

Point by point response to Reviewers comments

1st Reviewer

- I think something is wrong with Tables 11 and 12 (the captions are the other way round?)

Authors Response:

We have checked the Tables 11 and 12 and they are absolutely corresponding to the captions.

- I think the point of the exercise of Section 3.4. is to find statistical relationships between the reported cost figures and socioeconomic and behavioral variables. In other words, it is not "estimating" anything (indeed, the "estimates" reported in Tables 11 and 12 are almost identical with the figures reported in Table 9). I think "an econometric estimation" in the title of Section 3.4 should be replaced with "an econometric analysis" and drop the mentions of "estimation" throughout the subsection as well as in the corresponding Tables.

Authors Response:

The reviewer is right. We had already explained at the methodology that the econometric models are analysing the important variables of costs and floods rather. Therefore we have completely removed to term 'estimation' in this section replaced by analysis. Additionally, the title of the section has been changed to: An econometric analysis to identify variables that influence the costs of floods and droughts.

2nd Reviewer

I think that authors mostly addressed my concerns, although some criticalities are still unresolved (see below) and should be fixed. After these further corrections, the paper can be considered for publication in NHESS.

Still "open" questions

Introduction

The literature should be better organised to improve the comprehensibility of the manuscript. Some suggestions:

Authors' response:

We strongly believe that the literature is quite well organised in the current version and fully covers the scientific field.

- Page 1 lines 22-27: this part includes repetitions, please check

Authors' response:

We have checked it and did some changes in this part eliminating any repetitions.

- Page 2 line 25 – page 3 line 9: this part is very disorganized; it includes many logical gaps. I would rephrase

Authors' response:

We don't really find any logical gaps in this part. It has been in the previous reviews modified and improved at the point that we don't see any necessary changes.

- Page 3 line 17 -32: the description of the case study area should be moved in another section, before the description of the methodology

Authors' response:

We prefer to keep the description of the case study area in the introduction, rather than moving it in the methodology, which should strictly refer to the approach and methodology.

Section 2

I think that a table summarising main information (i.e. data, parameters) collected by means of the survey should be added to increase the comprehensibility of the manuscript and the analyses of significant variables in Section 3.4.

Authors' response:

In the previous revision we have added Table 1 and 2 that include all the survey parameters and socioeconomic characteristics of the sample. Additionally, Table 10 includes all the variables of the econometric analysis and analytically we provide in the Annex the full questionnaire. Therefore, what the reviewer mentions is already fully covered.

Section 3

Pg. 12 line 18

"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

Authors' response:

The author is right for this inconsistency which has been corrected in the text. Indeed it counts what mentioned in Table 7: Only a small percentage of the respondents (68 out of in total 660 interviewed households) stated that they **had** experienced any flood occurrence during the last two years.

Pg. 14 line 7

"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" ☒ Data from the survey were mainly reported in FCFA. Please, be consistent to allow comparison; the same can be state for model results on droughts

Authors' response:

The statistical estimations and econometric analysis in the tables are reported in FCFA and only when it comes to average and aggregate values they are also converted to euro. In the text we prefer to indicate the respective values in euro since it is easier for the readers to understand the volume of the value. Therefore we don't see any inconsistency at this point or a comparison problem.

Section 4

Pg. 15 line 27

“The cost assessment is two-folded based on the sample estimations and the application of two linear multivariate regression econometric models. The average cost of flood events in the period 2014-2015 was estimated at 495 euro per affected household, based on the average declared losses. The average cost of extreme droughts was 391 euro per household”
☒ I still think that a comparison between observations and models’ results is required along with a discussion on usability of such results (difficulty in damage estimation). Nonetheless, given that the main reason for the models is to explain significant variables for damage costs, a comment on significant variables should be added to section 4 as it reports main conclusions from the other sections but this one.

Authors’ response:

In the manuscript, there is a clear distinction among the statistical estimations and the econometric analysis. The later has been further modified and is explicitly stated throughout the document that it is about analysing the most significant explanatory variables of the costs of floods and droughts. After these modifications, we don’t see the need for further changes.

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. Reported examples are not real examples but generic (authors rephrase previous concepts) and do not help readers to appreciate the real value of the research

Authors’ response:

The discussion part is already well reviewed. However, based on the comment of the reviewer we added a couple of specific policy domain examples where this methodology could be applied.

Tables

Figure 1 The caption and the legend should include the meaning of numbers

Authors’ response:

The caption and the legend has been modified according the comment of the reviewer.

Figure 2 The figure is still not clear. Data in the table are not understandable without a description that is still lacking. I do not understand the link between the data reported in the table and the graph

Authors’ response:

The caption of Figure 2 has been modified according the comment of the reviewer and now it is more explanatory linking the graph with the table.

List of Changes

See above in detail how the comments of the reviewers have been addressed.

