanian aspect pointed out by the referee, The author would like to specify that this study provides informations about the evolution of extreme parts of hydrological regimes of the catchments used. This particular point is also an important original contribution giving the small number of studies that adress this issue.

8. Does the abstract provide a concise and complete summary?

One of the comments of the discussion states that title is too much large giving the impression that all the west African basins will be treated; the reviewer thinks that the great geographical extension of the basins location let us consider that the sub-region is well represented by those basins. The biggest problem to be addressed is the very low number of Sahelian basins (3); however, as Mahé et al (2011) shown, there is very few equipped basins in West Africa overall on long time series.

Response to the comment 5 and 8

Thank you for this comment. It is clear that that the number of catchments used in this study is not enough to conclude about a regional behavior. In this respect the comment above can be supported by the comment of Daniel Sighomnou (**SC C3383, 28 Aug 2015)** in his first review:

'1) Alors que le titre de l'article laisse sous-entendre l'analyse de la tendance des crues en Afrique de l'Ouest, dans son ensemble, les bassins versants étudiés couvrent une zone relativement limitée de cette région. En particulier la zone d'étude de la région Sahélienne concerne trois bassins versants voisins d'un même pays, le Burkina Faso. D'autre part, la longueur des chroniques de données étudiées n'est pas homogène et le nombre de bassins disposant de longues chroniques de données couvrant à la fois la période humide d'avant 1970 et celle sèche d'après 1970 est limité à deux. Les conclusions de l'étude mériteraient par conséquent d'être confirmées par de nouvelles études sur d'autres bassins de la région, comme cela est d'ailleurs souligné dans le papier. Il serait par conséquent plus prudent, pour ce qui concerne le titre de l'étude, de parler d'une contribution à l'analyse de la tendance des crues en Afrique de l'Ouest.'

In his comment, Daniel SIGHOMNOU recommended to change the title of the paper, so that it appears to be a contribution to the knowledge of West African rivers behavior, instead of a regional study. As response to this comment, we specified that the title of the paper will be changed, see the section ***Response to the short comments (SC C3383) by Daniel Sighomnou*** page 5 of this document.

9. Is the overall presentation well structured and clear?

Yes, the presentation is quite good, the text well structured and clear; Tables and figures are clear and sufficient to illustrate the demonstration

10. Is the language fluent and precise?

No !! it remains a lot of grammar and syntax errors; however, as you can see, the reviewer is completely unable to propose corrections in English language; I just noticed some errors to be corrected:

Page 5088 line 25: "Regarding" instead of "a regarding"

And some "frenchisms" such as:

Page 5089, line 25: "monitored" instead of "followed"

Page 5091, line 22: "wetness" instead of "humidity"

Page 5100, line16: "strong" or "quick" (??) instead of "galloping"

Otherwise, page 5096 line 16, and page 5102, line 3, replace "Briquet" with "Bricquet"

Response to the comment 10

Thank you for the remarks and corrections. All errors of grammar and vocabulary will be cheked and corrected in the new version of the paper, including the observed errors highlighted here.

11. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?

Yes, the formulations are clear and correct.

12. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?

No, at my sense, the manuscript is clear and equilibrated, after the changes yet proposed by reviewers and realized by the authors.

Response to the comment 6

Thank you for the comment.

13. Are the number and quality of references appropriate?

At my sense, the two cited references of Gil mahé and collaborators must be included because this scientist always attempted to collect and criticize all African hydrological data and these two papers (amongst more than 12 dedicated to West African hydrology);

I also recommend you to cite the following paper, probably not yet published when you firstly submitted your manuscript:

Valentin Aich , Stefan Liersch , Tobias Vetter , Jafet C. M. Andersson , Eva N. Müller and Fred F. Hattermann; Climate or Land Use?—Attribution of Changes in River Flooding in the Sahel Zone. *Water* 2015, *7*, 2796-2820; doi:10.3390/w7062796

Although these authors only consider the same basins that (cited) Descroix et al (2012), demonstrating the difficulty to find new data set….. and although they only consider sahelian basins, this paper is to be referenced because it also considers as you done, land use changes and climate changes in order to explain the hydrological functioning evolution.

Response to the comment 13

Thank you for this comment, and for these recommendations.

The studies of Mahé et al. (2011) and Mahé et al. (2013) gives accurate informations about the expansion of sahelian paradox. In addition, Mahé et al. (2013) highlight the main difficulty presented in this study, which concern the availability of data, and also the lack of knowledge of the flow regime of sudanian catchments. These aspects will then be mentionned as complementary information in the introduction of the new version of our paper.

In their study, Aich et al. (2014) made a comparison of trends of different component of flood risk, including maximum discharge and heavy precipitation, in order to identify the main flood risk component which is responsible of the flood damage expansion on the Niger bassin. However in our paper we did not consider the link between maximum discharge trends and flood risk trends in the catchment studied, a part of the results presented by Aich et al. (2014) reinforce the statistical hypothesis made on the trends of maximum discharge in the sahelian region in our study.

In the Guinean zone of his study, he showed that maximum flood are still increasing, but the time series of Fadougou which is also located in the guinean part of the Niger basin presented a decreasing trend in our case.

Thus, it is important to present the similarities and differences between the two studies, and this will be included in the discussion of the results presented in the new version of our article.

14. Is the amount and quality of supplementary material appropriate?

No supplementary material found

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Trends of floods in West Africa: Analysis based on 11 catchments of the region.

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Abstract:

After the drought of the 1970s in West Africa, the variability of rainfall and land use changes affected mostly flow, and recently flooding has been said to be an increasingly common occurrence throughout the whole of West Africa. These changes raised many questions about the impact of climate change on the flood regimes in West African countries. This paper investigates whether floods are becoming more frequent or more severe, and to what extent climate patterns have been responsible for these changes. We analyzed the trends in the floods occurring in 14 catchments within West Africa's main climate zones. The methodology includes two methods for sampling flood events, namely the AM (annual maximum) method and the POT (peak over threshold), and two perspectives of analysis are presented: long-term analysis based on two long flood time series, and a regional perspective involving 14 catchments with shorter series. The Mann-Kendall trend test and the Pettitt break test were used to detect non-stationarities in the time series. The trends detected in flood time series were compared to the rainfall index trends and vegetation indices using contingency tables, in order to identify the main driver of change in flood magnitude and flood frequency. The

Commentaire [BNN1]: Correction according to comment of review SC C3383, 28 Aug 2015, by Daniel Sighomnou.

Commentaire [BNN2]: Correction T1 of review RC C2829 on 24 Jul 2015

Commentaire [BNN3]: Correction comment Spe.4.2 of review RC C2829 on 24 Jul 2015 relation between the flood index and the physiographic index was evaluated through a success criterion and the Cramer criterion calculated from the contingency tables.

The results point out the existence of trends in flood magnitude and flood frequency time series with two main patterns. Sahelian floods show increasing flood trends and one Sudanian catchments present decreasing flood trends. For the overall catchments studied, trends in the maximum 5-day consecutive rainfall index (Rx5d) show good coherence with trends of flood, while the trends in NDVI indices do not show a significant agreement with flood trends, meaning that this index has possibly no impact in the behavior of floods in the region.

1. Introduction

The drought that affected West African countries after the end of the 1960s is known as one of the "the most undisputed and largest recent climate changes recognized by the climate research community" (Dai et al., 2004) and is well documented in terms of rainfall variability (Le Barbé et al., 2002; Lebel et al., 2009a; Paturel et al., 1998). Although there is recent agreement on the resurgence of rainfall since the end of the 1990s (Lebel et al., 2009b; Lebel and Ali, 2009; L'Hôte et al., 2002), Mahé and Paturel (2009) showed that the mean rainfall of the 1970–2009 decades remained lower than the 1900–1970 decades. Moreover, some authors found an intensification of the rainfall regime in the Sahelian region since 2000, characterized by a greater contribution of extreme precipitation to the annual total rainfall (Descroix et al., 2013; Panthou et al., 2014).

