Point by point response to Reviewers comments

1st Reviewer

I don't think that the authors adequately addressed my comments on their previous version. Below are the points that I still find problematic.

Authors Response:
We are thankful for the comments of the referee and as in the first revision also in the second one we have tried to address his comments as much as possible. Analytically see below:

- Some new information has been provided on the sampling method, but key information is still missing. How many villages and towns (rural and urban settlements?) exist in the regions, and how many people are living there? Did they conduct a stratified random sampling, or a different method? How high was the response rate, meaning the percentage of households that did not refuse to answer? When a household refused to participate in the survey, how did the interviewer find an alternative household? – this is important because it could lead to a selection bias

Authors Response:
The sampling approach is better described in the revised version. Addtionally we have included Table 1 that includes all the info requested by the reviewer.

- Summary statistics (a standard table of the number of observations, the mean, the standard deviation, etc.) need to be given for demographic characteristics of the respondents

Authors Response:
Table 2 has been added that included all the main demographic characteristics of the respodents.

- I understand that there is no breakdown information on the cost estimates of floods and droughts from the survey, but some more intuitions still need to be given about what these cost figures may or may not include in the context of the studied areas. Right now, it is hard for the reader to interpret these numbers in any ways as there is hardly any hint of what they really mean.

Authors Response:
As in the first review also in this one we have to repeat that unfortunately due to the relatively low incidence of cost damages among the respondents and the high rate of respondents who could not indicate a loss value although being affected by an extreme event we prefer to indicate only the average costs of floods and droughts. These values on their own are already a quite important finding in this paper and especially in the context of Africa where such estimations are rare. We tried using econometric modelling to correlate these values to other attributes of the survey but again we did not find any significance, most probably for the above mentioned reasons. In this context, trying to interpret the costs induces a high risk to provide misleading information and therefore we prefer to provide the analysis as it is.

2nd Reviewer

Journal: NHESS Title: **Assessing floods and droughts in the Mékrou River Basin (West Africa): A combined household survey and climatic trends analysis approach** Author(s): V. Markantonis et al.
MS No.: nhess-2017-195 MS Type: Research Article

Iteration: Second review

The paper aims at assessing the occurrence of floods and droughts events in the Mékrou river basin, as well as at estimating damage costs at the household level and mitigation behaviours adopted by the population due these kinds of events. To this aim, it combines a quantitative approach for detecting hydro-meteorological hazard prone areas (through the analysis of gridded climate datasets) with a quali-quantitative analysis of a household survey.

The paper is well structured, the research question is clear, methods are appropriately described but results presentation and discussion is still poor and imprecise. In general, I would say that, although the paper has significantly improved with respect to its first version and major concerns raised by the two previous referees were mainly addresses, it still suffers of several technical imprecisions (also in the English Grammar) and minor criticisms that prevent its publication in the present form.
In the following specific comments are provided.

Authors Response:
We thank the reviewer for his constructive comments. Specifically concerning the language, the reviewed version has been gone through a thorough proof reading and is substantially improved. Regarding all the other comments, we provide our response one by one as follows.

Specific comments

Introduction

In general, the literature review could be better organised to improve the comprehensibility of the manuscript.

Pg. 2 line 1
"A recent study (Shiferaw et al 2014), for instance, found that frequent drought conditions have limited the economic growth of many African countries and frustrated the benefits derived from development strategies implemented in other economic sectors," → Which other sectors? Not clear

Authors Response:
The sentence was modifies as follows:
"A recent study (Shiferaw et al 2014), for instance, found that frequent drought conditions have limited the economic growth of many African countries and frustrated the benefits derived from development strategies implemented in the education and technological innovation sectors, confirming also the findings of a previous study (Toya and Skidmore, 2007). "

Pg. 2 line 7
"For these reasons, in the recent past, the disaster risk management community has extensively worked on the development of methodologies aimed at monitoring the risk prone areas and the overall vulnerability of the population threatened by the hydro-meteorological hazards. Progresses have been made in the assessment of the occurrence of extremes events, their magnitude, and the expected climate change impacts. Additional efforts were directed towards the improvement of both the assessment of risk and the estimation of the direct and indirect impacts, in particular related to loss of human lives, economic activities, infrastructures, natural and man-made capital. Technical advancement efforts allowed also an improved assessment of current mitigation measures and policies" → References are required for this part

Authors Response:

The references for the mentioned sentences were added as requested.
The paragraph reads now as follows:
"For these reasons, in the recent past, the disaster risk management community has extensively worked on the development of methodologies aimed at monitoring the risk prone areas and the overall vulnerability of the population threatened by the hydro-meteorological hazards (UNISDR, 2017, 2013, 2011, 2008, 2004). Progresses have been made in the assessment of the occurrence of extremes events, their magnitude, and the expected climate change impacts (Alfieri et al., 2012; Hallegatte, 2012). Additional efforts were directed towards the improvement of both the assessment of risk and the estimation of the direct and indirect impacts, in particular related to loss of human lives, economic activities, infrastructures, natural and man-made capital (UNISDR, 2015). Technical advancement efforts allowed also an improved assessment of current mitigation measures and policies (Bouwer et al., 2011; Bubeck and Kreibich, 2011; Green et al., 2011; Logar and van den Bergh, 2011; Markantonis et al., 2012). "

Pg. 2 line 21
"Regarding cost estimation and impact assessment, instead, the knowledge about losses caused by past extreme events is still limited for a detailed quantitative analysis in many of the African countries. As described in Markantonis et al. (2012 and 2013), the methodologies used in literature are various: Hedonic Pricing; Travel Cost; Cost of Illness Approach; Replacement Cost; Contingent Valuation; Choice Modeling ; and Life Satisfaction Analysis (Welsch and Kühling, 2009; Luechinger and 25 Raschky, 2009; Welsch, 2006)." → I guess these methodologies are not quantitative nor based on knowledge about past losses, otherwise the two sentences are discordant. Please, clarify

Authors Response:
The whole sentence has been re-written.

<u>Section 2</u>

Although the full questionnaire is attached to the paper, a Table summarising main information (i.e. data, parameters) collected by means of the survey can increase the comprehensibility of the manuscript and also the analyses of significant variables in Section 3.4.

Pg. 5 line 1
"Following the data cleaning and validation of the survey, the information collected was processed through statistical analysis including all the parameters investigated." → Which are these parameters? Please see the general comment before

Authors Response:
The parameters refer to all the questions included in the questionnaire; socioeconomic, mitigation measures, cost estimates etc.

Pg. 5 line 23
"In the frame of household survey interpretation, quantitative estimates of these events are needed to understand the underlying direct (rainfall and discharge) and indirect (heat-waves) factors that have an impact on the respondents answers." Which events are referred to? this sentence is not related to the previous and following ones.

Authors Response:
The sentence has been reframed to: "In order to ensure an efficient interpretation of household survey's results, quantitative estimates of trends in climate related variables are

needed to understand the underlying direct (rainfall and discharge) and indirect (heat-waves) factors that have an impact on the respondents answers."

Pg. 6 line 16
"Additionally, in order to identify precipitation anomalies, we calculated the Standardized Precipitation Index (hereafter SPI) proposed by McKee et.al (1993; 1995). This index could be applied over different time scales, each providing information about the impact of a given anomaly on the availability of water resources (WMO 2012)." → A better description of the index and its meaning is required for non-expert readers.

Authors Response:
A more accessible description of the Standardized Precipitation Index, directed to a non technical audience, was added as requested.The paragraph reads now as follows:
"Additionally, in order to identify precipitation anomalies, we calculated the Standardized Precipitation Index (hereafter SPI) proposed by McKee et.al (1993; 1995). The SPI measures the deviation of precipitation in a specific location from its long term mean and it is a widely used indicator for drought monitoring. This index could be applied over different time scales, each providing information about the impact of a given precipitation anomaly on the availability of water resources (WMO 2012). In this study, the 3 months and 6 months SPI (hereafter SPI-3 and SPI-6) were calculated, associated respectively to meteorological and agricultural droughts. Shorter time scales SPI is considered, in fact, a good indicator of variations of soil moisture, while on longer scales (up to 24 months), it could be associated with groundwater or reservoir levels variation (WMO 2012)."

Pg. 6 line 23
"The results are given in units of standard deviation, indicating how far a given precipitation event is below (drier events are associated with a negative SD) or above (wetter event, positive SD) the long term normal distribution" → The sentence is not clear, please rephrase

Authors Response:
The sentence was modified as follows:
"The results are given in units of standard deviation (SD), indicating how far a given precipitation event is below (drier events are associated with a negative SD) or above (wetter event, positive SD) the long term normal distribution of the precipitation observations in a given location. SPI values around the zero indicate a precipitation event in line with the long term precipitation in the specific period, negative (positive) values indicate precipitation levels below (above) historical values. SPI values could then be interpreted following a classification scheme where standard deviations are categorized into different classes, each associated to different levels of wet or dry anomaly. In this case we have divided the values following the seven categories proposed by Agnew (2000), where previous thresholds defined by McKee et al. (1993) were replaced by alternative classes (Table 3)."

Pg. 6 line 28
"Finally, in order to get a general overview of the anomalies in the different administrative units, we calculated the area percentage affected by each class over the entire time series" → Figure S1 should be included in the paper to increase the comprehensibility of presented results

Authors Response:
Figure S1 was transformed in a table and included in the body of the manuscript (Table 3 in the revised version of the manuscript).

<u>Section 3</u>

Please, be consistent in the units of measures and significant figures adopted in presenting the results, both within the text and in the corresponding tables

Pg. 8 line 10
"In the period under consideration, mean annual temperature ranged between about 30º C in the North to 26.5º C in the South. 10 April was the warmest month, with a maximum temperature of 40º C in the North and 35º C in the South. Minimum temperature in the coldest month (September) ranged between 19º C in the North and 15º C in the South, presenting the semi-arid region the highest range of variation of about 25ºC." → this part is not related to the contents of section 3.1.1. I would move this part in section 3.1.3 and change the section title into "Precipitation patterns"

Authors Response:
The sentence was moved as requested and the section renamed.

Section 3.1.4

What the analysis of river discharge says about the occurrence of floods?

Authors Response:
Unfortunately, lack of information about historical flood events did not allow to draw conclusion about possible flood propagation related with simulated discharge.
This was made clear in the section 3.1.4 by adding the following sentence:
"The analysis of the simulated river flows highlighted the large inter-annual variability of the discharge. In about 8 of the 18 years under consideration, the average discharge was estimated to be below the long term average by more than 20%, while in 4 instances the simulated discharge was estimated to exceed the average by more than 20% (Figure 5). Although the analysis of the river discharge saw daily values with river discharge unusually high respect to the average, due to lack of data about flood propagation during historical events and detailed topography, we were not able to estimate the possible number of flood events in the domain of the study."
Pg. 11 line 26
"Only a small percentage of the respondents (68 out of in total 660 interviewed households) stated that they had not experienced any flood occurrence during the last two years (Table 4)." → The table reports the opposite, please check

Pg. 12 line 16
"The cost of the recent floods is higher in Burkina Faso (Table 6), where the average cost for an affected household in 334,326 FCFA (West Africa Francs) (approximately 495 Euro in 2017)." → (1) 495 euro in Table 6 refers to all the basin and not only to Burkina Faso. I guess authors want to refer to the whole basin, please check (2) are three numbers after the comma significant/required? Please check

Authors Response:
334326 FCA was 510 euro in 2017 (1 euro = 656 FCA). It has been corrected accordingly in the text since it refers to Burkina Faso, not in the Basin. The comma in the whole document has been used to indicate below thousand. Indeed it can be confusing and therefore it has been removed from all the text and tables.

Pg. 13 line

"According to the multivariate regression model, the average cost of floods per household during the flood events of the last two years (2014-2015) was equal to 390.92 euro" → (1) Data from the survey were mainly reported in FCFA. Please, be consistent to allow comparison (2) are two numbers after the comma significant/required? Please check

Authors Response:
We include all the values in FCFA as well as in Euro when referring to the total Basin values in order to have a better comparison. The two numbers after comma are significant (0.92 euro) if someone considers that some cents are spent daily in these country from individuals to feed.

Section 4

Pg. 14 line 14
"Especially concerning droughts, 86.8% of the population reported that dry periods were more frequent during the 15 ten years ranging between 2006 and 2015, while 23.3% experienced an extreme drought event during the last two years (2014-2015) resulting in 3.93 extreme drought events in average." → In Section 3.1.5 authors report 4 droughts events in average. Please be consistent with significant figures in order to allow comparison and increase comprehensibility

Authors Response:
It has been corrected in section 3.1.5 where now it indicates the average of 3.93 drought events.

Pg. 15 line 7
"522 Euro" → I do not understand what this datum refers to, please check

Authors Response:
It has been corrected. The average cost of floods as indicated in Table 9 is 495 euro.