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 that demands integrated
10 approaches and high quality data. Especially in African developing countries, where information is limited, the assessment of
floods and droughts, though an overarching issue that influences economic and social development, is even more challenging.
This paper presents an integrated approach to assessing crucial aspects of floods and droughts in the transboundary Mékrou
River Basin (a portion of the Niger River Basin in West Africa), combining climatic trends analysis and the findings of a
household survey. The multi-variable trend analysis estimates, at the biophysical level, the climate variability and the
15 occurrence of floods and droughts. These results are coupled with an analysis of household survey data that reveals the
behaviour and opinions of 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 occurred over a two-year period (2014-2015).
Furthermore, two econometric models are set up to identify the factors that influence the costs of floods and droughts to
20 impacted households.

1. Introduction

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

~~agricultural and industrial production losses. They also pose a general threat to food security and development, leading to shocks in labour productivity, energy security, and political instability (Dell et al., 2014; Hsiang, 2010).~~ Floods and droughts, together with other natural disasters, were found to have a particularly damaging impact on the African continent, in particular with respect to fatalities, affected population, and economic damages (Cavallo, 2011). A recent study (Shiferaw et al., 2014),
5 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 the findings of a previous study (Toya and Skidmore, 2007). Reduced precipitation was found to be responsible for about 15 to 40% of the gap between the per capita Gross Domestic Product of African economies 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
10 conditions and precipitation was also confirmed by Berlemann and Wenzel (2015), who found drought-prone countries to be generally characterised by lower education levels, lower 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 that aim to monitor the risk-prone areas and the overall vulnerability of the population threatened by the hydro-meteorological hazards (UNISDR, 2017; 2013; 2011; 2008; 2004). Progress has been made in the assessment of the occurrence of extreme events,
15 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, infrastructure, and natural and man-made capital (UNISDR, 2015). Technical advancement efforts also allowed for 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.,
20 2012). However, the benefits derived from the progress made in this discipline were mainly concentrated in the most developed and technically advanced countries, where information is more readily available and mitigation strategies are more likely to be effectively implemented (UNISDR, 2015). In the case of African countries, the assessment of the physical impacts of hazard events followed the general level of technical development. As in the most advanced countries, in fact, the occurrence of floods and droughts was assessed by applying remote-sensing-based techniques, analysing precipitation and temperature records and
25 their spatio-temporal distribution, as for instance in a case study in Kenya carried out by Ngigi et al. (2005).

Although several quantitative and qualitative approaches have been developed in assessing costs of natural hazards, information about losses caused by past extreme events is still too limited to facilitate a detailed cost estimation and impact assessment analysis for many African countries. As described in Markantonis et al. (2012; 2013), the methodologies used in
30 the literature are various: Hedonic Pricing; Travel Cost; Cost of Illness Approach; Replacement Cost; Contingent Valuation; Choice 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 based on the direct testimony of the affected population. Several studies used household surveys to acquire qualitative and quantitative information from the local population 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 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). 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) 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 floods and droughts. In some of these studies, cost-benefit and willingness-to-pay analyses were used to add quantitative evidence to the qualitative descriptions.

The objective of this paper is to assess the occurrence of flood and drought events, estimate of damage costs at the household level, and describe the current mitigation behaviours adopted by the population of the Mékrou River Basin, a small catchment area in West Africa. It combines a quantitative approach for detecting hydro-meteorological hazard-prone areas (through the analysis of gridded climate datasets) with a qualitative and quantitative analysis of a household survey. This approach allows for the comparison of physical analyses of extreme events with human perceptions of the flood and drought phenomena in the Mékrou River Basin. The household survey provides sufficient information to estimate the impacts of natural hazards 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, 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. The wet season occurs between June and September, with average cumulated rainfall of 700 mm. Temperatures are also highly variable in space and time. The warmest and coldest months are April and September, respectively. Mean annual temperatures vary between 26°C and 30°C, reaching a maximum of 35-40°C and minimum of 15-19°C. The Mékrou catchment is located in a temperate transitional area characterised by a wet season that peaks in August and a long dry season that spans the period December-April (Masih et al., 2014). During the wet season, the whole Niger River Basin is subject to regular floods. Extensive research has been conducted on its complex hydrology, which is characterised by a large system of lakes and wetlands known as the Inland Delta (Bader et al., 2016; Tarpanelli et al., 2017), while less attention has been given to the Mékrou sub-basin. Flood and drought events are extremely frequent (Froidurot & Diedhou, 2017), and the impacts of climate change on their frequency and magnitude is unclear (Gautam, 2006). The Mékrou River Basin is 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. Therefore, climate variability is the main threat to the food and economic security of the area.