The rainfall deficit over West Africa has contrasting consequences on the hydrological regime of river basins. In Sudanian areas, the mean annual discharge of rivers has significantly and substantially decreased more than rainfall (Mahé, 2009; Mahé et al., 2013, 2011; Mahé and Olivry, 1995; Paturel et al., 2003), while in the Sahelian areas, a general increase in the runoff coefficient has been noted since the end of the 1980s, despite the low amount of precipitation compared to the 1950s (Albergel, 1987; Amani and Nguetora, 2002; Bricquet et al., 1996; Descroix et al., 2009; Mahé and Paturel, 2009, Roudier et al., 2014).

The causes of the runoff coefficient increase in Sahelian catchments is often attributed to the land clearing and land use changes that occurred in the region after 1970 (Amogu et al., 2010; Descroix et al., 2009; Mahe et al., 2010). Indeed, the largest variations in rainfall in the 1970s and 1980s over West Africa have consequently induced a reduction in vegetation cover, particularly in the Sahelian region (Anyamba and Tucker, 2005), and the growth of the

Commentaire [BNN4]: Correction T2 of review **RC C2829 on 24 Jul 2015**

Commentaire [BNN5]: Correction of comment 13 by supplement referee

population in Sahelian countries has led people to remove the natural vegetation in order to increase the surface area of cultivated land. However, evidence from recent data based on remotely sensed observations of vegetation have shown that the Sahelian region has been undergoing a “regreening” process since the beginning of the 1990s, due to the rainfall increase (Anyamba and Tucker, 2005; Fensholt et al., 2013; Herrmann et al., 2005).

Meanwhile, there is growing concern about fatalities related to floods in West Africa over the past half century (Di Baldassarre et al., 2010; Descroix et al., 2012; Sighomnou et al., 2012; Tschakert et al., 2010). Despite this widespread perception of increased flooding events in West Africa (Tarhule, 2005; Tschakert et al., 2010), there is very little information about the regional trend of floods and their potential causes, partly because of the scarcity and quality of long-term hydrological data. One can hypothesize that flood regimes have been impacted by the climatic and environmental changes that have occurred since 1970. Some authors have pointed out an increase in the number of heavy daily rainfall that might have caused changes in flood regimes in areas where the infiltration capacity has been reduced (Descroix et al., 2013).

Commentaire [BNN6]: Correction comment Spe. 5 of review **RC C2829 on 24 Jul 2015**

Identifying the drivers of change in the flood regimes of West Africa’s catchments is a challenging task because of the heterogeneity of the region and the modification of hydrological functioning of drainage basins. However, the detection of trends in flood time series has scientific and economic importance. It is essential for planning protection systems against flooding, where the common assumption for system design is the stationarity of the flood regime (Kundzewicz et al., 2005). The main study of Di Baldassarre et al. (2010) that focused on flood trend analysis concluded that for a majority of 30 river basins in Africa, there was no significant trend during the twentieth century. However, this study was based on a very large scale of catchments with quite diverse hydroclimatic settings and used sparse temporal data, which may have an effect on the coherence of the trends detected. This precludes deeper analysis on the role of extreme rainfall variability and land use changes. Another recent study by Aich et al. (2014) focused on the role of flood hazard in the increasing flooding risk of the Niger basin. They concluded that there is a correlation between flood damage and maximum discharge evolution in the main climatic areas of the Niger basin during the period 1970-2010.

Commentaire [BNN7]: Correction of comment 13 by supplement referee

In the present study, we investigate the trends on flood magnitude and flood frequency of eleven catchments reflecting the main hydroclimatic conditions in West Africa. We also investigate the agreement between flood trends and climate and environmental trends in order to identify the potential drivers of flood variability. Because data from the catchments studied have different record lengths, we focus our analysis firstly on two long-term time series for an historical perspective of flood behavior, and secondly on the 1970–2010 period, using the study's eleven catchments. Section 2 presents the general characteristics of the region and the data set used to create annual time series. In Section 3 we explain the methodology used for this analysis and Section 4 presents the results of this work.

2. Study domain and original data

The study domain refers to the region of West Africa. This region is usually divided into two climatic zones, the Sahelian and the Sudanian regions, separated by an isohyet of 750 mm/yr (Figure 1) as described by (Descroix et al., 2009). As presented in Table 1, we collected the mean daily flow records of eleven catchments with areas ranging from 1750 km^2 to 12,200 km^2. These eleven catchments are considered representative of the hydroclimatic diversity of West Africa.

Following the above-mentioned terminology, our database contains three Sahelian catchments, the Goudebo River at Falagontou, the Gorouol River at Koriziena, and the Dargol River at Kakassi, which are located north of isohyet 750 mm. These catchments are on the right bank tributaries of the Niger River. The other catchments located south of the isohyet 750 mm are Sudanian catchments. All these data have been subject to quality control before being included in the study. Time series of Burkina Faso were provided by the DGRE (Direction Générale des Ressources en Eau) in their raw form, including gaps, and a particular care was taken in the selection of the catchment set for this study. Conversely, data of Senegal and Mali have been processed, and their time series have been criticized by the research team of OMVS (Organisation pour la mise en valeur du fleuve Sénégal) and the IRD (Institut de Recherche pour le Développement) team of Senegal before being included in this study.

The hydrological functioning of West African rivers is closely related to rainfall seasonality, which is controlled by the West African Monsoon system (Lebel and Ali, 2009). In both regions, the rainfall season is generally limited to the boreal summer months, from May to October. In the sahelian region, the rainfall season ranges from 2 to 4 months, with maximum rainfall occurring in August (Nicholson, 2013), this correspond to the flow season with a maximum generally occuring within in August.

Commentaire [BNN8]: Correction according to comment 2 by supplement referee
Correction according to comment **SC C3534** by Ansoumana Bodian.

In the sudanian region, flows generally span from July to November. The maximum discharge occurs generally between the end of August and September, the rest of the year being dry for small watersheds. Figure 2 presents the monthly hydrograph of two representative catchments of the West African rivers studied, the Dargol River at Kakassi in the Sahelian region and the Faleme River at Fadougou in the Sudanian region. Ideally, the data set should have record periods spanning the same interval, but this is not the case for the eleven catchments studied. Only two long-term flow series were found, the Dargol River at Kakassi (1959–2009) and the Faleme River at Fadougou (1950–2010); the nine other flow time series generally start after 1970. Consequently, two data sets were considered in this study: a data set consisting of the long-term time series for the two catchments and a data set composed of more catchments (11) but over a shorter time period (typically from 1970 to 2010).

The latter data set with a shorter period of analysis ensures greater spatial coverage. They were considered for the 1970–2010 period, with at least 20 annual maximum records per catchment. This data set was used to assess the relation between the flood and rainfall indices. The former, with a longer period of analysis, increases the likelihood of identifying trends and provides an overview of the flood behavior before and after the drought that started in the 1970s.

Inherent uncertainties in using observations to detect trends in flood time series derive from the quality and quantity of data. Some problems linked to the quality of data such as missing values and gaps in time series can cause apparent changes, and are complicating factors for the analysis of the data, and interpretation of the results. However the main difficulty in the area of study is the availability of long term series with no gaps. In addition, comparatively to the sahelian region, very few studies have investigated trend of flow in the sudanian region. This is certainly due to a particular lack of data in this part of west Africa. While it is possible to find few more gauged catchments in the region, the data of most of these catchments are often deficient, which makes it impossible to use them for the study of hydrological extremes. Therefore, we decided to concentrate our analysis to the few mentioned catchments showing more reliable time series, and no supplement treatment was made on these data. In addition, significant uncertainties of measurement can impact the results of trends, but there have been no significant change in measuring technique of data in the West African region since 1970.