Pg. 15 line 5
*"*The cost assessment is two-folded based on the sample estimations as well as on the results of the application of two linear multivariate regression econometric models. The average costs caused by flood events in the period 2014-2015 was estimated in 522 Euro per affected household basing on the average declared losses. Regarding the cost assessment of extreme droughts, the average value of the sample was 390 Euro per household" → I think that a comparison between observations and model is required along with a discussion on usability of model results. Nonetheless, given that the main reason for the model is to explain significant variables for damage costs, a comment on significant variables should be added to section 4.

Authors Response:
We used the statistical sample analysis to estimate the costs of floods and droughts while the econometric models were applied to define the most significant variables. We think that this is already well explained in the paper.

Pg. 15 line 23
"In developing countries where information is limited such a coupling approach could integrated local characteristics and perceptions into natural hazards planning policies providing more efficient

mitigation measure" → some examples should be supplied on the use/usefulness of collected information in practice, to be more explicative

Authors Response:
Some examples for the use of the collected information have been added.

Tables

In general, captions are quite generic and could be improved in order to better reflect the contents of the tables

Table 2 → Are six numbers after the comma significant/relevant? What do they mean/tell?

Authors Response:
The values have been reworked and only two numbers are provided after the comma.

Table 5→ percentages should be reported beyond total count, to be coherent with the other tables and to increase the significance/understanding of data

Authors Response:
In this case, since the numbers are not too high and not distributed in many categories we selected only the absolute numbers to demonstrate the data.

Table 6 → (1) Are three numbers after the comma significant/relevant? What do they mean/tell? (2) commas are missing in the first column

Authors Response:
See above comments. Commas indicating below thousand have been removed from the whole document.

Figures

Figure 1→ (1) Caption is missing. (2) Numbers can be added near survey points to highlight the number of surveys carried out in each point
Figure 2 → The figure is illegible in printed versions. Data in the table are not understandable without a description. I suggest to redraw the figure, representing also table data in graphs
Figure 3→ Please indicate the long-term average in the figure. The unit of measure is missing on the y axis.

Authors Response:
All three Figures have been redrawn according to the reviewer's comments.

References

I did not check the correspondence between the list of references and quotations in the text, as well as availability of all references, for lack of time.

Authors Response:
The correspondence of references has been cross-checked.

List of Changes

Page1: Abstract has been further revised.

Page 1 and 2: The literature review has been revised and improved according to the comments of the second reviewer.

Page 4: The survey process has been improved and more information has been provided regarding the sample selection and the administration of the questionnaires, while two tables have been added including sampling and demographics of the respodents.

Page 15: The conclusions have been further improved.

General: A thorough language proofing has been applied to the manuscript.

For more detailed changes see above how we addressed each comment of the reviewer.

Assessing floods and droughts in the Mékrou River Basin (West Africa): A combined household survey and climatic trends analysis approach

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Abstract. The assessment of natural hazards such as floods and droughts is a complex issue ~~demanding~~that demands integrated approaches and high quality data. Especially in African developing countries, where information is limited, the assessment of floods and droughts, though an overarching issue ~~influencing~~that influences economic and social development, is even more challenging. This paper presents an integrated approach to ~~assess~~assessing crucial aspects of floods and droughts in the transboundary Mékrou River ~~basin~~Basin (a portion of the Niger ~~basin~~River Basin in West Africa~~)~~), combining climatic trends analysis and the findings of a household survey. The multi-~~variables~~variable trend analysis estimates, at the biophysical level, the climate variability and the occurrence of floods and droughts. These results are coupled with ~~the~~an analysis of household survey data that ~~reveal behaviors~~reveals the behaviour and opinions of ~~the~~ local residents regarding the observed climate variability and occurrence of flood and drought events, household mitigation measures and the impacts of floods and droughts. Based on survey data analysis, the paper provides a per-household cost estimation of floods and droughts that ~~emerged during~~occurred over a two ~~years~~-year period (2014-2015). Furthermore, two econometric models are set up to identify the factors that influence the costs of floods and droughts ~~of~~to impacted households.

1. Introduction

Extreme meteorological events ~~like~~such as droughts and floods represent an important limitation for the development of the poorest countries, impacting in particular the most vulnerable portion of the population. In these countries, agriculture remains the main economic activity, and farming practices are mainly represented by ~~rainfed~~rain-fed agriculture (Rosegrant et al., 2002). Agriculture, a sector extremely vulnerable to extreme events, is the main source of income~~, or more~~ and often ~~represents~~ the only means of self-sufficiency~~,~~ of the poorest portions of the rural population in the least developed countries, ~~as in the case of Sub~~including sub-Saharan Africa (Gautam, 2006; Hellmuth et al., 2007). Extreme events cause loss of lives, damage to dwellings and vulnerable rural infrastructures, reduction of capital stock, and agricultural and industrial production losses~~, and threaten, more in~~. They also pose a general~~,~~ threat to food security and development ~~causing~~, leading to shocks in labour productivity, energy security, and political instability (Dell et al., 2014; Hsiang, 2010). ~~Flood~~Floods and droughts,

~~jointly~~together with ~~the~~ other natural disasters ~~categories~~, were found to ~~be~~have a particularly ~~impacting in~~damaging impact on the African continent, in particular ~~for what concerns~~with respect to fatalities, affected population, and economic damages (Cavallo, 2011). A recent study (Shiferaw et al., 2014), for instance, found that frequent drought conditions have limited the economic growth of many African countries and frustrated the benefits derived from development strategies implemented in ~~other economic~~the education and technological innovation sectors, confirming ~~also~~ the findings of a previous study (Toya and Skidmore, 2007). ~~Precipitation decline~~ Reduced precipitation was found to be responsible ~~of~~for about 15 to 40 % of the gap between the per capita Gross Domestic Product of ~~the~~ African economies ~~respect to~~and that of the rest of the developing world (Barrios et al., 2010). The negative impact on economic growth of the stresses due to ever-increasing dry conditions and precipitation ~~stresses~~ was also confirmed ~~also~~ by Berlemann and Wenzzel (2015~~) that~~), who found drought-prone countries to be generally ~~characterized~~characterised by ~~a~~ lower education ~~level~~levels, lower ~~savings rates~~saving rates, and higher fertility levels. For these reasons, in the recent past, the disaster risk management community has extensively worked on the development of methodologies ~~aimed at monitoring~~that aim to monitor the risk-prone areas and the overall vulnerability of the population threatened by the hydro-meteorological hazards~~. Progresses have~~ (UNISDR, 2017; 2013; 2011; 2008; 2004). Progress has been made in the assessment of the occurrence of ~~extremes~~extreme events, their magnitude, and the expected climate change impacts~~.~~ (Alfieri et al., 2012; Hallegatte, 2012). Additional efforts were directed towards the improvement of both the assessment of risk and the estimation of the direct and indirect impacts, in particular those related to loss of human lives, economic activities, ~~infrastructures,~~ infrastructure, and natural and man-made capital~~.~~ (UNISDR, 2015). Technical advancement efforts also allowed ~~also~~for an improved assessment of current mitigation measures and policies~~. The~~ (Bouwer et al., 2011; Bubeck and Kreibich, 2011; Green et al., 2011; Logar and van den Bergh, 2011; Markantonis et al., 2012). However, the benefits derived from the ~~progresses~~progress made in this discipline~~, however,~~ were mainly concentrated in the most developed and technically advanced countries, where information is more ~~easily~~readily available and mitigation strategies are more likely to be effectively implemented~~.~~ (UNISDR, 2015). In the case of ~~the~~ African countries, the assessment of the physical ~~components~~impacts of ~~the~~ hazard ~~side~~events followed the general level of technical development~~: as~~. As in the most advanced countries, in fact, the ~~assessment of the~~ occurrence of floods and ~~drought has been conducted through the application of~~droughts was assessed by applying remote-sensing-based techniques, analysing precipitation and temperature records and their spatio-temporal distribution, as for instance in ~~the case of Ngigi et al. (2005) for~~ a case study in Kenya~~.~~ carried out by Ngigi et al. (2005).

~~Regarding cost estimation and impact assessment, instead, the knowledge~~Although several quantitative and qualitative approaches have been developed in assessing costs of natural hazards, ~~I~~information about losses caused by past extreme events is still too limited ~~for~~ to facilitate a detailed ~~quantitative~~ cost estimation and impact assessment analysis ~~in~~for many ~~of the~~ African countries. As described in Markantonis et al. (2012~~ and~~; 2013), the methodologies used in the literature are various: Hedonic Pricing; Travel Cost; Cost of Illness Approach; Replacement Cost; Contingent Valuation; Choice ~~Modeling~~ Modelling; and Life Satisfaction Analysis (Welsch and Kühling, 2009; Luechinger and Raschky, 2009; Welsch, 2006). In this

study, however, it was decided to estimate the cost of natural disasters in the case study area ~~through~~based on the direct testimony ~~provided by~~of the affected population. Several studies ~~made use of~~used household surveys to acquire qualitative and quantitative information from the local population ~~and use the knowledge collected~~in order to estimate the damages of past hydro-meteorological events (as, for instance, in~~:~~ Fitchett et al., 2016; Ologunorisa and Adeyemo, 2005). Depending on the key economic sectors of the case study area, various examples of cost and impact assessment could be listed. Among the most representative~~, could be mentioned~~ were studies analysing the following sectors: health (Schmitt et al.~~,~~., 2016), agriculture and food security (Ngigi et al., 2005; Shiferaw et al., 2014; Shisanya and Mafongoya, 2016), and tourism (Fitchett et al., 2016). ~~The~~An analysis of the hazard components and the various impact assessments conducted in the recent past~~,~~ allowed for the evaluation of risk mitigation measures and adaptation strategies. For instance, Shisanya & Mafongoya (2016~~), for instance,)~~ analysed the effectiveness of shifts in agricultural practices; Brower et al. (2009) focused on the evaluation of the installation of risk mitigation infrastructures; Oyekale (2015) analysed the implementation of more advanced forecasting and early warning systems; Halsnæs & Trærup (2009) focused on the implementation of specific integrated policies and practices for ~~flood~~floods and ~~drought~~droughts. In some of ~~the mentioned~~these studies, cost-benefit and willingness-to-pay analyses were used to add quantitative evidence to the qualitative ~~description of the case studies in object~~descriptions.

The objective of this paper is to assess the occurrence of ~~floods~~flood and ~~droughts~~drought events ~~as well as to~~, estimate of damage costs at the household level, and ~~finally,~~describe the current mitigation behaviours adopted by the population ~~in~~of the Mékrou ~~river basin~~River Basin, a small catchment area in ~~Western~~West Africa. It combines a quantitative approach for detecting hydro-meteorological hazard ~~–~~prone areas (through the analysis of gridded climate datasets) with a ~~quali-~~qualitative and quantitative analysis of a household survey. This approach allows ~~comparing~~ for the comparison of physical ~~analysis~~analyses of extreme events with human ~~perception~~perceptions of the flood and drought phenomena in the Mékrou ~~river basin~~River Basin. The household survey ~~collects~~provides sufficient information to ~~conduct an estimation of~~estimate the impacts of natural hazards ~~impacts~~ in terms of economic cost, and to present the most widely adopted mitigation behaviours.

Mékrou is a sub-basin of the Niger River, covering an area of 10,635 km², about 3% of the total Niger Basin surface, ~~crossing the borders of~~across three countries~~:~~ Benin (80% of the basin territory), Burkina Faso (10%) and Niger (10%). Mean annual precipitation ranges from a maximum of about 1,300 mm in the southern region and 500 mm in the north~~, being the~~. The wet season occurs between June and September, with ~~an~~ average cumulated rainfall of 700 mm. ~~Temperature is~~ Temperatures are also highly variable in space and time. ~~Warmest~~The warmest and coldest months are April and September, respectively. Mean annual temperatures ~~spatially~~ vary between ~~26-~~26˚C and 30˚C, ~~being there~~reaching a maximum of 35-~~40 ˚C~~40˚C and ~~the~~ minimum of 15-~~19 ˚C~~19˚C. The Mékrou catchment is located in a temperate transitional area ~~characterized~~characterised by a wet season ~~peaking~~that peaks in ~~august~~August and a long dry season ~~spanning~~that spans the period December-April (Masih et al., 2014). During the wet season, the whole Niger River ~~basin~~Basin is subject to regular floods ~~and extensive~~. Extensive research has been conducted on its complex hydrology ~~made unique~~, which is characterised by ~~the~~a large system of lakes and

~~wetland~~wetlands known as the Inland Delta (Bader et al., 2016; Tarpanelli et al., 2017), while ~~lower~~less attention ~~was~~has been given to the Mékrou sub-basin. Flood and drought events are extremely frequent (Froidurot & Diedhou, 2017), ~~while~~and the impacts of climate change on their frequency and magnitude is unclear (Gautam, 2006). The Mékrou ~~basin~~River Basin is ~~characterized~~characterised by lack of or poor infrastructural development and very low socioeconomic conditions. Agriculture is the key economic sector, with the arable land used for food production, cattle farming, and the production of cotton. ~~That for~~Therefore, climate variability ~~constitutes~~is the main threat ~~for~~to the food and economic security of the area.