This paper is structured as follows: Section 2 presents the methodological framework regarding the development and application of the household survey (section 2.1) and the analysis of the biophysical variables (section 2.2). The findings of this integrated approach are given in Section 3. This section analytically presents the findings regarding precipitation patterns, temperature and river discharge in the Mékrou 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 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

10 2.1 Household survey implementation and analysis

A household survey 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 between urban and rural settlements. The number of households proportionally represents the total population of the respective villages or towns selected, and the number of households per country represents the country's population within the basin. 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. Table 1 presents the detailed sample and population of the selected villages. . The survey was carried out by experts of the Joint Research Centre of the European Commission in cooperation with local universities from Benin, Niger and Burkina Faso. Interviews were conducted in person by a team of students supervised by a professor for each country. Before starting the survey, the students received training in which the questionnaire was thoroughly explained and discussed. 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 communication with the local population, overcoming possible language 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 large section of the survey focused on identifying and 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 still had a fresh memory of the impacts suffered. 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

5

The survey process resulted 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 greater than 95% significance in the statistical findings (a minimum of 400 questionnaires are required for 95% significance rate). In Table 2 we present basic information on the socioeconomic characteristics of the surveyed population.

15 Figure 1. The Mékrou River Basin and the household survey area [\(including number of questionnaires per village/town\)](#)

Table 2. Socioeconomic characteristics of the surveyed sample

Following the data cleaning and validation of the survey, the information collected was statistically analysed including all the parameters investigated in the questionnaire. The survey responses were evaluated using descriptive statistics that aggregate data both at river-basin and at country level. The findings were analysed at the river-basin scale, illustrating the differences 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 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 to investigate the determinants of flood and drought costs following a cause-effect logic. Performing a thorough multi-variate regression 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 used to explain the costs of extreme hydro-meteorological events. Several types of regression models were tested, both linear and logarithmic. Linear multivariate regression models were 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 greater than 0.05 was included due to its importance in the context of the analysis, but its value (0.068) is still below the least acceptable P-value (0.1). R-square and F-test values were estimated, and correlation among the independent variables was tested in order to avoid bias in the model due to collinearity.

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

Precipitation and temperature patterns and changes are the main drivers of local populations' perception of water availability, especially in an area where the main economic activity is based on 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. As analysis of rainfall events above and below the long-term average distribution in conjunction with inter and intra-annual analyses are useful for depicting anomaly patterns and trends. They help better understand, for example, the main drivers of meteorological droughts. This is particularly relevant in order to compare local populations' perception of climate variables with quantitative estimates. Events above and below the long-term rainfall average distribution were studied in conjunction with intra-annual precipitation analysis. 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 levels, reservoir depletion, etc. (Liu et al., 2016). Secondly, considering the increasing number of heatwaves that occurred during the past decade in Africa (Ceccherini et al., 2017), we studied 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 the survey results, offering empirical evidence of their concurrence, or explaining the underlying causes of possible contrasting results.

2.2.1 Precipitation pattern analysis

Descriptive statistics of annual and seasonal rainfall were analysed jointly with the results of a Seasonal Kendall test for monotonic trend (SK) applied 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 0.05° , corresponding to approximately 5 km (at the equator), and covers all longitudes in the latitude range 50°S - 50°N spanning a time horizon of 1981 to the present 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 ten-year period considered in the household survey (2006-2015). The test is a modified version of the previous SK test proposed by Hirsch et al. (1982), and attempts to reduce the serial dependence 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). The magnitude of trends are calculated using Sen's Slope Estimator and Kendall's Tau as the rank correlation coefficient.

In addition, 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 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-month and 6-month SPI (hereafter SPI-3 and SPI-6) were calculated, associated respectively 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).

5 For the purpose of this paper, as the Mékrou communities' economy is mainly based on rain-fed agriculture, we focused on the precipitation anomalies during the wet season, presenting the SPI-3 for the period June-August (JJA), and the SPI-6 for the period April 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 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 categorised into different classes, each associated with different levels of wet or dry 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 (Table 3). Finally, in order to get a general overview of the anomalies

10 in the different administrative units, we calculated the area percentage affected by each class over the entire time series.

15

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

2.2.2 Heatwave analysis

Russo et al. (2015) defined the Heat-Wave Magnitude Index daily (hereafter HWMId) as the maximum magnitude of the heatwaves in a year, where a heatwave is defined as a period equal to or greater than three consecutive days with maximum temperature above a daily threshold calculated for a 30-year 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

20 past 35 years across the study area.

25

2.2.3 Discharge in the Mékrou River

In order to have a quantitative estimation of water availability within the Mékrou River Basin, the hydrological model SWAT (Neitsch et al., 2011) was 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.

30

SWAT sub-basins were delineated using the ArcSWAT interface with a Digital Elevation Model of 90 m spatial resolution, resulting in 32 sub-basins for the whole area.

5 The historical discharge data recorded at the Barou gauge station (outlet of the river basin) and at the Kompoungou gauge station (a draining area that accounts for about 56% of the river basin) were used for model calibration. Lack of data availability represents a huge limitation for the hydrological analysis of the basin. In addition, these discharge observations are incomplete, as they are only available for a limited number of years (1990-2000 for Barou and 2004-2013 for Kompoungou). We used the SWAT-CUP program and manual setup to calibrate the outflow of the two monitoring stations, and obtained satisfactory efficiency statistics (Moriasi et al., 2007) at monthly 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-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.