Commentaire [BNN9]: Correction T3 of review **RC C2829 on 24 Jul 2015**

Commentaire [BNN10]: Response to comment Spe.2 of review **RC C2829 on 24 Jul 2015**

And regarding the history of the gauging stations used in this study there is no major hydraulic infrastructure within the catchments that can impact flows.

Commentaire [BNN11]: Correction of comment 10 by supplement referee

Daily rainfall data were obtained from the SIEREM database for the 1970–2000 period (http://www.hydrosciences.fr/sierem/index_en.htm). In Burkina Faso, we also collected data for the 2000–2010 period from the country's National Meteorological Service. For the data collected from other countries, data record periods ended in 2000. Generally speaking, we were able to find a sufficient number of local rain gauges that allowed us to compute the mean areal rainfall of each catchment. The Thiessen Polygon method was applied to determine the mean areal daily rainfall for each catchment. Table 1 presents the mean annual precipitation of the eleven catchments over the 1970–1999 period, and the number of rain gauges used to obtain these values for each catchment.

The Normalized Difference Vegetation Index (NDVI, source: International Research Institute for Climate and Society Data library online) is used in this study as an environmental variable providing information on the evolution of vegetation or land degradation (Fensholt et al., 2013). NDVI data are derived from imagering obtained with the Advanced Very High Resolution Radiometer (AVHRR) instrument onboard the NOAA satellite series (Tucker et al., 2004). This is a product of the GIMMS (Global Inventory Modeling Mapping Studies) available for a 25-year period from 1981 to 2006. The NDVI values are recorded every 2 weeks on each 0.072°×0.072° pixel, allowing the study of seasonal and interannual vegetation changes. The NDVI data are dimensionless numbers varying from zero to unity depending on vegetation density. NDVI values near zero indicate very sparse vegetation, while dense vegetation is indicated by NDVI values approaching unity.

3. Methods

The relatively large and homogeneous data set used in this study allows one to address the issue of flood non stationarity in West Africa, with particular consideration given to the diverse results obtained according to rainfall and vegetation indices in the region. To this aim, a series of methods were monitored to derive annual time series of high-flow characteristics, rainfall indices, and vegetation characteristics. For all these time series, we applied a trend detection test that is also presented in this section. Last, the agreements between the trends

Commentaire [BNN12]: Correction of comment 10 by supplement referee

detected for high flows and the trends detected for climatic and vegetation indices were compared.

3.1. Flood sampling

Two time series were derived from daily flow records using two sampling methods, annual maximum (AM) sampling and peak-over-threshold (POT) sampling.
Annual maximum sampling consists in extracting the peak values of daily discharge within the calendar year of a series. AM is a well-established and simple approach that allows investigation of the changes in flood magnitude (Qmax) (Di Baldassarre et al., 2010; Robson et al., 1998). However, the disadvantage of this concept is that only the major event is selected for years with more than one high flow, while in years without substantial flow, the event selected can correspond to a medium or even a low flow (Kundzewicz et al., 2005).

Figure 3 illustrates the specific Qmax (Qmax divided by the catchment area) for the eleven catchment studied. Figure 3 shows that all Qmax time series have skewed distributions. The Sokoroto River at Bafing is the smallest catchment in terms of area, but presents the highest specific maximum discharge values. Generally, Sahelian catchments have a lower specific Qmax than Sudanian catchments.

The second sample derived from daily flow series is the nPOT series. The nPOT time series presented in Figure 4 were constructed from POT sampling, for which all independent floods exceeding a certain threshold are considered (Lang et al., 1999). The POT series are useful to investigate the trends in either flood frequency or flood magnitude (Svensson et al., 2005). In this study, we analyzed the flood frequency (nPOT), which is the number of floods extracted in each year of the time series the data were collected.

The strategy used for POT sampling is schematically represented in Figure 4 and the following sequence was observed. 1) All nPOT must exceed the flow threshold (u). In this study, the threshold was taken as the minimum value of the respective annual maximum time series. This choice was made because at least one nPOT per year can be obtained for all the catchments studied, while remaining within the range of maximum values sampled in the corresponding Qmax series. 2) The time between two consecutive nPOT (Θ) is greater or equal to corresponds to the average duration of half of the exceeding maximum discharges in the mean flood hydrograph. Consequently, a mean duration of flood events was estimated on the basis of historical flood events. 3) The minimum daily flow value ($X_{\min}$) between two consecutive nPOT X_i and X_{i+1} shall be less than a second threshold that is $C1 = 0.5\min(X_i; X_{i+1})$. Thus we ensure that the two values sampled are derived from different and independent events. Figure 5 provides a summary of the nPOT. It should be noted that with these criteria and given the hydrological behavior of some of these catchments, we did not obtain a large number of POT events per year for some catchments such as Samendeni, Sokoroto, and Missira.

3.2. Rainfall and vegetation indices

International research teams such as the Expert Team on Climate Change Detection Monitoring Indices (ETCCDMI) have proposed a set of climate indices enabling comparison across different regions (New et al., 2006; Peterson, 2002; Vincent et al., 2005). From this set of indices, we selected the most meaningful for the study of floods in the West African region.

For each catchment, we computed the annual time series of the rainfall indices presented in Table 2. These indices provide information on both intensity and frequency of rainfall characteristics that were subject to change within the last few decades in West Africa (Klein et al., 2009; Ly et al., 2013; New et al., 2006; Sarr et al., 2013). Rtot and SDII provide information on the wetness of catchments within the rainy season, while R20, Rmax, R95p, and Rx5d are valuable for the study of extreme rainfall patterns.

Commentaire [BNN13]: Correction of comment 10 by supplement referee

With reference to previous studies, the indices selected present observable trends since 1950. The decrease in annual total rainfall in the 1950–2000 period over West Africa has been well documented (Le Barbé et al., 2002; Lebel and Ali, 2009; L'Hôte et al., 2002), but the climate is less dryer since the beginning 1990s (Nicholson, 2005; Ozer et al., 2002). As for the indices related to extreme climate, Descroix et al. (2013) and Panthou et al. (2013) noticed that extreme daily rainfall have increased over the central Sahel region. They also suggested that the contribution of extreme rainfall in the annual total rainfall has increased over the 2000s. Ly et al. (2013) came to the same conclusion for the 1961–1990 period in the Sahelian region. These trends are evaluated here in a comparative approach with flood trends.

Commentaire [BNN14]: Correction comment Spe.5 of review **RC C2829 on 24 Jul 2015**

For each catchment and each date, we computed the mean spatial value of all NDVI pixels within the catchment. The seasonal evolution of NDVI is known to be closely related to the rainfall pattern, and since the catchments studied present similar hydrological regimes (one wet season and one dry season), we computed three yearly mean NDVI values for each catchment. The yearly means of the NDVI index for the full 12 months (NDVI_m), for the dry season (NDVI-d) from January to June, and for the wet season (NDVI_w) from July to

December. This choice of dry and wet seasons was made to take into account the lag time of the greening process after the rainy season.

3.3. Trends and breaks in the time series

In this study, the Mann-Kendall (Kendall, 1975; Mann, 1945) and the Pettitt (Pettitt, 1979) tests are used to identify trends and break dates in the annual time series. These tests are recognized as being robust for trend analysis of hydroclimatic data in the sense that they are nonparametric and thus do not make assumptions on the distributions of the variables (Kundzewicz et al., 2005). For all these tests, the null hypothesis is that there is no trend or no break in the time series at the significance level 0.10.

The result of the Mann-Kendall test is given through its two estimated coefficients, namely the correlation coefficient (τ_{MK}) and the *p*-value (α_{MK}). The τ_{MK} value of the Mann-Kendall varies between −1 and 1, either positive or negative for increasing and decreasing trends respectively. An absolute value close to 1 indicates that the correlation between the two variables involved (in this case the data and the time) is high. The value of α_{MK} is then compared to the significance level of the test. The null hypothesis is rejected if α_{MK} is less than the significance level; if not the null hypothesis is not rejected.