~~The~~This paper ~~structure~~ is ~~the following~~structured as follows: Section 2 presents the methodological framework ~~both~~ regarding the development and application of the household survey (section 2.1) ~~as well as~~and the analysis of the biophysical variables (section 2.2). The findings of this integrated approach are ~~shown~~given in Section 3. This section analytically presents the findings regarding precipitation patterns, temperature and river discharge in the Mékrou ~~river basin~~River Basin. Moreover, it includes the main findings of the household survey concerning the observed occurrence of floods, droughts and climate variability, household mitigation measures, the impacts of floods and droughts, and ~~finally~~ an econometric estimation of the costs of floods and droughts. Section 4 summarises the main findings of this approach, discusses its potential and limitations, and presents the main conclusions.

2. Methodology

2.1 ~~Households~~Household survey implementation and analysis ~~techniques~~

A household survey ~~aimed at evaluating~~to evaluate several water-related dynamics, including extreme natural hazards, was designed in 2015 and conducted in early 2016 (February to April). Specific villages and towns were selected to include a geographically representative sample of the river basin that belongs to the three countries (Benin, Burkina Faso, and Niger). The selection process was designed to keep a balance ~~among~~between urban and rural settlements. The number of ~~the selected~~ households proportionally represents the total population of ~~each selected village~~the respective villages or ~~town as well as~~towns selected, and the number of households per country represents the country's population within the basin. ~~Household~~Since there were no available lists of households including their socioeconomic conditions we have selected them randomly based on their location in the village/town keeping a distance of five households between the interviewing ones ~~every five households~~. Table 1 presents the detailed sample and population of the selected villages. ~~Households were selected randomly~~. The survey was ~~implemented~~carried out by experts of the Joint Research Centre of the European Commission in cooperation with local universities from Benin, Niger and Burkina Faso. ~~The~~ Interviews were conducted in person by a team of students supervised by a professor for each ~~of~~country. Before starting the ~~countries. The~~survey, the students received ~~a~~ training ~~before starting the survey where~~in which the questionnaire was thoroughly explained and discussed ~~with them~~. Since the area is francophone, all the material used was written in French. The fact that the survey was conducted by students of local universities facilitated ~~the~~ communication with the local population, overcoming possible language ~~or~~and cultural barriers. Prior to the conduction of

the survey the survey country administrators have visited each selected village and informed the local authorities. This process secured the acceptance of the survey on the ground resulting to a 100% response rate. The information included in the household survey aims to retrieve opinions and observations based on personal judgement. A ~~main~~large section of ~~this~~the survey ~~was to identify~~focused on identifying and ~~assess~~assessing the impacts and costs of flood and drought events, climate variability as well as household mitigation measures. Regarding the occurrence of floods and droughts in the study area, two time periods were selected: 10 years (2006-2015) and 2 years (2014-2015). The logic behind this selection was to identify the most recent events (2 years), for which the local households ~~could~~ still ~~have~~had a fresh memory ~~on~~of the impacts suffered ~~while affected.~~. The second time period (10 years) offers a longer assessment of climate variability and the occurrence of floods and droughts, which could potentially still be evaluated according to personal judgement. The whole questionnaire is included in Appendix A.

Table 1. Sample and population of the survey area

The survey process resulted ~~to~~in the collection of 660 randomly surveyed questionnaires retrieved from the areas of the three countries (Benin, Burkina Faso, and Niger) that are located in the Mékrou catchment (Figure 1). Specifically, 332 questionnaires were collected in 16 villages from the municipalities (called "Communes" in French) of Banikoara, Kouande~~,~~ and Kerou~~,~~ in Benin~~.~~;. 148 questionnaires were collected in 6 villages from the Communes of Diagaga and Tansarga in Burkina Faso~~.~~;. and 180 questionnaires were collected in 8 villages from the Communes of Falmey and Tamou in Niger. The total number of surveyed households offers ~~a more~~greater than 95% significance in the statistical findings (a minimum of 400 questionnaires ~~minimum~~are required for 95% significance rate). In Table 2 we present basic information on the socioeconomic characteristics of the surveyed population.

Figure 1. The Mékrou ~~river basin~~River Basin and the household survey area

Table 2. Socioeconomic characteristics of the surveyed sample

Following the data cleaning and validation of the survey, the information collected was ~~processed through statistical analysis~~statistically analysed including all the parameters investigated in the questionnaire. The survey responses were evaluated using descriptive statistics ~~aggregating~~that aggregate data both at river ~~-~~basin and at country level. ~~In this way, the~~The findings were analysed at the river ~~-~~basin scale, illustrating~~, at the same time,~~ the differences ~~among~~between the three countries.

Apart from the statistical analysis, an econometric estimation was applied to identify the specific parameters that are highly correlated to the costs of droughts and floods that ~~occurred~~were incurred in the last two years of the study (2014-2015). Hence, besides the cost estimation based on the sample mean, two econometric models were set up ~~investigating~~to investigate the

determinants of flood and drought costs following a cause-effect logic. Performing a thorough multi-variate regression ~~among costs~~cost analysis of floods and droughts as stated in the survey and other covariates~~,~~ (such as socioeconomic characteristics of the population, impacts, and mitigation measures~~,~~) led to the construction of models that could be ~~eventually~~ used to explain the costs of extreme hydro-meteorological events. Several types of regression models were tested, both linear and logarithmic. ~~Eventually, linear~~Linear multivariate regression models were ~~selected~~finally chosen since they fitted the selected variables with a higher statistical performance level. Moreover, in order to ensure the coherence and readability of the models, only independent variables whose P-value was less than 0.05 were selected. One independent variable with a P-value ~~higher~~greater than 0.05 was included due to its importance in the context of the analysis~~. Its~~, but its value (0.068~~), however,~~) is still below the least acceptable P-value (0.1). R-square and F-test values were estimated ~~as well as~~, and correlation ~~was tested~~ among the independent variables was tested in order to avoid bias in the model due to collinearity ~~among the selected variables~~.

2.2 Analysis of biophysical variables: precipitation, temperature, and river discharge

Precipitation and temperature patterns and changes are the main drivers ~~affecting~~of local ~~population~~populations' perception ~~about~~of water availability, especially in an area where the main economic activity is based on ~~rainfed~~rain-fed agricultural production. In order to ensure an efficient interpretation of household survey's results, quantitative estimates of trends in climate related variables are needed to understand the underlying direct (rainfall and discharge) and indirect (heat-waves) factors that have an impact on the respondents answers. ~~Analysis~~As analysis of rainfall events above and below the long-term average distribution in conjunction with inter and intra-annual ~~analysis~~analyses are useful ~~to depict~~for depicting anomaly patterns and trends~~, thus, they contribute to~~. They help better understand, for example, the main drivers of meteorological droughts. This is particularly relevant in order to compare local ~~population~~populations' perception ~~on~~of climate variables with quantitative estimates. ~~Characterization of events~~Events above and below the long-term rainfall average distribution were studied in conjunction with intra-annual precipitation analysis ~~were studied~~. To complement this, we analysed river discharge regimes, as precipitation anomalies could be translated into hydrological droughts, thus~~,~~ generating a water resource imbalance, reduced groundwater ~~level decrease~~levels, reservoir depletion, etc. (Liu et al., 2016). Secondly, considering the increasing number of ~~heat wave events~~heatwaves that occurred during the ~~last~~past decade in Africa (Ceccherini et~~.~~ al.., 2017), we ~~have~~ studied ~~its~~their magnitude and spatio-temporal evolution in the Mékrou Area of Influence to explain possible misperceptions that could arise in the surveys. The objective was to compare both precipitation and temperature stress with ~~survey's~~the survey results, offering empirical evidence of their concurrence, or ~~eventually~~ explaining the underlying causes of possible contrasting results.

2.2.1 Precipitation pattern analysis

~~Annual~~Descriptive statistics of annual and seasonal rainfall ~~descriptive statistics~~ were analysed jointly with the results of a Seasonal Kendall test for monotonic trend (SK) applied ~~over~~to precipitation data derived from the Climate Hazards Group

Infrared Precipitation with Station data v. 2.0 (hereafter CHIRPS). This database has a spatial resolution of 0.05º, corresponding to approximately 5 km (at the equator~~)~~), and covers all longitudes in the latitude range 50°S-50°N spanning a time horizon ~~included in~~of 1981 to the ~~period 1981~~ present ~~days~~day (Funk et~~.~~ al.., 2014). The SK test used is based on Hirsch and Slack (1984) and it was applied over two different time ranges: the entire time series (about 35 years), and over the ~~last~~ ten~~ years, the~~ year period considered in the household survey~~.~~ (2006-2015). The test is a modified version of the ~~previously~~previous SK test proposed by Hirsch et al. (1982), and attempts to reduce ~~variables~~the serial dependence~~, being~~ of variables (given that seasonal precipitation data are serially correlated~~.~~). Both are based on the non-parametric Mann-Kendall test (Mann, 1945~~,~~; Kendall, 1975~~,~~; Warren and Gilbert, 1987). ~~Magnitude~~The magnitude of trends are calculated ~~by means of~~using Sen´s Slope Estimator and ~~Kendall tau~~Kendall's Tau as the rank correlation coefficient.

~~Additionally~~In addition, in order to identify precipitation anomalies, we calculated the Standardized Precipitation Index (hereafter SPI) proposed by McKee et~~.al (1993; 1995).~~ al. (1993; 1995). The SPI measures the deviation of precipitation in a specific location from its long-term mean, and is a widely used indicator for drought monitoring. This index could be applied over different time scales, each providing information about the impact of a given precipitation anomaly on the availability of water resources (WMO, 2012). In this study, the 3~~ months~~-month and 6~~ months~~-month SPI (hereafter SPI-3 and SPI-6) were calculated, associated respectively ~~to~~with meteorological and agricultural droughts. A shorter SPI time scale is considered to be a good indicator of variations in soil moisture, while on longer scales (up to 24 months) could be associated with groundwater or reservoir variations (WMO, 2012). For the purpose of this paper, ~~being~~as the Mékrou communities' economy is mainly based on ~~rainfed~~rain-fed agriculture, we focused on the precipitation anomalies ~~over~~during the wet season, presenting the SPI-3 for the period June-August (JJA), and the SPI-6 for the period ~~included between~~ April ~~and~~to September (AMJJAS). The results are given in units of standard deviation~~,~~ (SD), indicating how far a given precipitation event is below (drier events are associated with a negative SD) or above (wetter event, positive SD) the long~~ term normal distribution.~~-term normal distribution of the precipitation observations in a given location. SPI values of around zero indicate a precipitation event in line with the long-term precipitation of the specific period, negative (positive) values indicate precipitation levels below (above) historical values. SPI values could then be interpreted following a classification scheme where standard deviations are ~~categorized~~categorised into different classes, each associated ~~to~~with different levels of wet or dry ~~anomaly~~anomalies. In this case we have divided the values following the seven categories proposed by Agnew (2000), where previous thresholds defined by McKee et al. (1993) were replaced by alternative classes (~~Figure S1~~Table ~~1~~3). Finally, in order to get a general overview of the anomalies in the different administrative units, we calculated the area percentage affected by each class over the entire time series.

Table ~~1~~3. Standardized Precipitation Index categorization and associated probability of occurrence (Agnew 2000)

2.2.2 ~~Heat-wave~~Heatwave analysis

Russo et al. (2015) defined the Heat-~~wave~~Wave Magnitude Index daily (hereafter HWMId~~),~~) as the maximum magnitude of the ~~heat-waves~~heatwaves in a year, where a ~~heat-wave~~heatwave is defined as a period equal to or ~~higher~~greater than three consecutive days with maximum temperature above a daily threshold calculated for a 30-year ~~long~~ reference period. The index is based on daily maximum temperatures, taking the intensity and duration of the event into account. In our case, the source used to retrieve the maximum daily temperatures is the ERA-Interim reanalysis dataset (Berrisford et al., 2011; Dee et al., 2011) available from 1979 onwards, with an approximate spatial resolution of 80 km at the equator. The index was applied to study these events for the ~~last~~past 35 years across the study area.

2.2.3 Discharge in the Mékrou ~~river~~River

In order to have a quantitative estimation of water availability within the Mékrou ~~river basin~~River Basin, the hydrological model SWAT (Neitsch et al., 2011) was ~~setup~~set up and calibrated to assess annual and monthly river discharge. The SWAT model integrates all relevant eco-hydrological processes, including water flow, surface runoff, percolation, lateral flow, groundwater flow, evapotranspiration, transmission losses, nutrient transport and turn-over, vegetation growth, land use, and water management. SWAT ~~subbasins~~sub-basins were delineated using the ArcSWAT interface with a Digital Elevation Model ~~with a~~of 90 m spatial resolution, resulting in 32 ~~subbasin~~sub-basins for the whole area.