3. Results

3.1 Biophysical variables: precipitation, temperature, and river discharge

15 3.1.1. Precipitation patterns

Mean Annual Precipitation in the study area varies from 500 mm in the northern administrative units (Bottou, Tamou, Kirtachi and Falmey), to a maximum of about 1,000-1,300 mm upstream in the southern portion of the basin (Kouandé, Kérou and Banikoara (Figure 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 20 200 mm and 300 mm, respectively, with the driest months (November-February) being close to zero.

Comparing the precipitation patterns of a short- (2007-2016) and a long term (1981-2006), it was possible to identify a slight decrease in rainfall during August and September, while a moderate increase was detected during June and July (Figure 2). However, long- and short-term Seasonal Kendall analyses, performed at a significance level $\alpha = 5\%$, were not able to identify 25 any significant trend (Figure 2). Some spatial differences were identified analysing the last 10 years of the study: in that regard, negative slopes were detected in the southern regions of Benin.

30 Figure 2. Box-whiskers plot comparison (top) of monthly precipitation for the first 25 years of the time series versus the last 10 years (2007-2016 vs 1981-2006). On the bottom, the results of the Seasonal Mann-Kendall (MK) test for detecting significant increasing or decreasing trends (Kendall Score) in the precipitation patterns for each of the areas taken into consideration in this study. The MK test was conducted using the observed precipitation records of the most recent time period (2007-2016) and the full time series available (1981-2016). The test performed did not highlight statistically significant (significance threshold p-value <0.010) increasing or decreasing trends in the analysis of the two precipitation time series. Box-whiskers plot comparison of monthly precipitation for the first 25 years of the time series versus the

3.1.2 Precipitation stress analysis

5 The results of the SPI-3 and SPI-6 analyses highlighted a period of moderate to extreme droughts during the earlier part of the 1980s; this could also be seen in mean monthly precipitation values, where the overall rainfall from 1981 to 1985 is noticeably less than the long-term average (Figure 3). After this period, the positive and negative anomalies were found to be more erratic, presenting alternate series of positive and negative events, such as some severe wet anomalies in the southern regions in 2003 and drought events in northern regions in 1997. Regarding the last ten years of the study period, only few drought anomalies
10 affected at least 40% of the administrative areas. 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 predominantly recorded during the years 2003, 2005, and 2007 in the entire Mékrou Area of Influence. Summarising the results derived from the analysis of the SPI, we found that the decade considered in the household survey was mainly characterised
15 by precipitation in line with the long-term average. The anomalies were not particularly intense and most frequently related to wet conditions 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 S2 and S3).

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

3.1.3 Heatwaves

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

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

Figure 4. HWMI index computed for 1981 to 2015 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. 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.

Modelled discharge in the period under consideration averaged around 24 m³/sec, corresponding to an average annual water flow of about 760 Mm³ (ranging from 190 to 1,400 Mm³ in 1997 and 2008, respectively). The spatial distribution of the water resources follows the topography of the basin, making the headwaters (where annual discharge remains below 100 Mm³) particularly subject to inter- and intra-annual variability (Figure 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 follows the seasonal precipitation patterns: most abundant flows are reached after the rainy season (July-November), with the peak flow being reached in the period Aug-Sep-Oct (Figure 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 extreme events and climate variability

The household representatives gave their personal opinions on the occurrence of specific extreme events in the Mékrou River Basin during the last ten years of the study period (2006-2015) (Table 4). The selection of this 10-year framework allows for a relatively mid-term assessment of 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 quite high (71.5%). In addition, the vast majority of the local population (88.5%) 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 decrease but, according to the local population (92.7%), the seasonal distribution also changed. In fact,

the majority of the respondents (83%) stated that the rainy season started with a delayed onset during the last 10 years of the study period, whereas almost all respondents (91.8%) declared an earlier end to the season. Regarding heatwaves, 76% of the interviewed population (62% in Benin) stated that periods of intense 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, with a
5 general frequency of 0 to 6 events. On average, the local population experienced in average 3.93 drought events when considering the whole Mékrou River Basin (Table 3). The number is higher in Burkina Faso (4.8 events) and slightly lower in Niger (3.4 events).

Concerning flood events, opinions are less homogeneous over the whole Mékrou area. The majority (62%) of the respondents
10 stated that flood frequency did not increase over the 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 72.2% of the respondents in Niger found an increasing flood frequency in the period under consideration. When asked about the 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
15 of the events, this varied across the three countries. In Benin, 60.7% of the population did not experience any flood during the last 10 years of the study period. On the other hand, large numbers of flood events were recorded primarily in Niger, followed by Burkina Faso (Table 5). In Benin, 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 River Basin was the most prone to flood events in the period under consideration. Regarding both flood and drought events,
20 the perceptions are heterogeneous across the three countries in the basin, with no difference based on different socioeconomic characteristics. This could be explained by the homogeneity of the socioeconomic characteristics within the basin across three countries.