The Pettitt test investigates the existence of a break in the time series. The result is given through a *p*-value (α_{PET}) and the probable date for a break. As for the Mann-Kendall test, the Pettitt test *p*-value is compared to the significance level. If the *p*-value is less than the significance level, the null hypothesis is rejected. If not, the null hypothesis is not rejected and the computed date of change is rejected. This test was used only for the two long flood time series.

Commentaire [BNN15]: Correction of comment Spe.4.1 of review **RC C2829 on 24 Jul 2015**

3.4. Statistical agreement between flood evolution and rainfall /vegetation indices evolution

For each catchment of the short series sample, we performed the Mann-Kendall test on the Qmax time series, the nPOT time series, and the physiographic indices (either rainfall or vegetation); then the trend obtained on each flow index was compared to the trend of each physiographic index using contingency tables for all catchments. To obtain a synthetic assessment of the contingency tables, we computed two criteria:

The Cramer index (Cramer, 1946; Johnson, 2004) is commonly used to estimate the dependency between variables in contingency tables. Its value ranges between zero and unity, a value of 1 meaning a complete dependency of the variables. The Cramer Index is also associated with the chi-squared test, which gives a *p*-value (α) indicating the significance of the test.

Commentaire [BNN16]: Correction T4 of review **RC C2829 on 24 Jul 2015**

We also computed the Success Criterion (SC), inspired from the Critical Success Index (Schaefer, 1990). The SC can be considered as a quality criterion, with values ranging from zero to unity. However, the use of this criterion requires some assumptions about the known and possible combinations of trends between floods and rainfall. Table 3 presents the basic considerations made for the calculation of SC, and Equation 1 gives the formulation of SC.

$$\textbf{Success Criterion} = \textbf{SC} = \frac{\sum \textbf{CD} + \sum \textbf{CR}}{\sum \textbf{CD} + \sum \textbf{FD} + \sum \textbf{MD} + \sum \textbf{CR}} \qquad (1)$$

where CD (correct detection) is the number of catchments that present similar trends for both flood and physiographic indices, FD (false detection) is the number of catchments that present opposite trends for both flood and physiographic indices, MD (missed detection) is the number of catchments that are stationary for one index and non stationary for the other, and CR (correct rejection) is the number of catchments that present non stationary behavior for both indices.

The SC value gives the proportion of agreements (correct detection and correct rejection) between flood trends (either Qmax or nPOT) and each physiographic index trend in the whole catchment set. A value close to unity indicates good agreement between both flood and physiographic trends. On the contrary, a value close to zero indicates that there is no agreement between the trends of the indices involved.

Commentaire [BNN17]: Correction of comment Spe.3 of review **RC C2829 on 24 Jul 2015**

4. Results

This section presents the results of the trend analyses on flood characteristics as well as on rainfall and vegetation indices. As mentioned in section 2, the catchment set presents different record period lengths. We investigated the temporal variability of the trends on two catchments presenting long series. Then we investigated the spatial variability of the trends by analyzing the flood trends on the whole catchment set, but focusing on the 1970–2010 period. Flood trends were compared to rainfall trends and last, flood trends were compared to vegetation trends over the 1981–2006 time period. This allowed us to identify the factor with the greatest influence on flooding.

4.1. Historical perspectives of trends in flood magnitude and frequency

For long-term analysis, we only considered the two long time series representing the climatic region of West Africa, namely the Dargol River at Kakassi and the Faleme River at Fadougou. The results of the Mann-Kendall and Pettitt tests performed on the flood time series of these two catchments are presented in Table 4.

The evolution of flood in the two long times series (Figure 6) presents two main behaviors. For the Dargol River at Kakassi, the Qmax and nPOT time series significantly increased over the 1959–2009 period according to the Mann-Kendall test, and breaks were also detected with the Pettitt test. The break in the Qmax time series occurred in 1987 and for nPOT the break date occurred later, in 1993. The same tests were also applied to the subperiod time series for each flood index and the subseries were found to be stationary. The comparison of the mean Qmax and nPOT values within the two subperiods shows that the Qmax and nPOT values in the second subperiod were on average twice as high as their values in the first subperiod. For the Faleme River at Fadougou, the results highlight a decreasing Qmax trend with a break in 1971, while the nPOT time series was stationary. As for Kakassi, the Mann-Kendall and Pettitt tests performed on the subperiods of Fadougou's Qmax index revealed no significant trend and no significant break. According to the mean Qmax value in the subperiods, a decrease of Qmax at Fadougou between the two subperiods was also demonstrated.

The tests performed on the annual total rainfall index (Rtot) of the two catchments agreed on a break in the Rtot in 1967, which corresponds to the beginning of the drought. The mean value decreased from the first subperiod to the second. For Kakassi, no significant trend was detected in the rainfall index time series, but a break date occurred for the Simple Daily Intensity Index (SDII) in 1993. In this case, the mean SDII value was higher in the second subperiod, meaning that daily rainfall over the catchment were less frequent but more intense, which was also observed in previous studies (Descroix et al., 2013; Le Barbé et al., 2002; Panthou et al., 2014). As for Fadougou, all rainfall indices presented significant negative trends, and break dates all occurred within the 1967–1977 period, within the drought period.
Considering the Dargol River at Kakassi, we can assume that after the drought, the catchment experienced a stationary flood regime between the end of 1960 and the beginning of 1990.

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Since the end of the 1980s, substantial changes in the catchment led to the increase of flood magnitude and flood frequency. In the Sahelian zone, land use changes and land clearing were often mentioned as the main contributing factors of runoff increase since 1987. The coherence of a break in the SDII time series with the Qmax and nPOT time series for this catchment suggests that flooding in these Sahelian catchments has been rising more than what can be explained by land use changes alone, and that some rainfall indices could have an impact on the increase in flooding. Interestingly, the *p*-value of the Pettitt test for other rainfall indices such as the R20 (0.13) and Rx5d (0.13) are close to the significance level (0.10). Although these *p*-values are not significant, the estimated break dates for these indices' time series (1993 for R20 and 1987 for Rx5d) are in the same period as the Qmax and nPOT breaks, which suggests agreement with the breaks in flood time series. Finally, these results show that for the Faleme River at Fadougou, the Qmax decrease within the 1950–2000 period is consistent with the decrease in rainfall indices over the 1950–2000 period. Even if the 1950–2010 period is considered, the Fadougou Qmax still shows a decreasing trend, but unfortunately the rainfall time series for this catchment stopped in the year 2000, so no information was provided for the last decade. The decrease in Qmax for Faleme at Fadougou, which is in agreement with the decrease in the annual discharge of the Sudanian rivers, reinforces the hypothesis that strongly decreasing groundwater flow is the factor explaining the high reduction of discharges with regard to the rainfall reduction since the 1970s in the Sudanian basins .

4.2. Regional perspective of trends in flood magnitude and frequency

To assess the flood trends in a regional perspective, we focused on short time series since 1970. The results of the Mann-Kendall trend test applied to Qmax and nPOT of the eleven catchments studied are presented in Table 5. Eight out of the eleven catchments do not show significant trends on Qmax, while the remaining three catchments present increasing trends (the Dargol River at Kakassi, the Gorouol River at Koriziena, and the Goudebo River at Falagontou a).

When using the short time series, the trend detected the Qmax time series of the Falémé River at Fadougou in section 4.1 is no longer dominant. This suggests that since the 1970 drought, the catchment has experienced stationary behavior with regard to its flood regime, while the Kakassi Qmax and nPOT time series still exhibit an increasing trend since 1970.

The results of the Mann-Kendall trend test on nPOT are similar to the flood magnitude results. The three Sahelian catchments also present a significant positive trend, all the remaining time series being stationary. These results suggest that the Sahelian catchments analyzed in this study have experienced more frequent floods.