The historical discharge data recorded at the Barou gauge station (outlet of the river basin) and at the Kompoungou ~~(~~gauge station (a draining area ~~is~~that accounts for about 56% of the river basin) ~~gauge stations~~ were used for model calibration. Lack of data availability represents a huge limitation for the hydrological analysis of the basin. ~~The mentioned~~In addition, these discharge observations~~, in fact, cover~~ are incomplete, as they are only available for a limited ~~and not overlying period~~number of years (1990-2000 for Barou and 2004-2013 for Kompoungou~~) and are not complete.~~). We used the SWAT-CUP program and manual setup to calibrate the outflow ~~in~~of the two monitoring stations ~~reaching~~, and obtained satisfactory efficiency statistics (Moriasi et al., 2007) at monthly ~~scale~~scales. In Barou, the NSE (Nash–Sutcliffe model efficiency coefficient~~, (~~; Nash and Sutcliffe, 1970) is 0.87 and linear regression R^2 is 0.88, and in Kompoungou, the NSE is 0.77 and R^2 is 0.71. We used the SWAT-~~modeled~~-modelled discharges to consider an extended time period, required in particular to take into account climate variability, and to cover areas of the basin where observations are not available.

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3. Results

3.1 Biophysical variables: precipitation, temperature, and river discharge

3.1.1. Precipitation ~~and heat wave~~ patterns

Mean Annual Precipitation in the study area varies from 500 mm in the northern administrative units (Bottou, Tamou, Kirtachi and Falmey), to ~~about~~ a maximum of about 1,000-1,300 mm upstream in the southern portion of the basin (Kouandé, Kérou and Banikoara (Figure ~~S2~~S1). Generally, rainfall is highly variable in time and space, and follows a cyclical trend of wet and dry periods. The mean monthly precipitation for the wettest month (August) in the southern and northern regions varies between 200 mm and 300 mm, respectively, with the driest months (November-February) being close to zero.

~~In the period under consideration, mean annual temperature ranged between about 30º C in the North to 26.5º C in the South. April was the warmest month, with a maximum temperature of 40º C in the North and 35º C in the South. Minimum temperature in the coldest month (September) ranged between 19º C in the North and 15º C in the South, presenting the semi-arid region the highest range of variation of about 25ºC.~~ Comparing the precipitation patterns ~~over~~of a short- (2007-2016) ~~versus~~and a long- term (1981-2006), it was possible to identify a slight decrease ~~of~~in rainfall during August and September, while a moderate increase was detected during June and July (Figure 2). ~~Long~~However, long- and short- term Seasonal Kendall ~~analysis~~analyses, performed at a significance level $\alpha = 5\%$, ~~however, was~~were not able to identify any significant trend (Figure 2). Some spatial differences were identified analysing the last 10 years of the study: in that ~~regards~~regard, negative slopes were detected in the southern regions of Benin.

Figure 2. ~~Comparison~~Box-whiskers plot comparison of ~~seasonal distribution of~~monthly precipitation for the first 25 years of the time series versus the last 10 years ~~(left)~~ and Seasonal Mann-Kendall results ~~(right)~~. The Seasonal Mann-Kendal test performed did not highlight significant (p-value <0.010) increasing or decreasing trends in the analysis of the two precipitation time series.

3.1.2 Precipitation stress analysis

The results of the SPI-3 and SPI-6 ~~analysis~~analyses highlighted a period of moderate to extreme droughts during the earlier part of the 1980s; this could ~~be~~ also ~~noticed~~be seen in mean monthly precipitation values, where the overall rainfall ~~amount~~ from 1981 to 1985 is noticeably ~~below~~less than the long-term average (Figure 3). After this period, the positive ~~or~~and negative anomalies were found to be more erratic, presenting ~~an alternated~~alternate series of positive and negative events, such as some severe wet anomalies in the southern regions in 2003 ~~or~~and drought events in ~~the north~~northern regions in 1997. Regarding the last ten years~~, there are~~ of the study period, only few drought anomalies ~~affecting~~affected at least 40% of the administrative areas. ~~In particular, the~~The northern portion of the basin in Niger (communes of Tamou and Kirtachi) was affected by a moderate to severe drought event during 2011, while in 2014 a similar event hit the southern portion of the basin in Benin

(Banikoara, Kérou, Pehúnco and Kouandé). On the other hand, severe to extremely wet anomalies~~,~~ were ~~recorded~~ predominantly recorded during the years 2003, 2005, and 2007 in the entire Mékrou Area of Influence. ~~Summarizing~~Summarising the results derived from the analysis of the SPI, we found that the decade considered in the household survey was mainly ~~characterized~~characterised by precipitation in line with the long-term average. The anomalies were not particularly intense and most frequently related to wet conditions ~~if~~when considering the meteorological precipitation stress indicator (SPI-3~~–~~: 18 wet versus 15 dry anomalies), while a predominance of dry conditions was recorded when considering the agricultural precipitation stress (SPI-6: 17 dry versus 14 wet anomalies) (Figures ~~S3~~S2 and ~~S4~~S3).

Figure 3. Temporal monthly precipitation profile for the Mékrou Area of Interest

3.1.3 ~~Heat-waves~~Heatwaves

The spatio-temporal evolution of the ~~heat-wave magnitude index~~ Heat-Wave Magnitude Index (HWMI) between 1981 and 2015 is ~~presented~~represented in Figure 4. Despite some isolated events during 1987-1988 and some ~~other extreme~~extremes in 1998, the analysis highlighted a ~~constant~~constantly increasing trend ~~of~~in the ~~heat-waves'~~heatwave magnitude, starting in 2004. The spatial pattern, ~~instead~~however, is not clear, ~~being~~as the whole Mékrou Area of Influence was affected. In 2005, the HWMI was found to be higher in the central and northern ~~part~~parts of the basin, while ~~in 2006~~ the highest values in 2006 were recorded in the southern part, and in the northern part in 2010 (Figures ~~S5~~S4 and ~~S6~~S5).

In the period under consideration, mean annual temperature ranged between about 30º C in the North to 26.5º C in the South. April was the warmest month, with a maximum temperature of 40º C in the North and 35º C in the South. Minimum temperature in the coldest month (September) ranged between 19º C in the North and 15º C in the South, presenting the semi-arid region the highest range of variation of about 25ºC.

Figure 4. HWMI index computed for 1981 to 2015 ~~on~~for the Mékrou River area

3.1.4 River water flow trends

The annual river discharge resulting from model simulation for the period 1995-2012 is presented in Figure 5. The first 5 years of the simulation period (1990-1994) were discarded to consider an adequate model spin-up period.

Figure 5. ~~Mékrou river~~Daily average discharge of the Mékrou River at the Barou station, as modelled using SWAT for the period 1995-2012. The dashed line indicates the average of the total period under consideration.

~~,daily average discharge at Barou station as modelled in SWAT in the period 1995-2012. Dashed line indicates the average of the total period under consideration.~~

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Modelled discharge in the period under consideration averaged around 24 m^3/sec, corresponding to an average annual water flow of about 760 Mm^3 (ranging from 190 to 1,400 Mm^3 ~~respectively~~ in 1997 and 2008~~). Spatial~~, respectively). The spatial distribution of the water resources ~~follow~~follows the topography of the basin, making the headwaters~~,~~ (where annual discharge remains below 100 Mm^3~~,~~) particularly subject to inter- and intra-annual variability (Figure ~~S8~~S7). High annual variability of the river discharge is an important issue for the sustainable water use in the basin, especially considering that agriculture is the main economic activity and the lack of water storage infrastructures in the basin. Intra-annual discharge variability in the Mékrou ~~river basin~~River Basin follows the seasonal precipitation ~~seasonal~~ patterns: most abundant flows are reached after the rainy season ~~period~~ (July-November), ~~being~~with the peak flow being reached in the period Aug-Sep-Oct (Figure ~~S7~~S6).

The analysis of the simulated river flows highlighted the large inter-annual variability of the discharge. In about 8 of the 18 years under consideration, the average discharge was estimated to be below the long term average by more than 20%, while in 4 instances the simulated discharge was estimated to exceed the average by more than 20% (Figure 5). Although the analysis of the river discharge saw daily values with river discharge unusually high respect to the average, due to lack of data about flood propagation during historical events and detailed topography, we were not able to estimate the possible number of flood events in the domain of the study.

3.1.5 Analysis of the population perception on the occurrence of ~~extremes~~extreme events and climate variability

The household representatives ~~stated~~gave their personal ~~opinion~~opinions on the occurrence of specific ~~extremes~~extreme events in the Mékrou ~~basin~~River Basin during the last ten years of the study period (2006-2015) (Table ~~1~~24). The selection of this 10 ~~years~~-year framework allows ~~and~~for a relatively mid-term assessment of ~~the~~ past climatic events. Regarding the occurrence of droughts, 86.8% of the households declared an increasing trend in the period under consideration. This percentage is lower in Niger, but still ~~considerably~~quite high (71.5%). In addition, the vast majority of the local population (88.5%) ~~estimates~~estimated that the levels of rainfall decreased during the last ten years~~.~~ of the study period. This result is particularly evident in Benin and Burkina Faso (93.7% and 95.3~~%~~%, respectively). Not only did the rainfall ~~decreased~~decrease but ~~also~~, according to the local population~~,~~ (92.7~~%~~)%), the seasonal distribution also changed. In fact, the majority of the respondents (83%) ~~states~~stated that the rainy season started with a delayed onset during the last 10 years of the study period, whereas almost ~~the totality~~all respondents (91.8%) declared an earlier end ~~of~~to the season. Regarding ~~heat-waves~~heatwaves, 76% of ~~Mékrou's~~the interviewed population (62% in Benin) stated that periods of intense ~~heat-wave~~heatwaves became longer during the last 10 years~~.~~ of the study period. Regarding the number of events experienced, an increasing number of drought events were recorded ~~and appeared in~~, with a general frequency ~~mainly from none~~of 0 to 6 events. On average, the local population experienced ~~approximately 4~~in average 3.93 drought events ~~if considered~~when considering the whole Mékrou ~~basin~~River Basin (Table ~~2~~3). The number is higher in Burkina Faso (4.8 events) and slightly lower in Niger (3.4 events).

Concerning flood events, ~~the~~ opinions are less homogeneous over the whole Mékrou area. The majority (62%) of the respondents stated that ~~floods~~flood frequency did not increase over the ~~past~~last 10 years of the study period. This trend is quite heterogeneous among the three countries: 84.9% of the households in Benin agreed with the majority, the responses are discordant in Burkina Faso, whereas ~~in Niger~~ 72.2% of the respondents in Niger found an increasing flood frequency in the period under consideration. When asked about the ~~numbers~~number of flood events experienced, almost one third of the families stated that no flood events had occurred. The remaining replies are mostly distributed among 1 (23.3%), 2 (17.4%) and 3 (13.1%) events. As for the change in the frequency of the events ~~frequency~~, this ~~occurrence is different when looking~~varied across the three countries. In ~~Beninese part~~Benin, 60.7% of the population did not experience any flood during the last 10 years~~.~~ of the study period. On the other hand, ~~the larger flood event~~large numbers ~~are~~of flood events were recorded primarily in Niger, followed by Burkina Faso (Table ~~2~~35). In Benin, ~~only~~ an average of only 0.7 flood events was declared during the last 10 years of the study period, 1.8 in Burkina Faso and 3.5 in Niger. The combination of these results suggests that the Nigerien portion of the Mékrou ~~basin~~River Basin was the most prone to flood events in the period under consideration. Regarding both ~~floods~~flood and ~~droughts~~drought events, the perceptions ~~do not differentiate~~are heterogeneous across the three countries in the basin, with no difference based on different socioeconomic characteristics ~~apart from the heterogeneity among the three countries in the basin.~~. This could be explained by the homogeneity of the socioeconomic characteristics within the basin ~~although it is spread~~ across three countries.

Table ~~2~~4. ~~Table 1.~~ Observed climatic changes during the last 10 years of the study period: 2006-2015

Table ~~3~~5.

~~Table 2.~~ Statistical Analysis of reported number of floods and droughts during the last 10 years of the study period

3.2 ~~Floods and Droughts~~ Household results regarding Flood and Drought Mitigation Measures

This section provides an empirical analysis of the household mitigation measures. The ~~respondent had the choice~~respondents chose among 13 ~~mitigations~~mitigation strategies aimed at coping with changes in temperature and rainfall patterns. 8 ~~out~~ of the original 13 strategies were considered to be negligible due to a positive response rate lower than 10%, including: practicing off-season agriculture; application of more intensive irrigation; raising less livestock in order to increase crops; raising ~~less~~fewer small ruminants ~~for~~and switching to more cattle; raising less cattle and switching to camels; raising less sheep ~~for~~and switching to goats; adoption of specific techniques to regenerate the necessary grass cover for the livestock; and rent or mortgage land.