25 *Table 4. Observed climatic changes during the last 10 years of the study period: 2006-2015*

Table 5. Statistical Analysis of reported number of floods and droughts during the last 10 years of the study period

3.2 Household results regarding Flood and Drought Mitigation Measures

This section provides an empirical analysis of the household mitigation measures. The respondents chose among 13 mitigation
30 strategies aimed at coping with changes in temperature and rainfall patterns. 8 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 fewer small ruminants and switching to more cattle;

raising less cattle and switching to camels; raising less sheep 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 greater than 10% are: change of crop seeds; terracing the soil or using other methods to protect against erosion; planting more trees; emigration of at least one household member; increasing the practice of non-agricultural activities as sources of revenue (Table 6). Changing crop seeds is quite a common strategy for adapting to rainfall changes, and is widely applied in Burkina Faso and Nigerien areas (for around 60-65% of respondents), and to a lesser extent in Benin (34%). The practice of terracing the soil to prevent erosion is mostly applied in the Beninese part of the Mékrou River Basin. The 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 their members emigrating due to temperature and rainfall changes. 16.4% of Beninese respondents stated that at least one member emigrated in the last 10 years of the study period due to rainfall changes. Finally, an important number of households, primarily in Benin (around 35%) and in Niger (around 15%), increasingly practice non-agricultural activities as sources of revenue to cope with the loss of income due to both rainfall and temperature changes.

Table 6. Household mitigation measures

3.3 Flood and Drought impacts and their cost assessment

The local population of the Mékrou River Basin also indicated the occurrence of extreme events during the two-year period 2014-2015. The relatively recent occurrence of these events, some of which are still ongoing, allows for a more accurate estimation of the impacts and associated costs. Only a small percentage of the respondents (68 out of the total 660 interviewed households) stated that they had not experienced any flood occurrence during the two years (Table 7). However, the occurrence of events differs between the three countries, with most of the events being reported in Burkina Faso (34.5% of households affected by floods). Aligning with the frequency of reported events, the impacts of floods are proportionally more common in Burkina Faso. The most commonly reported impacts are the loss of agricultural production, damage to houses and loss of livestock (Table 8).

The same analysis was applied for recent drought events. The vast majority (76.7%) stated that they had not experienced any drought event during the last two years of the study period. However, more droughts are reported compared to floods, with 152 of the total 660 households interviewed experiencing an extreme drought event. Similarly, the occurrence of droughts is heterogeneous across the three countries. Droughts are less prominent in Niger (Table 7), where only a few droughts were reported, while a quarter of the population in Benin had experienced droughts during the last two years of the study period. In Burkina Faso, almost half of the households had experienced droughts during the two-year period. The impacts of the recent

drought were mostly recorded in Burkina Faso and Benin (Table 8) presenting a different profile. In Burkina Faso the impacts were exclusively manifested as losses of agricultural production, while in Benin most of the impact of the recent droughts was felt in the loss of agricultural production, as well as malnutrition and loss of livestock. Both the flood and drought impacts recorded relate to general categories of impacts, mainly agriculture, livestock and housing, as it was not feasible to collect more in-depth qualitative characteristics of the impacts.

Table 7. Extreme flood events experienced during the last two years of the study period (2014-2015)

Table 8. Impacts of extreme floods and droughts on households

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The estimated flood costs to households differ among the three countries. The cost of the recent floods is highest in Burkina Faso (Table 9), where the average cost to an affected household is 334326 FCFA (West African Francs) (approximately 510 euro in 2017). The estimated flood costs in Benin and Niger are 40000 and 160000 FCFA, respectively. Furthermore, we observed a difficulty among the households in estimating the costs of the recent floods, especially in Benin and Niger (the less affected countries), where most of the affected households were not able to provide a cost estimation. 20 out of 68 affected households in the basin were not able to provide a cost estimation of the floods they experienced. The average cost of the recent droughts, 256440 FCFA (~391 euro), was almost the same in Burkina Faso and in Benin (Table 9), and was lower than the average cost of the recent floods. Again, it is evident that 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. Regarding the geographical differentiation of the cost of both floods and droughts, heterogeneity is observed among the three countries but not within the countries where costs are homogenous among the selected villages and towns. Also, the small sample of the households affected by floods and droughts is insufficient for statistical aggregation to the total population of the basin.