The few significant trends detected in this section contrast with the perception that floods had regionally increased in West Africa, but these results are consistent with the results obtained by (Di Baldassarre et al., 2010), who found 17% significant trends detected in a global database of 79 annual maximum time series in Africa before the 2000s.

However, it is important to note the clustering of the trends detected. All positive trends were detected for the three Sahelian catchments. This is in line with the "Sahelian paradox" (Descroix et al., 2009), which implies an increase in annual runoff coefficients while at the same time annual rainfall remains low compared to wet years (1950–1970).

To identify the similarities between flood patterns and environmental indices more accurately, the agreement between flood trends and physiographic index trends for the catchments studied are analyzed hereafter, first on the entire set of catchments with particular attention paid to the same time interval for the flood and physiographic index time series.

When analyzing all catchments at the same time, we expect the rainfall–runoff relationships of the 14 catchments studied to be quite different, since the catchments are known to have different hydrological processes due to the spatial variability of the climate and the heterogeneity of the soil. However, this has been considered an advantage in this section because it more clearly identifies which index is in agreement with the flood trends in the two climatic zones.

The results presented in Table 6 on the SC and Cramer criteria show similar Qmax and nPOT scores. The best SC criterion scores are recorded for Rtot (0.82) and Rx5d (0.73) in both cases. The other indices showed a SC score between 0.36 and 0.55, which will be considered as non significant given the small number of catchments. The Cramer criterion has low scores for the Rtot (0.16) and Rx5d (0.35) indices in both cases, with associated *p*-values (α) higher than 0.10, meaning that these scores are not significant and conclusions cannot be drawn on the relation between flood trends and rainfall index trends. However, these results show good consistency between the two criteria chosen for this analysis and highlight two main indices

(Rtot and Rx5d) for which trends are in agreement with flood trends (Qmax and nPOT) according to the SC criterion.
As mentioned above, we used series of different lengths, which may have had an effect on the coherence of the trends detected. Abdul Aziz and Burn (2006), Hamed (2008), and Burn et al. (2004) showed that using the Mann-Kendall trend test on different extents of the same time series can lead to contradicting results, due to the existence of non-monotonic temporal patterns in time series. This is also true for the Fadougou time series as presented above. Therefore, for better coherence of the period in the analysis, only the Burkina Faso catchments will be used in the following, since they present longer time series; this allows us to analyze trends in the 1970–2010 period. The Goudebo River at Falagontou, the Gourouol at Koriziena, and the Dargol at Kakassi are considered hereafter for Sahelian catchments, and the Mouhoun River at Samendeni, the Noaho at Bittou, the Bambassou at Batie and the Bougouriba at Diebougou are considered for Sudanian catchments. The new SC criterion and Cramer test values are presented in Table 7.

According to the results obtained when catchments with more homogenous time series periods are considered, the Rx5d index appears to match the flood trends of the two climatic areas perfectly. For this index, the SC criterion is equal to 1, and the Cramer criterion is significant, with a high score of 0.71 for Qmax and nPOT. This suggests that the Rx5d index is the overriding climatic factor that is most likely to impact the flood behavior in the two climatic zones. This could be attributed to the fact that for the range of catchment areas studied herein, the maximum discharge was found with a substantial accumulation of rainfall recorded over several days.

To take into account the difference between the climatic zones, the trends of the seven catchments in Burkina Faso were calculated in a more detailed analysis to determine which rainfall indices match flooding trends for each climatic zone. In this case, the Cramer criterion was not calculated since the number of catchments taken into account for each group was too low.

According to the results presented in Table 8, the Sahelian flood trends are the same for three indices, namely R20, Rx5d, and SDII. In this case, they all presented a significant increase, thus confirming the results obtained so far on the long time series of the Dargol River at Kakassi. In this respect, (Descroix et al., 2013) showed that in the central Sahel, the mean daily rainfall has increased in 2000–2010 compared to 1971–1990, and its value reached the value of wet decades (1950–1970). The number of heavy rainfall days (R20) also increased over the 1990–2010 decade in the central Sahel. The greatest contribution of extreme rainy days in the annual total rainfall since the beginning of 1990s (Descroix et al., 2013; Panthou et al., 2014) can also explain the increasing SDII trend since 1970 for the Sahelian catchments presented here.

For the Sudanian catchments, the Rtot, Rmax, and Rx5d indices showed the same trend as the Qmax and nPOT for the group's four catchments, which has already been shown in the long-term perspective analysis of Fadougou.

4.3. Agreements between flood trends and NDVI index trends

Generally speaking, NDVI characteristics tend to increase for the studied catchments over the 1981–2006 period, and this was more pronounced for NDVI_w and the Sahelian catchments. According to the results of the Mann-Kendall trend test presented in Table 9, similar behaviors for NDVI_w and NDVI_m was detected in nine catchments of the eleven investigated. When integrating NDVI_d, only five catchments showed similar trends for the three vegetation indices.

Concerning the results of SC on flood/NDVI indices presented in Table 10, the agreements are similar between Qmax and NDVI in one hand and between nPOT and NDVI in this the second hand. The Cramer Index, presents very poor scores indicating that the relation between the flood index trends and the NDVI trends is not significant.

With regard to the NDVI, several publications have established that the Sahelian region has been going through a "regreening" process for almost 20 years now (Anyamba and Tucker, 2005; Fensholt et al., 2013; Herrmann et al., 2005). The NDVI changes on the catchments used in this study confirm this theory. However, this points out an obvious discrepancy with the "Sahelian paradox" concept, which implies an increase in the runoff coefficient due to land clearing. In that respect, (Dardel et al., 2014) explained that these two behaviors of the vegetation index can take place in the same area but at different spatial scales depending on the type of soil.

5. Conclusion

This paper aimed to study the trends of maximum flows in West African rivers, and the study was based on eleven catchments of sahelian and sudanian zones of the region. To isolate the related climate and environmental impact on flood regime, we compared the trends of floods with the trends of physiographic variables of the medium size catchments (1750 km^2 to 12200 km^2). However this study was based on small sample of catchment comparatively to the region, the methodology applied allows us to confidently assert that for the set of data used two opposite trends can be observed on flood magnitude and flood frequency depending on the climatic zone.

The Sahelian catchments studied showed increasing trends in both flood magnitude and flood frequency, in accordance with the evolution of flow in Sahelian catchments attributed to the increase in annual runoff coefficients, but we also found significant similarities between flood trends and the trends indicated by certain extreme rainfall indices, namely the number of heavy rainfall, the maximum amount of rainfall in 5 consecutive days, and the mean daily rainfall. This climate signal is possibly another aggravating factor of the increase in runoff coefficients in the sahelian region. Since the number of catchments was relatively low, this result needs to be confirmed on other catchments.

For the Sudanian catchments studied, we identified only one decreasing trend in flood magnitude in the long time series, but the large sample of short time series used can be considered stationary with respect to flood magnitude and occurrence. The decreasing trends, as well as the stationarity of flood time series, are more attributable to the evolution in mean rainfall since 1970 which have induce a continual decrease in base flow (Mahé, 2009, 2011).

We did not find a significant link between NDVI trends and flood magnitude trends. Therefore, the overall increase of NDVI does not appear here as a particular environmental pattern affecting flood magnitude trends, but rather as a regional behavior related to the resurgence of rainfall.

For years now, the design of hydraulics structures is based on standards computed since 1960, with the hypothesis that extreme hydrological regimes are stationary, but after the drought in the 1970s, a number of elements contributed to the alteration of hydrological regime in West Africa, such as demographic changes, increasing urbanization, and land usage, to mention a few known examples. The change in watershed environment and the results presented in this

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Commentaire [BNN21]: Correction of comment 10 by supplement referee

study suggest that the assumption of stationarity of floods is no longer valid for some catchments, and special care have to be taken when designing hydraulic structures, specifically with the use of old standards for the calculation of design flood.