The mitigation measures that recorded a positive a response rate ~~above~~greater than 10% are: change of crop seeds; terracing the soil or using other methods to protect against erosion; ~~plantation of~~planting more trees; emigration of at least one household

member; ~~practicing more often~~ increasing the practice of non-agricultural activities as sources of revenue (Table ~~3~~6). Changing crop seeds is ~~a~~ quite a common strategy ~~mainly to adapt~~for adapting to rainfall changes, and is widely applied in Burkinabe and Nigerien areas (for around 60-65% of respondents), ~~but also in Benin in~~ and to a ~~smaller~~lesser extent in Benin (34%). The practice of terracing the soil ~~for preventing~~to prevent erosion is mostly applied in the Beninese part of the Mékrou ~~river basin~~River Basin. The ~~plantation~~planting of more trees is a common adaptation practice across the basin, due to both changes in precipitation (31%) and changes in temperature (20%). Emigration appears as an adaptation strategy to mitigate the economic losses resulting from the impacts of changes in rainfall patterns. Around 25% of households saw one of ~~its member migrating~~their members emigrating due to temperature and rainfall changes. ~~Secondary,~~ 16.4% of Beninese respondents ~~state~~stated that at least one member ~~migrated~~emigrated in the last 10 years of the study period due to rainfall changes. Finally, an important number of households, ~~primary~~primarily in Benin (~~-~~around 35%) and ~~secondary~~ in Niger (around 15%), ~~are practicing more often~~increasingly practice non-agricultural activities as ~~source~~sources of revenue to cope with the loss of income due to both rainfall and temperature changes.

Table ~~3~~4~~6~~. Household mitigation measures

3.3.~~3 Floods~~ Flood and ~~Droughts~~Drought impacts and their cost~~-~~ assessment

The local population of the Mékrou ~~has additionally~~River Basin also indicated the occurrence of extreme events during ~~a~~the two~~-years-~~year period 2014-2015. The ~~relative~~relatively recent occurrence of these events, some of ~~them~~which are still ongoing, allows for a more ~~thoughtful~~accurate estimation of the impacts and associated costs. Only a small percentage of the respondents (68 out of ~~in~~the total 660 interviewed households) stated that they had not experienced any flood occurrence during the ~~last~~ two years (Table ~~4~~57). However, the occurrence of events ~~differentiates among~~differs between the three countries, ~~whereas~~with most of the events ~~are~~being reported in Burkina Faso (34.5% of ~~the~~ households affected by floods). Aligning with the frequency of reported events, the impacts of ~~the~~ floods are proportionally more common in Burkina Faso. The most commonly reported impacts ~~regard~~are the ~~losses~~loss of agricultural production, ~~damages~~damage to ~~the~~ houses and loss of livestock (Table ~~5~~68).

~~Similarly, the~~ The same analysis was applied for ~~the~~ recent drought events. The vast majority (76.7%) stated that they ~~have~~had not experienced any drought event during the last two years~~.~~ of the study period. However, more droughts are reported compared to floods ~~resulting that~~ , with 152 of ~~in~~the total 660 households interviewed ~~households experienced~~experiencing an extreme drought event. ~~Likewise~~Similarly, the occurrence of droughts ~~are~~is heterogeneous across the three countries. Droughts are less prominent in Niger (Table ~~4~~57), where only a few droughts ~~are~~were reported, while ~~in Benin one fourth~~a quarter of the population ~~has~~in Benin had experienced droughts during the last two years~~.~~ of the study period. In Burkina Faso, almost half of the households ~~have~~had experienced droughts during the ~~last~~ two ~~years~~-year period. The impacts of the recent drought ~~are~~were mostly recorded in Burkina Faso and Benin (Table ~~5~~68) presenting a different profile. In Burkina Faso the impacts

referwere exclusively tomanifested as losses of agricultural production, while in Benin still the majority indicates most of the impact of the recent droughts was felt in the loss of agricultural production but states also, as well as malnutrition and loss of livestock as result of the recent droughts. Regarding. Both the flood and drought impacts, for both floods and droughts the collected information relates recorded relate to general categories of impacts, mainly agriculture, livestock, and housing without being , as it was not feasible to collect more in- depth qualitative characteristics of the impacts.

Table 4. Experienced extreme

Table 57. Extreme flood events experienced during the last two years of the study period (2014-2015)

Table 68.

Table 5. Impacts of extreme floods and droughts to theon households

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The The estimated flood costs to households differ among the three countries. The cost of the recent floods is higherhighest in Burkina Faso (Table 679), where the average cost forto an affected household inis 334,326 FCFA (West AfricaAfrican Francs) (approximately 495 510 Euroeuro in 2017). The estimated flood costs differ among the three countries whereas it is much higher in Burkina Faso (334,326 FCFA) than Benin and Niger (are 40,000 and 160,000 FCFA, respectively).. Furthermore, we observeobserved a difficulty fromamong the households to estimatein estimating the costs of the recent floods, especially in Benin and Niger, (the less affected countries,), where the majoritymost of the affected households were not able to provide a cost estimation. 20 out of 68 in total affected households in the basin were not able to provide a cost estimation of the floods they experienced floods. The average cost of the recent droughts, 256,440 FCFA (~391 Euro), iseuro), was almost the same in Burkina Faso and in Benin (Table 6)79), and was lower than the average cost of the recent floods. Again, in this case a difficultyit is evident from thethat households found it difficult to estimate the costs of the recent droughts, especially in Benin where the majority (61 out of the 152 households) of the affected households were not able to provide a cost estimation. In this case, 61 out of the 152 households that were affected by droughts were not able to provide a cost estimation. Regarding the geographical differentiation of the cost of both floods and droughts costs the, heterogeneity is observed among the three countries but not within the countries where costs are homogenous among the selected villages and towns. AdditionallyAlso, the small sample of the affected households affected by floods and droughts statistically does not allow theis insufficient for statistical aggregation of the estimated values to the total population of the basin.

Table 679. Estimated costs of the recent floodfloods and droughts (in FCFA)

3.4 Cost assessment of floods and droughts: an econometric estimation

AdditionallyIn addition to the statistical estimation of the cost of floods and droughts costs, two econometric models were developed to provide a reasoningan estimate of costs withbased on socioeconomic and other relative factors. A wide series of

independent variables of the household, such as socioeconomic conditions and mitigation measures ~~e.g. have been~~ , were used to find the determinants of the cost of extreme events ~~costs~~ and to estimate the ~~costs~~cost of floods and droughts. Using several regression models and a combination of independent variables, two models were set up ~~including~~that exclusively included statistically significant independent variables (P-value less than 0.05, and in one case slightly higher than 0.05 but less than 0.1). Table ~~7~~8~~10~~10 presents the total of the independent variables, including their scaling and ~~their~~ correlation. The latter is important for the coherence of the multivariate models, since low correlation among the independent variables excludes the existence of multicollinearity.

Table ~~7~~8~~10~~10. Selected independent variables for modelling the costs of floods and droughts

Regarding floods, the multivariate regression model in Table ~~8~~9~~11~~11 includes ~~as independent variable~~ the self-stated economic status (ECONSTAT) of ~~the~~ households as an independent variable and as a qualitative alternative to ~~the~~ household income. The model reveals a strong economic status effect, meaning that the richer the ~~households are~~household, the higher ~~are~~ the economic ~~impacts~~impact of ~~flood~~floods. The negative sign is due to the structure of the variable scaling (where 1 ~~meaning~~represents rich and 5 ~~much worse~~represents significantly poorer economic ~~condition~~conditions than the other households). ~~Additionally, two~~Two of the main flood impacts, loss of crop productivity (CropProdLoss) and loss of livestock (LivestockLoss) were included in the model as independent variables, and were found to be significant. According to the multivariate regression model, the average cost of floods per household during the flood events of the last two years of the study period (2014-2015) was equal to 390.92 euro. In order to avoid problems of multicollinearity, correlation among the independent variables was tested. The calculated Pearson's R values, all below the 0.3 threshold, suggest a low correlation among the independent variables.

Table ~~8~~9~~11~~11. Costs of floods – Multivariate linear regression model

Similarly, a multivariate regression model was applied to estimate the costs of droughts (Table ~~9~~1~~0~~2). The independent variable related to loss of livestock was found to have a strong effect in this model too. However, drought costs are found to significantly depend on the total crop production of the households (PRODCROP). According to this regression model, the estimated cost of droughts per household that experienced drought events during the last two years of the study period (2014-2015) was 494.76 euro. Similarly low ~~correlation was~~correlations were detected among the independent variables.

Table ~~9~~1~~0~~2. Costs of droughts - Multivariate linear regression model

4 Discussion and Conclusions

This paper combines the results of a household survey and climate data analysis to assess floods ~~and,~~ droughts ~~as well as~~and climate variability in the Mékrou ~~river basin~~River Basin in West Africa. The opinions and perceptions of household representatives revealed ~~a~~ strong climate variability ~~at~~over a ten ~~years~~-year period (2006-2015). It is worth mentioning that 83% of the population~~, during this period,~~ noticed a delayed onset of the rainy season~~.~~ during this period. In addition, 91% of the population also observed ~~also~~ an ~~anticipated~~early end of the wet season. Moreover, 88.5% of the respondents reported a general reduction ~~of the~~in precipitation during the ten ~~years~~-year period under consideration, and 75.9% reported an increase in the magnitude and frequency of ~~the~~ extreme heat events. This tendency is partially confirmed by the analysis of ~~the~~ climatic variables, mainly based on precipitation and temperature data. The findings of the analysis confirmed the increase ~~of~~in both the frequency and magnitude of ~~the heat waves~~heatwaves in the ~~area of~~ study area. The climatic variability was also found to be noticeably high, but the Mann Kendall analysis failed ~~in finding~~to find statistically significant trends in the precipitation patterns. It was not possible to clearly identify ~~clearly~~ a shift ~~of~~in the intra-annual temporal distribution of ~~the~~ precipitation, ~~neither indicating~~ as there was no indication of a slightly delayed onset nor an ~~anticipated~~early end of the rainy season.

~~Regarding the occurrence of floods and droughts, the~~The survey-based findings revealed a substantial ~~differentiation among these two events. Especially concerning~~difference between the occurrence of floods and droughts. With regard to droughts, 86.8% of the population reported that dry periods were more frequent during the ten years ~~ranging between~~from 2006 ~~and~~to 2015, while 23.3% experienced an extreme drought event during the last two years (2014-2015~~)~~), resulting in 3.93 extreme drought events ~~in~~on average. ~~Flood~~Fewer flood events ~~were reported to be less~~ than drought events were reported by the local population. More than 60% of the respondents stated that flood frequency did not change during the period 2006-2015, and only 10.3% of the population experienced an extreme flood event during the period 2014-2015 (~~in average~~ 1.69 extreme flood events on average per household). The ~~judgement~~perceptions of the local population ~~was~~were confirmed by the ~~findings of the analysis of the~~ climatic factors regarding flood events. ~~The~~An analysis of ~~the~~ extreme precipitation in the past 30 years~~, in fact,~~ did not report a significant increasing trend in the occurrence of flood events. Similar conclusions, but this time ~~in disagreement with~~contrary to the impressions of the local population, were derived from the analysis of ~~the~~ dry periods. This difference ~~among~~between perceived occurrence and observed droughts could be explained by the misperception of the local population confounding the observed increasingly frequent ~~heat wave~~heatwave events ~~as~~with more frequent droughts. However, ~~the~~an analysis of the meteorological (SPI-3) and agricultural (SPI-6) drought indicators~~,~~ confirmed the occurrence of a number of dry periods that could be in line with ~~the ones~~those reported by the local population in the portion of the basin ~~laying~~located within the borders of Benin and Niger. On the other hand, the analysis of the SPI failed to find any significant dry periods in the Beninese portion of the Mékrou River Basin.

The household survey analysis reported ~~additional~~ important findings regarding the measures adopted by the ~~household~~households of the Mékrou ~~river basin~~River Basin to mitigate floods and droughts. ~~Among~~From a list of options, the most significant household mitigation measures were identified ~~among change of~~as being: changing crop seeds, ~~plantation of~~planting more trees, ~~practicing more often~~and increased practice of non-agricultural economic activities, while, especially in Niger, a considerable part of the population ~~migrates~~emigrated due to the ~~losses~~loss in ~~agriculture~~agricultural production caused by the ~~decreased~~reduced rainfall. ~~Indicative are also the~~The findings regarding the impacts of floods and droughts and their costs~~.~~ are also interesting. For those households that experienced an extreme flood event during the period 2014-2015, the most frequent impacts were reported to be crop production losses, damages to houses, and loss of livestock. ~~At the same time, the~~The loss of crop production, malnutrition, and the loss of livestock were the most important impacts of extreme droughts. ~~Additionally, to specifying~~In addition, the total cost per household of the impacts of extreme floods and droughts~~, their total costs per household~~ was estimated. The cost assessment is two-folded based on the sample estimations ~~as well as on the results of~~and the application of two linear multivariate regression econometric models. The average ~~costs caused by~~cost of flood events in the period 2014-2015 was estimated ~~in~~at ~~522~~ 495 ~~Euro~~euro per affected household ~~basing~~, based on the average declared losses. ~~Regarding the~~The average cost ~~assessment~~ of extreme droughts ~~the average value of the sample~~ was ~~390~~ 391 ~~Euro~~euro per household. This study confirmed the difficulty ~~in~~of estimating the costs of natural ~~hazard cost estimation~~hazards at the household level, even in the case of recent events. A considerable percentage of ~~the~~ household representatives (27% for floods and 38% for droughts) were not able to provide an estimation of the costs of the extreme events that they recently experienced.