25 *Table 9. Estimated costs of the recent floods and droughts (in FCFA)*

3.4 An econometric analysis to identify variables that influence the costs ~~Cost assessment of floods and droughts: an econometric estimation.~~

In addition to the statistical estimation of the cost of floods and droughts, two econometric models were developed to provide an estimate-analysis of costs based on socioeconomic and other relative factors. A wide series of independent variables of the household, such as socioeconomic conditions and mitigation measures, were used to find the determinants of the cost of extreme events and to estimate-analyse the cost of floods and droughts. Using several regression models and a combination of independent variables, two models were set up 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 10 presents the total of the independent

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variables, including their scaling and 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 10. Selected independent variables for modelling the costs of floods and droughts

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Regarding floods, the multivariate regression model in Table 11 includes the self-stated economic status (ECONSTAT) of households as an independent variable and as a qualitative alternative to household income. The model reveals a strong economic status effect, meaning that the richer the household, the higher the economic impact of floods. The negative sign is due to the structure of the variable scaling (where 1 represents rich and 5 represents significantly poorer economic conditions than the other households). Two of the main flood impacts, loss of crop productivity (CropProdLoss) and loss of livestock (LivestockLoss) were also 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 11. Costs of floods – Multivariate linear regression model

Similarly, a multivariate regression model was applied to estimate-analyse the costs of droughts (Table 12). 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 correlations were detected among the independent variables.

25 *Table 12. 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, droughts and climate variability in the Mékrou River Basin in West Africa. The opinions and perceptions of household representatives revealed strong climate variability over a ten-year period (2006-2015). It is worth mentioning that 83% of the population noticed a delayed onset of the rainy season during this period. In addition, 91% of the population also observed an early end of the wet season. Moreover, 88.5% of the respondents reported a general reduction in precipitation during the ten-year period under consideration, and 75.9% reported an increase in the magnitude and frequency of extreme heat events. This tendency is partially

confirmed by the analysis of climatic variables, mainly based on precipitation and temperature data. The findings of the analysis confirmed the increase in both the frequency and magnitude of heatwaves in the study area. The climatic variability was also found to be noticeably high, but the Mann Kendall analysis failed to find statistically significant trends in the precipitation patterns. It was not possible to clearly identify a shift in the intra-annual temporal distribution of precipitation, as
5 there was no indication of a slightly delayed onset nor an early end of the rainy season.

The survey-based findings revealed a substantial 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 from 2006 to 2015, while 23.3% experienced an extreme drought event during the last two years (2014-2015), resulting in 3.93 extreme drought events
10 on average. Fewer flood events 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 (1.69 extreme flood events on average per household). The perceptions of the local population were confirmed by the climatic factors regarding flood events. An analysis of extreme precipitation in the
15 past 30 years did not report a significant increasing trend in the occurrence of flood events. Similar conclusions, but this time contrary to the impressions of the local population, were derived from the analysis of dry periods. This difference between perceived occurrence and observed droughts could be explained by the misperception of the local population confounding the observed increasingly frequent heatwave events with more frequent droughts. However, 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
20 with those reported by the local population in the portion of the basin 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 important findings regarding the measures adopted by the households of the Mékrou River Basin to mitigate floods and droughts. From a list of options, the most significant household mitigation measures were identified as being: changing crop seeds, planting more trees, and increased practice of non-agricultural economic activities,
25 while, especially in Niger, a considerable part of the population emigrated due to the loss in agricultural production caused by the reduced rainfall. 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. The loss of crop production, malnutrition, and the loss of livestock were the most important impacts of extreme droughts. In addition, the total cost per household of the impacts of
30 extreme floods and droughts was estimated. The cost assessment is two-folded based on the sample estimations and the application of two linear multivariate regression econometric models. The average cost of flood events in the period 2014-2015 was estimated at 495 euro per affected household, based on the average declared losses. The average cost of extreme droughts was 391 euro per household. This study confirmed the difficulty of estimating the costs of natural hazards at the

household level, even in the case of recent events. A considerable percentage of 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.

5 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 such the Mékrou River Basin, where 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, such as floods and droughts. Potential limitations of this approach are mainly the information biases and misperceptions of the local population, which could influence the objectivity of their responses. Furthermore, such a survey approach depicts the opinions within a
10 specific timeframe and, therefore, should be periodically repeated to better validate the findings. This would require increased financial and human resources. The major potential benefit of this approach is that it provides information to support decision-makers and local governments, leading to the more effective and efficient design of flood and drought mitigation policies and measures. Most often, natural hazards risk mitigation measures and policies use either climate modelling tools or socioeconomic analyses, but rarely combine both. In developing countries where information is limited, such a coupling
15 approach could integrate local characteristics and perceptions into natural hazard planning policies, 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 in the framework of Transboundary River Basin Management Plans or even ~~and~~ design climate adaptation strategies combining climate and socioeconomic analysis while structuring National Adaptation Programmes of Action (NAPAs).