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Limitations inherent to the rainfall–runoff relationship analysis using statistical tools derive from the fact that hydrological processes as well as their spatial and temporal variability are not taken into account. It is therefore important to use hydrological models, which have the advantage of more accurately accounting for certain hydrological processes.

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Table 1. General information on the 14 catchments and the flow and rainfall data sets used for the study. Annual rainfall is computed over the 1960–1999 period. Value of missing years recorded for the catchments Fadougou, Sokoroto, Missira and Kedougou represent the number of filled maximum discharge for these catchments.

Country	**Main river**	**Tributary**	**Gauging station**	**Area (km^2)**	**First and last years for floods**	**Missing years**	**Mean annual precipitation (mm)**	**Number of rain gauges used**	**First and last years for rainfall**
Burkina Faso	Niger	Goudebo	Falagontou	3750	1987/2010	4	410	5	1970/2010
Burkina Faso	Niger	Gorouol	Koriziena	2500	1970/2010	8	371	4	1970/2010
Niger	Niger	Dargol	Kakassi	6950	1959/2009	12	408	6	1970/2010
Burkina Faso	Volta	Mouhoun	Samendeni	4580	1970/2006	0	996	8	1970/2010
Burkina Faso	Volta	Noaho	Bittou	4050	1973/2006	3	804	7	1970/2010
Burkina Faso	Volta	Bambassou	Batie	5485	1971/2004	2	1006	6	1970/2010
Burkina Faso	Volta	Bougouribga	Diebougou	12200	1970/2005	4	956	14	1970/2010
Mali	Senegal	Faleme	Fadougou	9350	1950/2010	23	1073	7	1970/2000
Guinea	Senegal	Bafing	Sokoroto	1750	1970/2010	12	1280	2	1970/2000
Senegal	Gambie	Koulountou	Missira	6200	1970/2000	2	1375	4	1970/2000
Senegal	Gambie	Gambie	Kedougou	8130	1970/2002	0	1262	7	1970/2000

Commentaire [BNN23]: Correction according to comment 2 of supplement.

Table 2. Description of the rainfall indices used.

ID	Description	UNIT
Rtot	Annual total rainfall, where precipitation $\geq$ 1 mm	mm
R20	Annual number of days when precipitation $\geq$ 20 mm	days
Rmax	Daily maximum rainfall per year	mm
R95p	Sum of daily rainfall exceeding the 95th percentile	mm
Rx5d	Maximum rainfall over 5 consecutive days.	mm
SDII	Simple Daily Intensity Index (annual total rainfall divided by the number of wet days in the year)	mm/day

Table 3. 3×3 Contingency table of trends for flood and physiographic indices. Each cell contains the number of catchments respecting the trends in the row (for flood indices) and column (for physiographic indices)

Flood index	**Physiographic index**		
	Positive	**Negative**	**Stationary**
Positive	correct detection **(CD)**	false detection **(FD)**	missed detection **(MD)**
Negative	false detection **(FD)**	correct detection **(CD)**	missed detection **(MD)**
Stationarity	missed detection **(MD)**	missed detection **(MD)**	correct rejection **(CR)**

Table 4. Results of Mann Kendall and Pettitt tests on Kakassi and Fadougou time series (flood and rainfall indices). "+" for significant positive trend; "-" for significant negative trend; "0" for no significant trend.

		MANN-KENDALL			**PETTITT**		**CONCLUSIONS**	
		α_{MK}	τ_{MK}	Conclusion	α_{PET}	Break date	Subperiod	Mean by subperiod
Kakassi (1959–2009)	Qmax (m^3/s)	0.01	0.3	+	0.01	1987	1959–1987	65
							1988–2009	135
	nPOT (---)	0	0.48	+	0.05	1993	1959–1993	2
							1994–2009	4
	Rtot (mm)	0.12	−0.17	0	0.06	1967	1959–1967	523
							1968–2009	398
	R20 (---)	0.49	0.08	0	0.13	No break	-------	-------
	Rmax (mm)	0.35	0.11	0	0.22	No break	-------	-------
	R95 (mm)	0.78	0.03	0	0.27	No break	-------	-------
	Rx5d (mm)	0.23	0.14	0	0.13	No break	-------	-------
	SDII (mm)	0.48	0.08	0	0.08	1993	1959–1993	7.4
							1994–2009	8.9
Fadougou (1950–2010)	Qmax* (m^3/s)	0	−0.38	-	0	1971	1950–1971	1006
							1972–2010	525
	nPOT* (---)	0.96	0.01	0	0.51	No break	-------	-------
	Rtot (mm)	0	−0.47	-	0	1967	1950–1967	1571
							1968–2000	1070
	R20 (---)	0	−0.47	-	0	1976	1950–1976	25
							1977–2000	16
	Rmax (mm)	0	0.28	0	0.01	1966	1950–1966	95.6
							1966–2000	62
	R95p (mm)	0	−0.44	-	0	1967	1950–1967	440
							1968–2000	180
	Rx5d (mm)	0	−0.32	-	0	1967	1950–1967	184
							1968–2000	126
	SDII (mm)	0	−0.52	-	0	1977	1950–1977	15.3
							1978–2000	11.1

(*)**For Fadougou, the Qmax and nPOT tests were performed on two periods. First for the 1950–2010 period and second on the 1950–2000 period for the comparison with rainfall index time series with a shorter length. The results obtained were the same for the two periods and for Qmax and nPOT.**

Table 5. Results of Mann Kendall trend test on *Q*max and nPOT time series for the 11 shortter time series. "+" for significant positive trend; "–"for significant negative trend; "0" for no significant trend.

Catchments	Area (km²)	Period	Mann-Kendall Qmax		Conclusion	Mann-Kendall nPOT		Conclusion
			α_{MK}	τ_{MK}		α_{MK}	τ_{MK}	
Falagontou	3750	1987–2010	0	0.46	+	0.04	0.36	+
Koriziena	2500	1970–2010	0.03	0.27	+	0.07	0.25	+
Kakassi	6950	1970–2010	0.01	0.35	+	0.07	0.25	+
Samendeni	4580	1970–2006	0.34	0.11	0	0.77	0.05	0
Bittou	4050	1973–2006	0.66	0.07	0	0.99	0	0
Batie	5485	1971–2004	0.28	0.14	0	1	0	0
Diebougou	12200	1970–2005	0.45	0.1	0	0.19	0.19	0
Fadougou	9350	1970–2010	0.78	−0.04	0	0.52	−0.08	0
Sokoroto	1750	1970–2010	0.67	−0.06	0	0.83	−0.03	0
Missira	6200	1970–2000	1	0	0	0.87	−0.03	0
Kedougou	8130	1970–2002	0.8	0.03	0	0.49	−0.1	0

Commentaire [BNN24]: Correction according to comment 2 of supplement.

Table 6. SC criterion and Cramer criterion values for precipitation index trends compared to Qmax trends and nPOT trends on the set of 11 short-term catchments.

	Qmax time series			**nPOT time series**		
	SC	**α**	**Cramer**	**SC**	**α**	**Cramer**
Rtot	0.82	0.59	0.16	0.82	0.59	0.16
R20	0.36	0.63	0.29	0.36	0.63	0.29
Rmax	0.55	1	0	0.55	1	0
R95p	0.55	1	0	0.55	1	0
Rx5d	0.73	0.24	0.35	0.73	0.24	0.35
SDII	0.36	0.63	0.29	0.36	0.63	0.29

Commentaire [BNN25]: Correction according to comment 2 of supplement.

Table 7. SC criterion and Cramer criterion values for precipitation index trends compared to Qmax trends and nPOT trends for the seven homogeneous catchments of Burkina Faso.