Regarding the methodological approach of this work, the combination of the household survey data analysis with the study of the climatic variables could provide an integrated assessment of floods and droughts, especially in cases ~~like~~such the Mékrou ~~river~~River Basin, where ~~the accessibility~~access to reliable information is very limited. The survey approach, in particular, could provide data at household level that could be used for a detailed qualitative and quantitative assessment of natural hazards ~~like~~, such as floods and droughts. Potential limitations of this approach are mainly ~~refer to~~ the information biases and misperceptions of the local population ~~that~~, which could influence the ~~objectiveness~~objectivity of their responses. Furthermore, such a survey approach depicts the opinions ~~at~~within a specific ~~time framework~~timeframe and, therefore, should be periodically repeated to better validate the findings. This ~~implies the need of~~would require increased financial and human resources ~~dedicated to this purpose.~~. The major potential benefit of this approach is ~~to provide~~that it provides information to support decision~~-~~makers and local governments, leading to the more effective and efficient design of ~~floods~~flood and ~~droughts~~drought mitigation policies and measures. Most often, natural hazards risk mitigation ~~measure~~measures and policies use either climate modelling tools or socioeconomic ~~analysis~~analyses, but rarely ~~combining~~combine both ~~sectors~~. In developing countries where information is limited, such a coupling approach could ~~integrated~~integrate local characteristics and perceptions into natural ~~hazards~~hazard planning policies ~~providing~~, in order to provide more efficient mitigation measures. More specific, such an

approach could be used by state and local authorities to design risk mitigation and prevention measures and design climate adaptation strategies combining climate and socioeconomic analysis.

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Author Contributions

Vasileios Markantonis, Celine Dondeynaz and Cesar Carmona Moreno designed the household survey and analysed the data. Fabio Farinosi, Iban Ameztoy, Marco Pastori, Luca Marletta and Abdou Ali ~~performed the analysis of~~analysed the climate data. Vasileios Markantonis, Celine Dondeynaz, Fabio Farinosi and Iban Ameztoy prepared the first draft of the manuscript. All authors discussed the results and commented on the manuscript at all stages.

Conflicts of Interest

The authors declare no conflict of interest.

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TABLES

Table 1. Sample and population of the survey area

Population of the Mékrou Area of Interest						
Benin	Burkina Faso	Niger	Total area			
294921	79632	173115	547668			
Surveyed Sample (Households)						
Benin	Burkina Faso	Niger	Total area			
332	148	180	660			
Sample (number of households) by selected Communes						
Benin			Burkina Faso		Niger	
Banikorara	Kérou	Kouandé	Diapaga	Tansagra	Tamou	Birni Ngaoure
160	80	92	95	53	100	80
Population and Sample (number of households) by Selected Village / town						
Banikoara						
	Sampéto	Gbéniki (Kérémou)	Wangouwirou	Banikoara (town)	Total	
Population	1 522	786	3799	28402	32987	
Sample	29	20	52	52	153	
Kouande						
	Béket Bouramè	Mekrougourou	Goufanrou	Kouandé (town)	Total	
Population	1876	2635	1835	20723	27069	
Sample	20	27	20	25	92	
Kérou						
	Koussou Ouinra	Yakrigourou	Bipotoké	Kérou (town)	Total	
Population	2842	2766	2871	34246	42725	
Sample	16	19	16	36	87	
Diapaga						
	Mangou	Tyaga	Diapaga (town)	Total		

Population	1600	1136	16000	18736	
Sample	28	20	40	88	
Tansagra					
	Kotchari	Lada	Tansarga (town)	Total	
Population	1024	720	14000	15744	
Sample	20	16	24	60	
Birni Ngaoure					
	Boumba	Fono Birgui	Kotaki	Flamey Djema (town)	Total
Population	1414	560	2447	4467	8888
Sample	12	8	20	40	80
Tamou					
	Tankoune	Diney Bangou	Foulan Walagorou	Tamou (town)	Total
Population	827	724	261	1827	3639
Sample	28	28	4	40	100

Table 2. Socioeconomic characteristics of the surveyed sample

***Age** (sample respondents)*							
Benin		*Burkina Faso*		*Niger*		*Total Area*	
Mean	*StdDev*	*Mean*	*StdDev*	*Mean*	*StdDev*	*Mean*	*StdDev*
41.2	*14.9*	*44.2*	*16.2*	*49.5*	*15.3*	*44.2*	*15.7*
***Age Distribution** (Total Area Population based on survey aggregation)*							
	Benin	*Burkina Faso*	*Niger*	*Total Area*			
0-5	*17.10%*	*23.50%*	*20.20%*	*19.50%*			
5-18	*32.90%*	*34.40%*	*31.30%*	*32.70%*			
18+	*49.90%*	*42.10%*	*48.60%*	*47.90%*			
***Gender** (sample respondents)*							
	Benin		*Burkina Faso*		*Niger*		*Total Area*	
	Count	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*
Male	*226*	*68.1%*	*95*	*64.2%*	*129*	*71.7%*	*450*	*68.2%*
Fenale	*106*	*31.9%*	*53*	*35.8%*	*51*	*28.3%*	*210*	*31.8%*
***Education** (sample respondents)*								
	No schooling	*No formal schooling*	*Primary school*	*Secondary school*	*Professional education*	*University*		
Count	*389*	*87*	*81*	*78*	*8*	*17*		
%	*58.90%*	*13.20%*	*12.30%*	*11.80%*	*1.20%*	*2.60%*		
***Profession** (sample respondents)*								
	Unemployed	*Self epmployed*	*public employee*	*Farmer*	*Livestock farmer*	*Other*		
%	*7.70%*	*18.90%*	*2.30%*	*50.10%*	*15.90%*	*5.10%*		
***Household Income [FCFA per month] 1 euro = 656 FCFA** (sample respondents)*								
	0 - 25000	*25001 - 50000*	*50001 - 75000*	*75001 - 100000*	*more than 100001*	*I don't know*		
Count	*200*	*100*	*77*	*37*	*414*	*121*		
%	*30.50%*	*15.20%*	*11.70%*	*5.60%*	*18.60%*	*18.40%*		

Table ~~13~~. Standardized Precipitation Index categorization and associated probability of occurrence (Agnew 2000)

SPI-n	Probability of Occurrence	Class
> 1.65	0.05	Extremely Wet
1.28 / 1.64	0.1	Severely Wet
0.84 / 1.27	0.2	Moderately Wet
-0.84 / 0.84	0.5	Normal
-1.28 / -0.83	0.2	Moderate Drought
-1.65 / -1.27	0.1	Severe Drought
< -1.65	0.05	Extreme Drought

Table ~~24~~. Observed climatic changes during the last 10 years of the study period: 2006-2015

	BENIN		BURKINA FASO		NIGER		Mékrou Basin	
	count	**%**	**count**	**%**	**count**	**%**	**count**	**%**
Change of the rainfall quantity								
No change	8	2.4%			4	2.2%	12	1.8%
Less rain	311	93.7%	141	95.3%	132	73.3%	584	88.5%
More rain	13	3.9%	7	4.7%	44	24.4%	64	9.7%
Total responses	332		148		180		660	
Distribution of the rainfall in the year								
No change	21	6.3%			4	2.2%	25	3.8%
Better distribution	16	4.8%	2	1.4%	5	2.8%	23	3.5%
Worse distribution	295	88.9%	146	98.6%	171	95.0%	612	92.7%
Total responses	332		148		180		660	
More frequent droughts								
YES	297	89.5%	147	99.3%	128	71.5%	572	86.8%
NO	35	10.5%	1	0.7%	51	28.5%	87	13.2%
Total responses	332		148		179		659	
More frequent floods								
YES	50	15.1%	76	51.4%	130	72.2%	256	38.8%
NO	282	84.9%	72	48.6%	50	27.8%	404	61.2%
Total responses	332		148		180		660	
Delay in the start of the rainy season								
YES	248	74.7%	139	93.9%	161	89.4%	548	83.0%
NO	84	25.3%	9	6.1%	19	10.6%	112	17.0%
Total responses	332		148		180		660	
Rainy season finishes earlier								
YES	293	88.3%	146	98.6%	163	92.6%	602	91.8%
NO	39	11.7%	2	1.4%	13	7.4%	54	8.2%
Total responses	332		148		176		656	
Periods of extreme heat								
No change	34	10.2%	10	6.8%	15	8.5%	59	9.0%
Shorter	75	22.6%	7	4.7%	17	9.7%	99	15.1%
Longer	223	67.2%	131	88.5%	144	81.8%	498	75.9%
Total responses	332		148		176		656	

Table 2~~3~~5. Statistical Analysis of reported number of floods and droughts during the last 10 years

	Mékrou Basin	Benin	Burkina Faso	Niger
		Floods		
Mean	1.690~~1141~~	0.732~~7554~~	1.783~~784~~	3.~~45833~~346
Standard Deviation	2.~~06730~~307	1.~~15831~~416	1.431~~143~~	2.644~~289~~
		Droughts		
Mean	3.933~~962~~	3.~~82769~~283	4.~~79729~~780	3.361~~963~~
Standard Deviation	2.~~82932~~583	2.951~~433~~	2.72~~942~~	2.~~48904~~349

Table ~~3~~46. Household mitigation measures

	BENIN		BURKINA FASO		NIGER		Mékrou Basin	
	count	%	count	%	count	%	count	%
Change of crop seeds								
Action taken due to temperature								
YES	50	16.2%	29	19.6%	5	2.8%	84	13.2%
NO	259	83.8%	119	80.4%	175	97.2%	553	86.8%
Action taken due to rainfall								
YES	110	34.0%	99	66.9%	110	61.1%	319	48.9%
NO	214	66.0%	49	33.1%	70	38.9%	333	51.1%
Terracing the soil or using other methods to protect against erosion								
Action taken due to rainfall								
YES	77	23.8%	26	17.6%	19	10.6%	122	18.7%
NO	247	76.2%	122	82.4%	161	89.4%	530	81.3%
Plantation of more trees								
Action taken due to temperature								
YES	84	27.2%	33	22.3%	8	4.4%	125	19.6%
NO	225	72.8%	115	77.7%	172	95.6%	512	80.4%
Action taken due to rainfall								
YES	112	34.6%	39	26.4%	51	28.3%	202	31.0%
NO	212	65.4%	109	73.6%	129	71.7%	450	69.0%
Emigration of at least one household member								
Action taken due to rainfall								
YES	53	16.4%	12	8.1%	46	25.6%	111	17.0%
NO	271	83.6%	136	91.9%	134	74.4%	541	83.0%
Practicing more often non-agricultural activities as sources of revenue								
Action taken due to temperature								
YES	100	32.3%	11	7.4%	32	17.8%	143	22.4%
NO	210	67.7%	137	92.6%	148	82.2%	495	77.6%
Action taken due to rainfall								
YES	119	36.6%	14	9.5%	20	11.1%	153	23.4%
NO	206	63.4%	134	90.5%	160	88.9%	500	76.6%

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Table ~~4~~57. Experienced extreme flood events during the last two years (2014-2015)

	BENIN		BURKINA FASO		NIGER		Mékrou Basin	
	count	%	count	%	count	%	count	%
Floods								
YES	9	2.7%	51	34.5%	8	4.4%	68	10.3%
NO	322	97.3%	97	65.5%	172	95.6%	591	89.7%
Droughts								
YES	83	25.5%	66	44.9%	3	1.7%	152	23.3%
NO	243	74.5%	81	55.1%	177	98.3%	501	76.7%

Table ~~5~~68. Impacts of extreme floods and droughts to the households

	BENIN	BURKINA FASO	NIGER	Mékrou Basin
	count	count	count	count
Impacts of floods				
Damage to the house	3	24	5	32
Loss of agricultural production	8	44	7	59
Injury or death of a household member		1	3	4
Loss of livestock		16	4	20
Impacts of droughts				
Loss of agricultural production	74	66	3	143
Malnutrition of at least one household person	41	4	2	47
Loss of livestock	20	4	3	27

Table ~~6~~7~~9~~. Estimated costs of the recent flood and droughts (in FCFA)

	Mékrou Basin	Benin	Burkina Faso	Niger
	Costs of floods			
Mean	324563 (~495 EURO)	40~~,~~000	334~~,~~326	160~~,~~000
Standard Deviation	373159		378~~,~~071	
	Costs of droughts			
Mean	256440 (~391 EURO)	262~~,~~184	252~~,~~803	0
Standard Deviation	324224	257~~,~~676	362~~,~~150	0

Table ~~7~~810. Selected independent variables for modelling costs of floods and droughts

Variable	***Scaling***	***Correlation***
ECONSTAT	1. Rich, 2. Relatively rich, 3. Average, 4. Below average, 5. Much worse than average	CropProdLoss: -0.0786 LivestockLoss: -0.134
CropProdLoss	0 (no impact), 1 (impact)	LivestockLoss: -0.017
LivestockLoss	0 (no impact), 1 (impact)	PRODCROP: 0.212
PRODCROP	Numerical Value	

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Table ~~8~~911. Costs of floods – Multivariate linear regression model