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10 **Author Contributions**

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

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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 (Kérérou)	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

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5 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%
Female	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 employed	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%		

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Table 3. 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 4. 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 5. Statistical Analysis of reported number of floods and droughts during the last 10 years

	Mékrou Basin	Benin	Burkina Faso	Niger
	<i>Floods</i>			
<i>Mean</i>	1.69	0.73	1.78	3.46
<i>Standard Deviation</i>	2.07	1.16	1.43	2.64
	<i>Droughts</i>			
<i>Mean</i>	3.93	3.83	4.80	3.36
<i>Standard Deviation</i>	2.83	2.95	2.72	2.49

Table 6. Household mitigation measures

	BENIN		BURKINA FASO		NIGER		Mékrou Basin	
	count	%	count	%	count	%	count	%
Change of crop seeds								
Action taken due to temperature								5
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%

Table 7. 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 8. 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

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

	Mékrou Basin	Benin	Burkina Faso	Niger
<i>Costs of floods</i>				
<i>Mean</i>	324563 (~495 EURO)	40000	334326	160000
<i>Standard Deviation</i>	373159		378071	
<i>Costs of droughts</i>				
<i>Mean</i>	256440 (~391 EURO)	262184	252803	0
<i>Standard Deviation</i>	324224	257676	362150	0

Table 10. Selected independent variables for modelling costs of floods and droughts

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

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Table 11. Costs of floods – Multivariate linear regression model

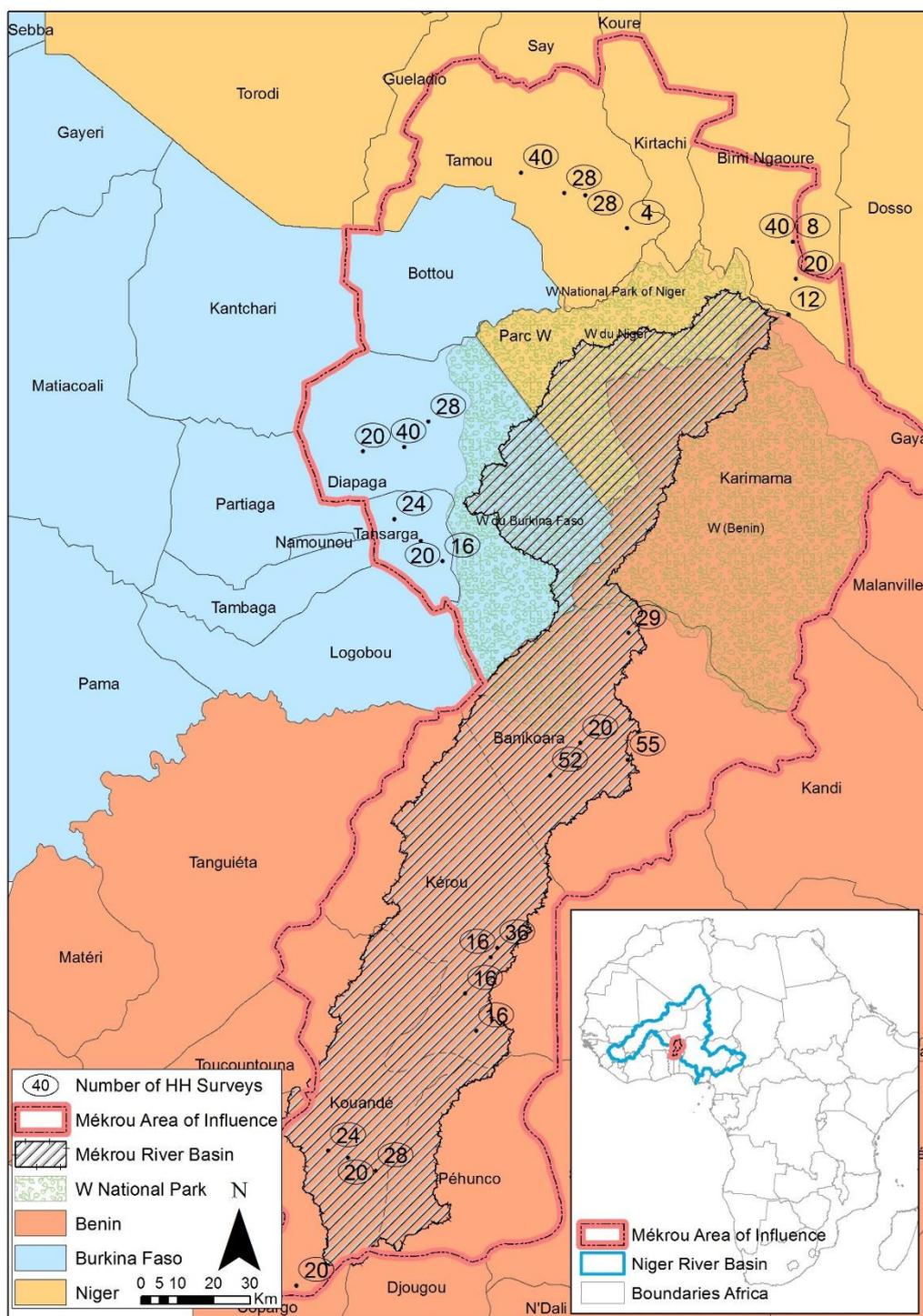
Number of obs = 48 R-sq: 0.4828 F-test: 7.842			
Independent Variables	Coef.	Std. Err.	P>z
ECONSTAT	-128548.5	47850.09	0.01
CropProdLoss	287269.9	129224.5	0.031
LivestockLoss	359272.4	92753.99	0
cons	429595.2	225058.3	0.063
Cost Estimate / household	256441 (FCFA)	390.92 (EURO)	