	Qmax time series			nPOT time series		
	SC	**α**	**Cramer**	**SC**	**α**	**Cramer**
Rtot	0.71	0.88	0.06	0.71	0.88	0.06
R20	0.57	1	0	0.57	1	0
Rmax	0.71	0.88	0.06	0.71	0.88	0.06
R95p	0.71	0.74	0.13	0.71	0.74	0.13
Rx5d	1	0.06	0.71	1	0.06	0.71
SDII	0.57	1	0	0.57	1	0

Table 8. SC criterion and Cramer criterion values for precipitation index trends compared to Qmax trends and nPOT trends for the seven homogeneous catchments in Burkina Faso, three Sahelian catchments, and four Sudanian catchments.

Rainfall indices	SC for Sahelian catchments	SC for Sudanian catchments
Rtot	0.33	1
R20	1	0.25
Rmax	0.33	1
R95p	0.67	0.75
Rx5d	1	1
SDII	1	0.25

Table 9. NDVI time series trends for the 11 catchments studied over the period 1981- 2006 according to the Mann-Kendall test. “+”, significant positive trend; “0”, no significant trend

	NDVI_m	NDVI_w	NDVI_d
Falagontou	0	+	0
Kakassi	+	+	0
Koriziena	+	+	0
Samendeni	+	+	+
Bittou	+	+	+
Batie	+	+	+
Diebougou	+	+	0
Fadougou	+	+	0
Sokoroto	0	0	0
Missira	+	0	+
Kedougou	0	0	0

Commentaire [BNN26]: Correction according to comment 2 by supplement referee.

Table 10. SC criterion and Cramer criterion values for the NDVI index trends compared to Qmax trends and nPOT trends for the set of 11 catchments..

	Qmax time series			**nPOT time series**		
	SC	**α**	**Cramer**	**SC**	**α**	**Cramer**
NDVI_m	0.36	0.69	0.12	0.45	1	0
NDVI_d	0.55	1	0	0.55	0.63	0.15
NDVI_w	0.55	1	0	0.45	0.63	0.15

Commentaire [BNN27]: Correction according to comment 2 of supplement.

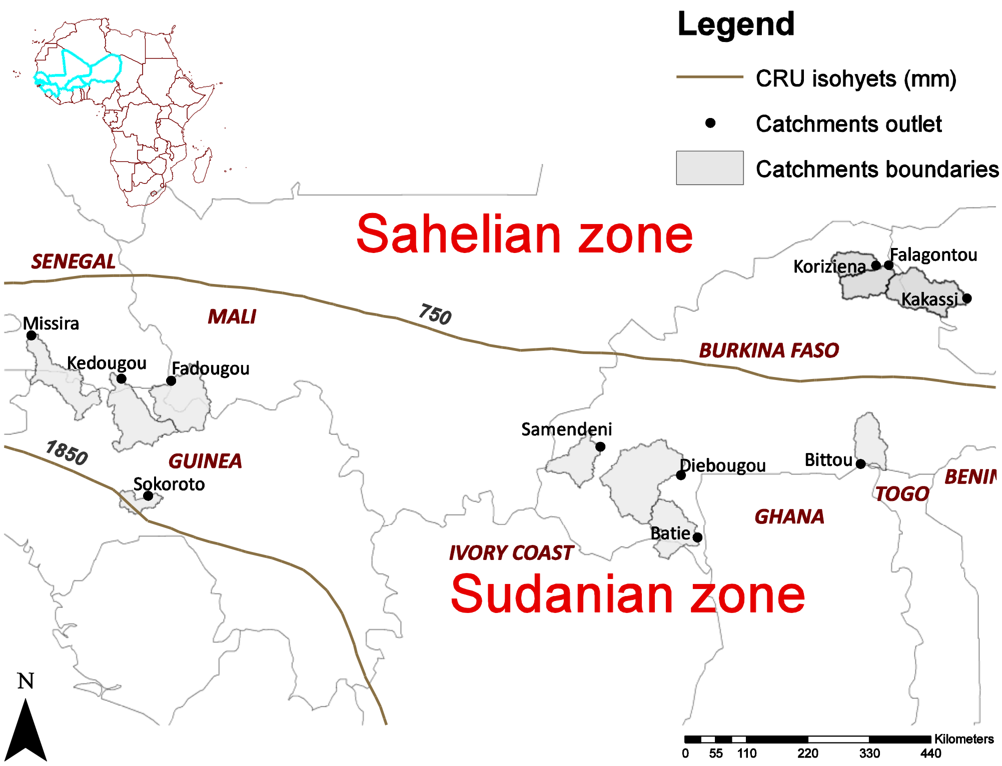


Figure 1. Location of the 11 West African catchments used for this study; the isohyets were created from climatic research unit (CRU) spatial rainfall data from 1960 to 1990.

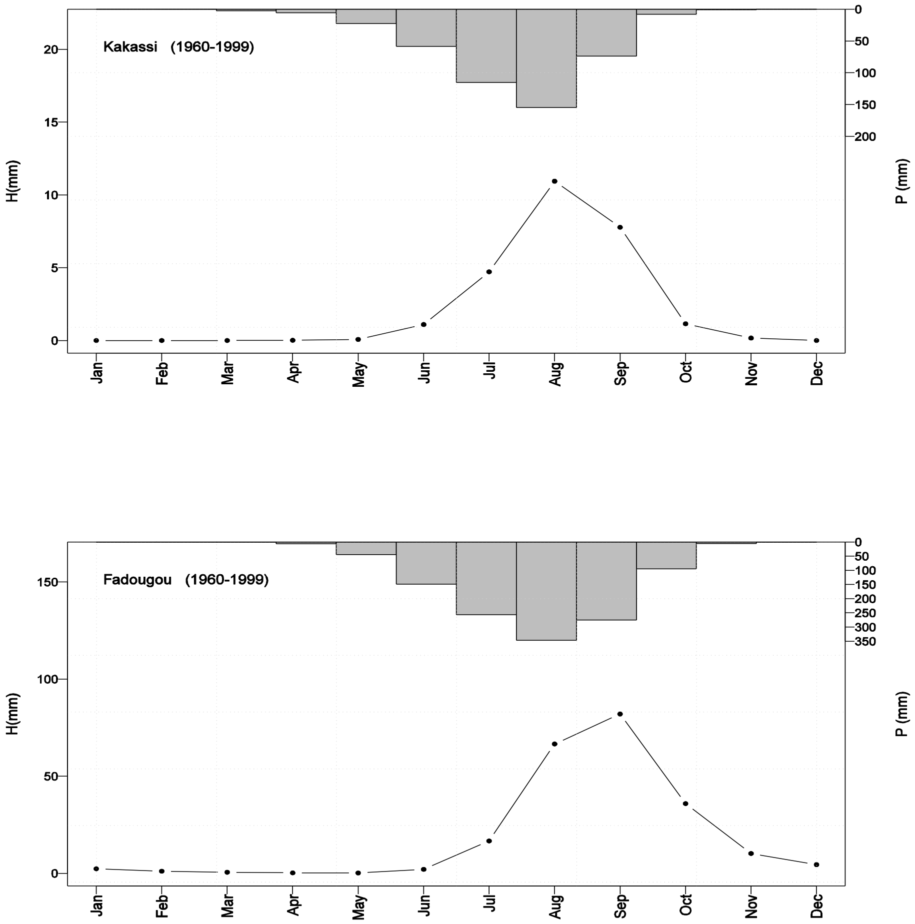


Figure 2. Mean monthly hydrograph for Kakassi (Sahelian catchment) and Fadougou (Sudanian catchment), 1960–1999.