Number of obs = 48	**R-sq: 0.4828**	**F-test: 7.842**	
Independent Variables	Coef.	Std. Err.	P>z
ECONSTAT	-128~~,~~548.5	47850.09	0.01
CropProdLoss	287~~,~~269.9	129224.5	0.031
LivestockLoss	359~~,~~272.4	92753.99	0
cons	429~~,~~595.2	225058.3	0.063
Cost Estimate / household	256~~,~~441 (FCFA)	390.92 (EURO)	

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Table 9102. Costs of droughts - Multivariate linear regression model

Number of obs = 98	**R-sq: 0.1907**	**F-test: 11.196**		
Independent Variables		Coef.	Std. Err.	P>z
PRODCROP		14.088011	3.643078	0
LivestockLoss		137,261.8	74243.4	0.068
_cons		130,367.5	39952.2	0.002
Cost Estimate / household		324,563 (FCFA)	494.76495 (EURO)	

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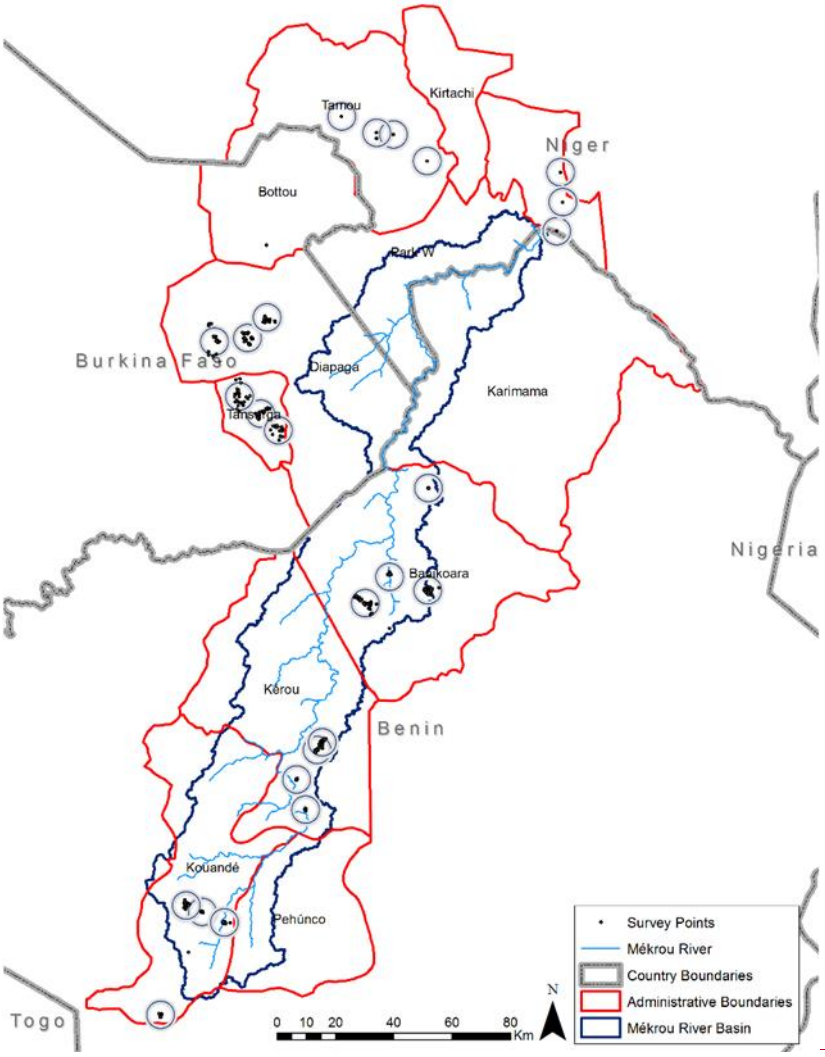
Figure 1. The Mékrou ~~river basin~~River Basin and the household survey area



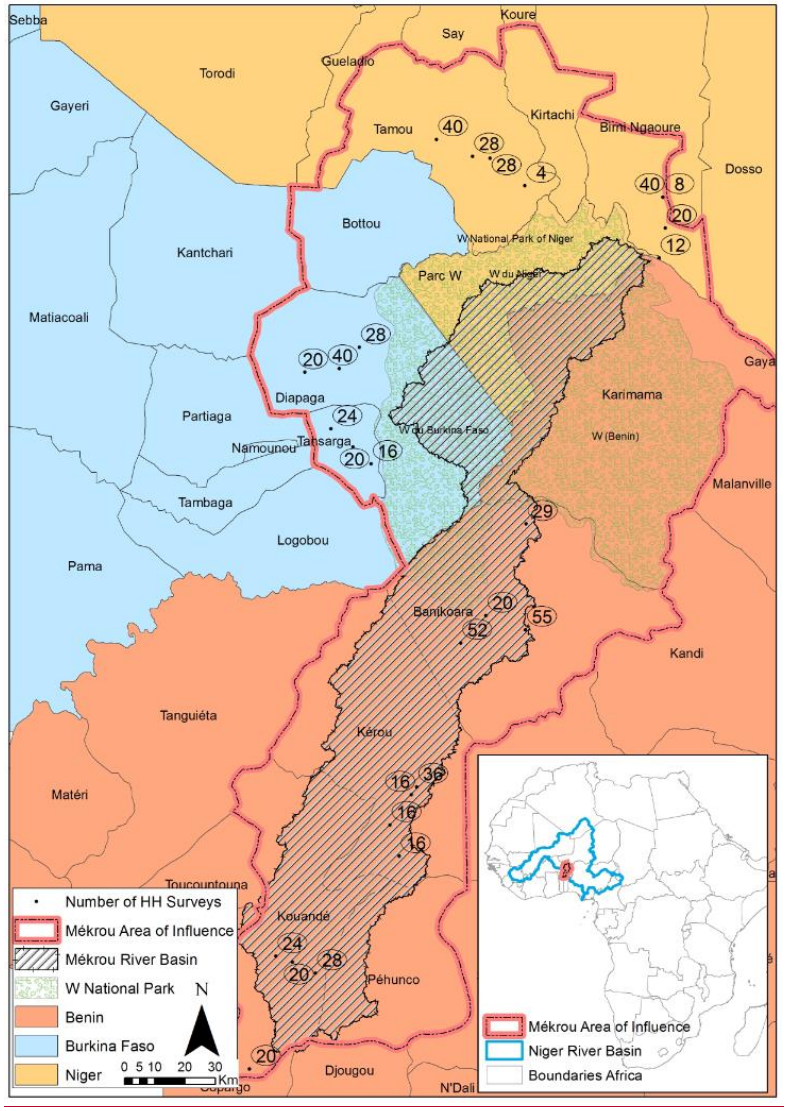
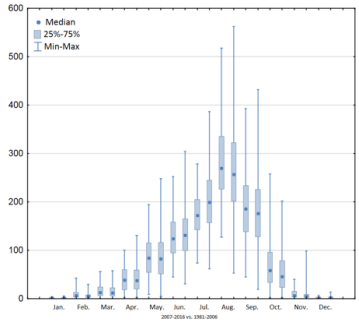

Sebba
Koure
Say
Torodi
Guelaadio
Gayeri
Tamou
Kirtachi
Birni Ngaoure
Dosso
Bottou
W National Park of Niger
Kantchari
Parc W
W du Niger
Matiacoali
Gaya
Karimama
Diapaga
Partiaga
W du Burkina Faso
W (Benin)
Namounou
Tansarga
Malanville
Tambaga
Logobou
Pama
Banikoara
Kandi
Tanguiéta
Kérou
Matéri
Toucountouna
Kouandé
Péhunco
Djougou
N'Dali
Number of HH Surveys
Mékrou Area of Influence
Mékrou River Basin
W National Park
Benin
Burkina Faso
Niger
N
0 5 10 20 30
Km
Mékrou Area of Influence
Niger River Basin
Boundaries Africa

Figure 2. ~~Comparison~~Box-whiskers plot comparison of ~~seasonal distribution of~~monthly precipitation for the first 25 years of the time series versus the last 10 years and Seasonal Mann-Kendall results. The Seasonal Mann-Kendal test performed did not highlight significant (p-value <0.010) increasing or decreasing trends in the analysis of the two precipitation time series.



Last 10 years (2007-2016)

id	country	region	Mann-Kendall trend test for monthly environmental time series by Regions: Kendall Score (S)	variance of S	two-sided p-value	Kendall's tau statistic	Seasonal Sen's slope and intercept: value of Sen's slope	intercept
1	Benin	Banikoara	-49	1491.6670	0.2045	-0.0913	-0.00250	35.238
2	Benin	Pehunco	-42	1500.0000	0.2782	-0.0778	-0.06025	68.334
3	Benin	Karimama	-21	1456.3330	0.5821	-0.0400	0.00000	20.684
4	Benin	Kounde	-36	1500.0000	0.3526	-0.0667	-0.04139	65.821
5	Benin	Kerou	-40	1498.0000	0.3014	-0.0742	-0.02008	42.826
6	Burkina Faso	Tansarga	-10	1389.3330	0.7885	-0.0197	0.00000	24.686
7	Burkina Faso	Bottou	46	1371.3330	0.2142	0.0915	0.00000	16.893
8	Burkina Faso	Diapaga	18	1456.0000	0.6371	0.0343	0.00000	23.632
9	Niger	Parc W	43	1379.6670	0.2470	0.0852	0.00000	16.875
10	Niger	Kirtachi	26	1229.3330	0.4584	0.0587	0.00000	8.492
11	Niger	Tamou	66	1355.3330	0.0730	0.1326	0.00000	10.338
12	Niger	Boboye	12	1419.3330	0.7501	0.0232	0.00000	9.178

All Time Series (1981-2016)

id	country	region	Mann-Kendall trend test for monthly environmental time series by Regions: Kendall Score (S)	variance of S	two-sided p-value	Kendall's tau statistic	Seasonal Sen's slope and intercept: value of Sen's slope	intercept
1	Benin	Banikoara	259	64624.3300	0.3083	0.0344	0.00052	31.010
2	Benin	Pehunco	349	64679.0000	0.1700	0.0462	0.01184	57.116
3	Benin	Karimama	-74	62939.3300	0.7680	-0.0100	0.00000	18.261
4	Benin	Kounde	421	64679.0000	0.0978	0.0557	0.01200	58.271
5	Benin	Kerou	397	64666.3300	0.1185	0.0526	0.00518	40.286
6	Burkina Faso	Tansarga	321	61339.6700	0.1949	0.0444	0.00000	24.718
7	Burkina Faso	Bottou	78	61251.3300	0.7526	0.0108	0.00000	13.290
8	Burkina Faso	Diapaga	324	62905.3300	0.1964	0.0440	0.00000	20.995
9	Niger	Parc W	112	59376.0000	0.6458	0.0160	0.00000	12.023
10	Niger	Kirtachi	-149	56234.3300	0.5298	-0.0225	0.00000	6.679
11	Niger	Tamou	79	59789.0000	0.7466	0.0112	0.00000	8.413
12	Niger	Boboye	-132	61726.0000	0.5952	-0.0182	0.00000	7.091

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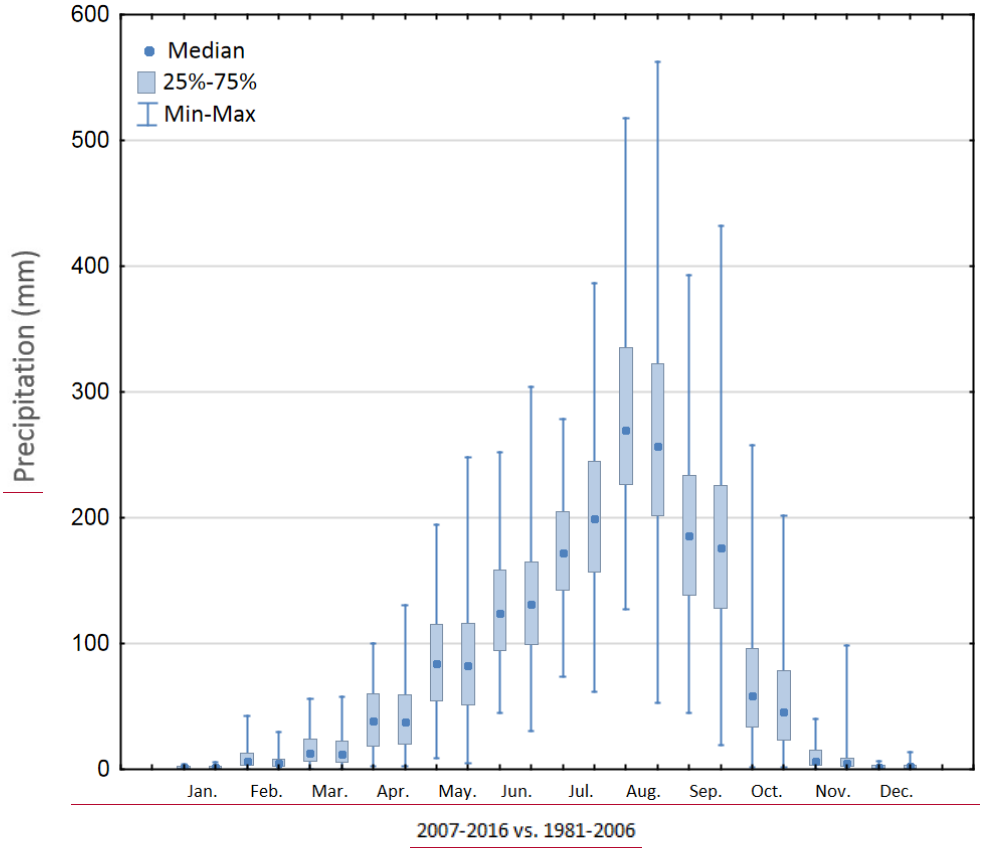