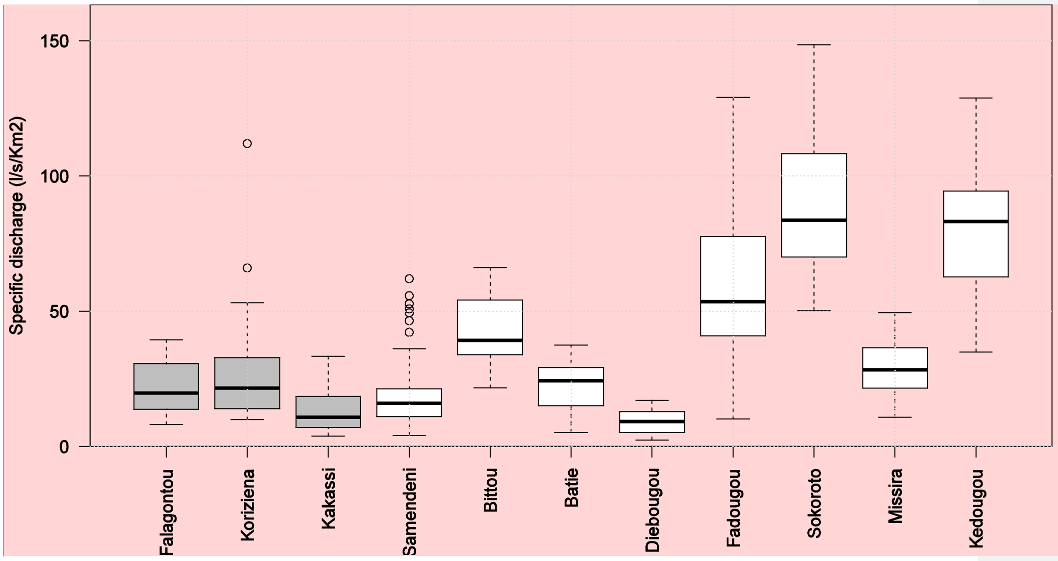


Figure 3. Boxplots of specific *Q*max of each catchment within the period 1970–2010. The boxplot represents the median on the middle hinge, 25th (75th) percentile on the lower (upper) hinge. The lower (upper) whisker is the border beyond which outliers are considered it is equal to 1.5* Interquartile range -25th (+75th). Empty circles represent outliers greater than the upper whisker or beyond the lower whisker. The three first boxes represent the time series for Sahelian catchments.

Commentaire [BNN28]: Correction according to comment 2 of supplement.

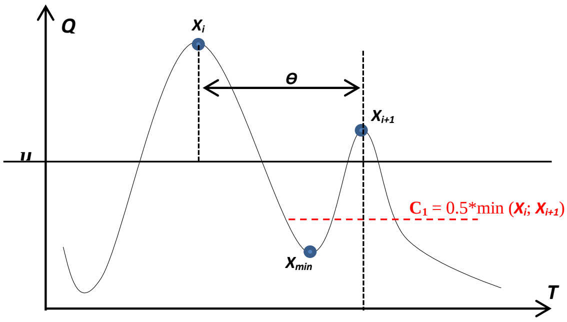


Figure 4. Extraction process of nPOT values. $\boldsymbol{u}$ is the threshold above wish all peak are selected; $\boldsymbol{\Theta}$ is the time interval between two consecutive nPOT; $\mathbf{X_{min}}$ refers to the minimum daily discharge between two consecutive nPOT $\mathbf{X_i}$ and $\mathbf{X_{i+1}}$; $\boldsymbol{C_1}$ is the minimum threshold between two consecutive nPOT .

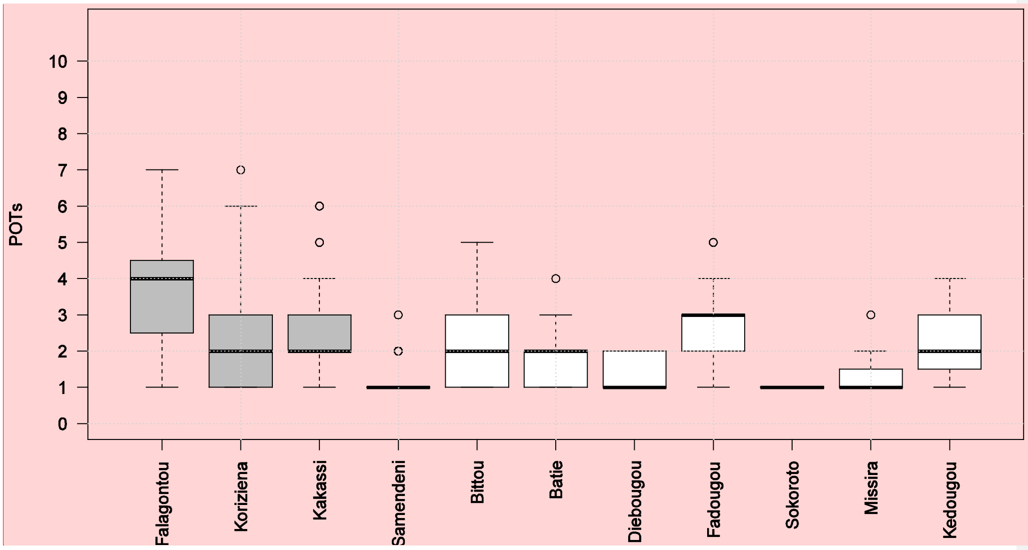
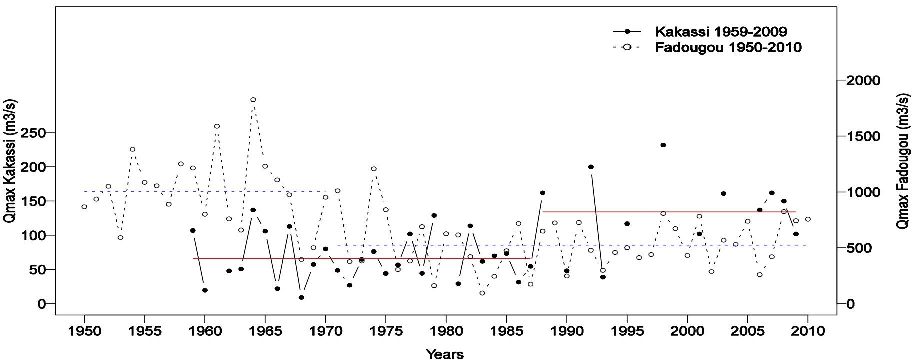
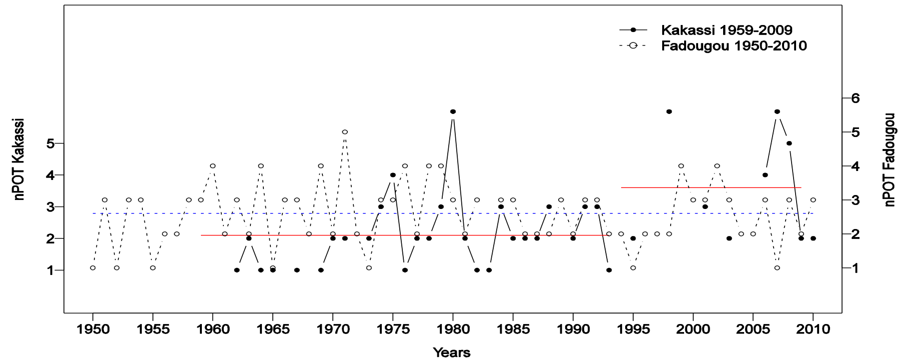


Figure 5. Boxplots for nPOT time series within the period 1970–2010 summarizing the characteristics of the nPOT series used. The boxplot represents the median on the middle hinge, 25th (75th) percentile on the lower (upper) hinge. The lower (upper) whisker is the border beyond which outliers are considered it is equal to 1.5* Interquartile range -25th (+75th). Empty circles represent outliers greater than the upper whisker or beyond the lower whisker. The three first boxes represent the time series for Sahelian catchments.

Commentaire [BNN29]: Correction according to comment 2 of supplement.



6.a



6.b

Figure 6. Qmax and nPOT of long-term time series and segmentation according to the Pettitt break test. The dashed blue lines (solid red lines) represent the mean value of the flood index for each subperiod at Fadougou (Kakassi).