Median
25%-75%
Min-Max
Precipitation (mm)
600
500
400
300
200
100
0
Jan.
Feb.
Mar.
Apr.
May.
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
2007-2016 vs. 1981-2006

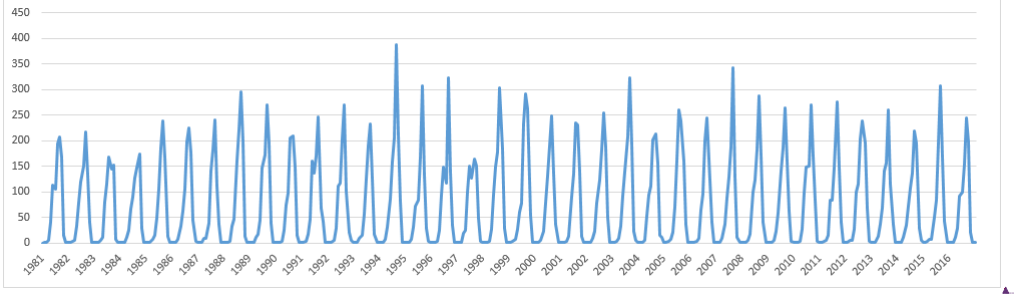
Last 10 years (2007-2016)

			Mann-Kendall trend test for monthly environmental time series by Regions				Seasonal Sen's slope and intercept	
id	country	region	Kendall Score (S)	variance of S	two-sided p-value	Kendall's tau statistic	value of Sen's slope	intercept
1	Benin	Banikoara	-49	1491.6670	0.2045	-0.0913	-0.00250	35.238
2	Benin	Pehunco	-42	1500.0000	0.2782	-0.0778	-0.06025	68.334
3	Benin	Karimama	-21	1456.3330	0.5821	-0.0400	0.00000	20.684
4	Benin	Kounde	-36	1500.0000	0.3526	-0.0667	-0.04139	65.821
5	Benin	Kerou	-40	1498.0000	0.3014	-0.0742	-0.02008	42.826
6	Burkina Faso	Tansarga	-10	1389.3330	0.7885	-0.0197	0.00000	24.686
7	Burkina Faso	Bottou	46	1371.3330	0.2142	0.0915	0.00000	16.893
8	Burkina Faso	Diapaga	18	1456.0000	0.6371	0.0343	0.00000	23.632
9	Niger	Parc W	43	1379.6670	0.2470	0.0852	0.00000	16.875
10	Niger	Kirtachi	26	1229.3330	0.4584	0.0587	0.00000	8.492
11	Niger	Tamou	66	1355.3330	0.0730	0.1326	0.00000	10.338
12	Niger	Boboye	12	1419.3330	0.7501	0.0232	0.00000	9.178

All Time Series (1981-2016)

			Mann-Kendall trend test for monthly environmental time series by Regions				Seasonal Sen's slope and intercept	
id	country	region	Kendall Score (S)	variance of S	two-sided p-value	Kendall's tau statistic	value of Sen's slope	intercept
1	Benin	Banikoara	259	64624.3300	0.3083	0.0344	0.00052	31.010
2	Benin	Pehunco	349	64679.0000	0.1700	0.0462	0.01184	57.116
3	Benin	Karimama	-74	62939.3300	0.7680	-0.0100	0.00000	18.261
4	Benin	Kounde	421	64679.0000	0.0978	0.0557	0.01200	58.271
5	Benin	Kerou	397	64666.3300	0.1185	0.0526	0.00518	40.286
6	Burkina Faso	Tansarga	321	61339.6700	0.1949	0.0444	0.00000	24.718
7	Burkina Faso	Bottou	78	61251.3300	0.7526	0.0108	0.00000	13.290
8	Burkina Faso	Diapaga	324	62905.3300	0.1964	0.0440	0.00000	20.995
9	Niger	Parc W	112	59376.0000	0.6458	0.0160	0.00000	12.023
10	Niger	Kirtachi	-149	56234.3300	0.5298	-0.0225	0.00000	6.679
11	Niger	Tamou	79	59789.0000	0.7466	0.0112	0.00000	8.413
12	Niger	Boboye	-132	61726.0000	0.5952	-0.0182	0.00000	7.091

Figure 3. Temporal monthly precipitation profile for the Mékrou Area of Interest



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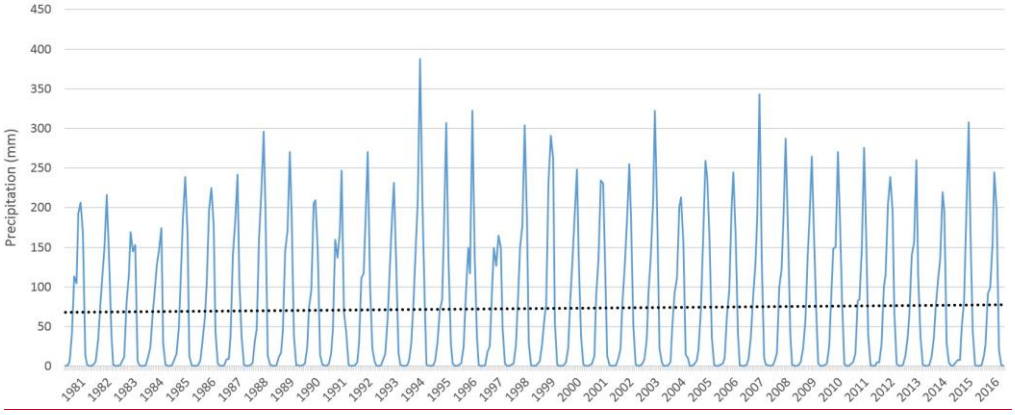
Precipitation (mm)
450
400
350
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250
200
150
100
50
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1981
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1983
1984
1985
1986
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1988
1989
1990
1991
1992
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1998
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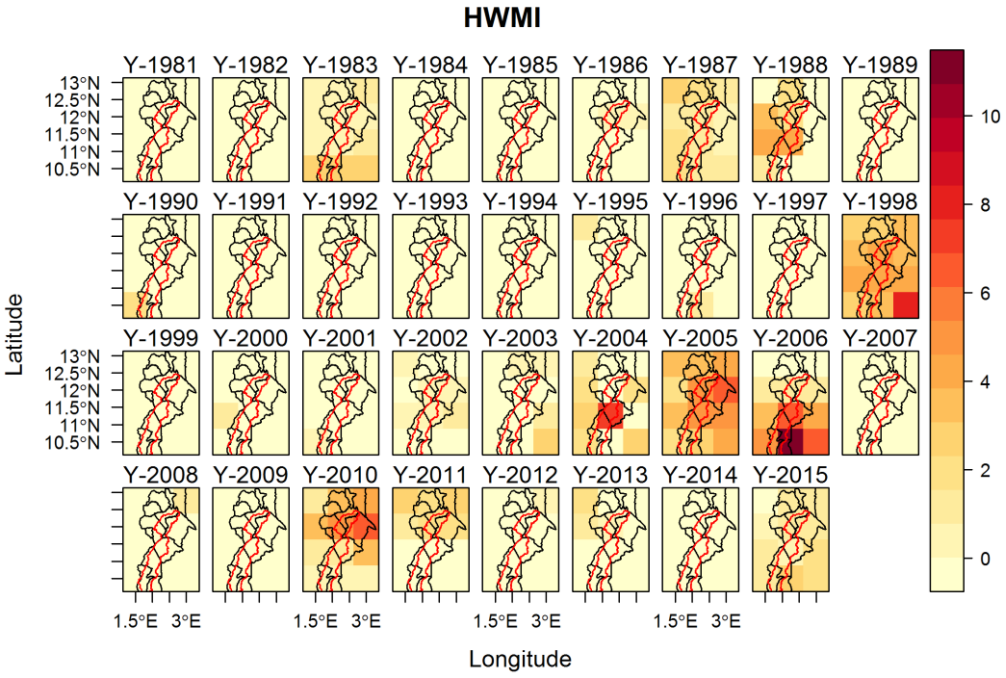
2016

Figure 4. HWMI index computed for 1981 to 2015 on the Mékrou



~~Figure 5. Mékrou river daily average discharge at Barou station as modelled in SWAT in the period 1995-2012. Dashed line indicates the average of the total period under consideration.~~

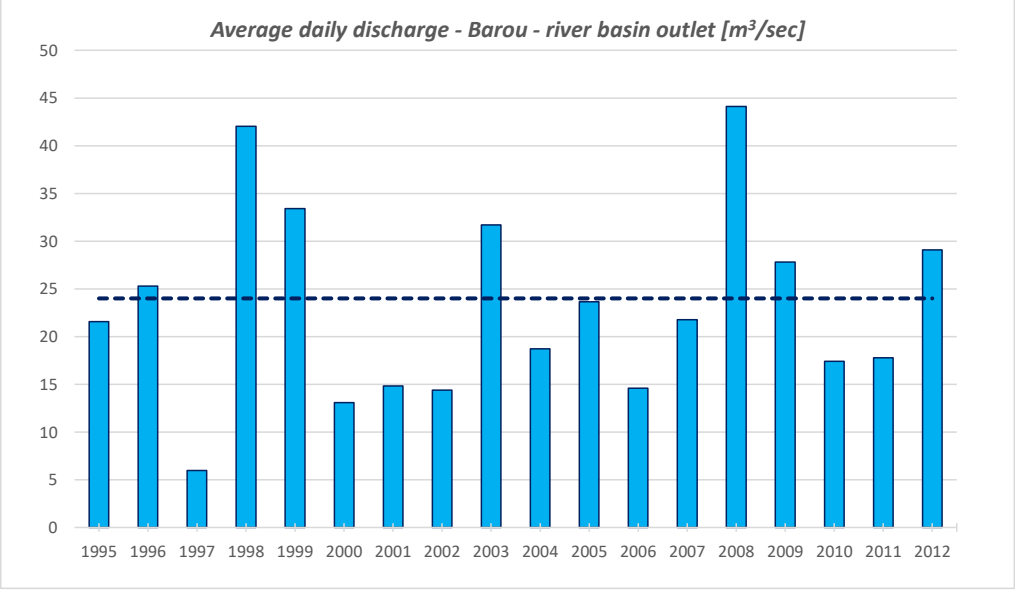


Figure 5. Mékrou River daily average discharge at Barou station as modelled in SWAT in the period 1995-2012. Dashed line indicates the average of the total period under consideration.

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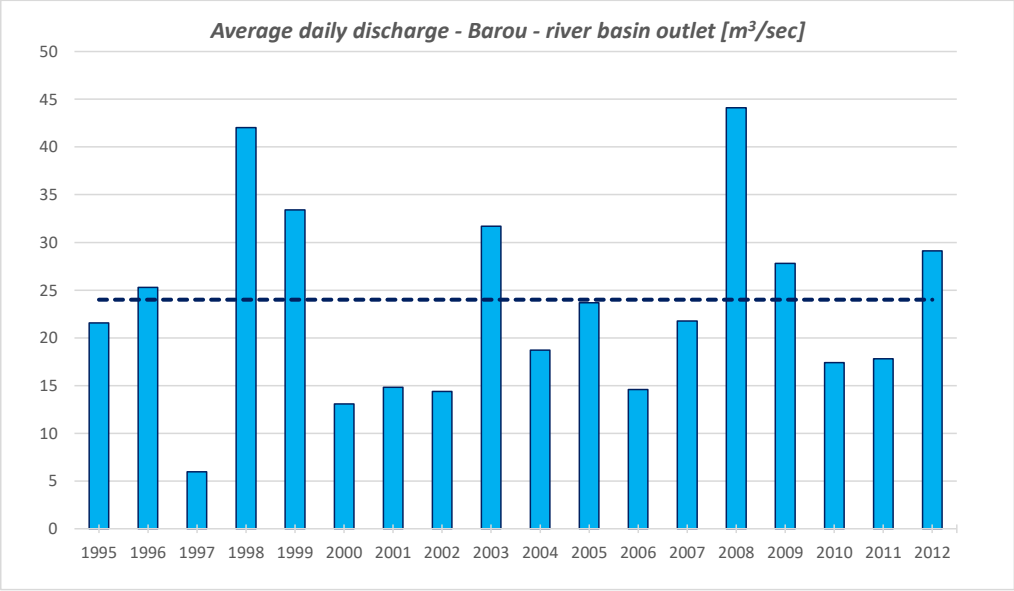

APPENDIX A.

QUESTIONNAIRE