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Table 12. 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	14.08	3.64	0		
LivestockLoss	137261.8	74243.4	0.068		
_cons	130367.5	39952.2	0.002		
Cost Estimate / household	324563 (FCFA) 495 (EURO)				

Figure 1. The Mékrou River Basin and the household survey area (including number of questionnaires per village/town)



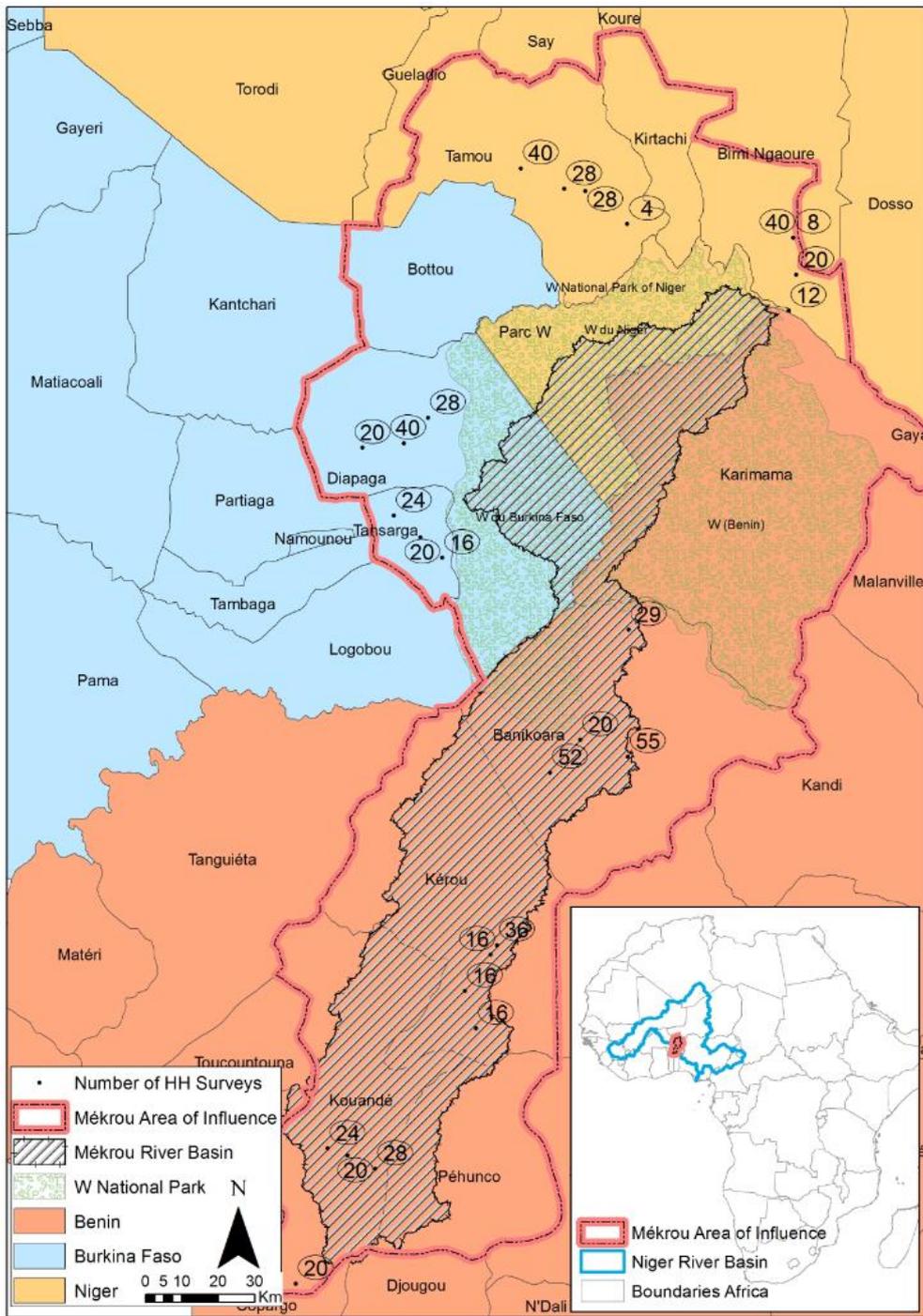
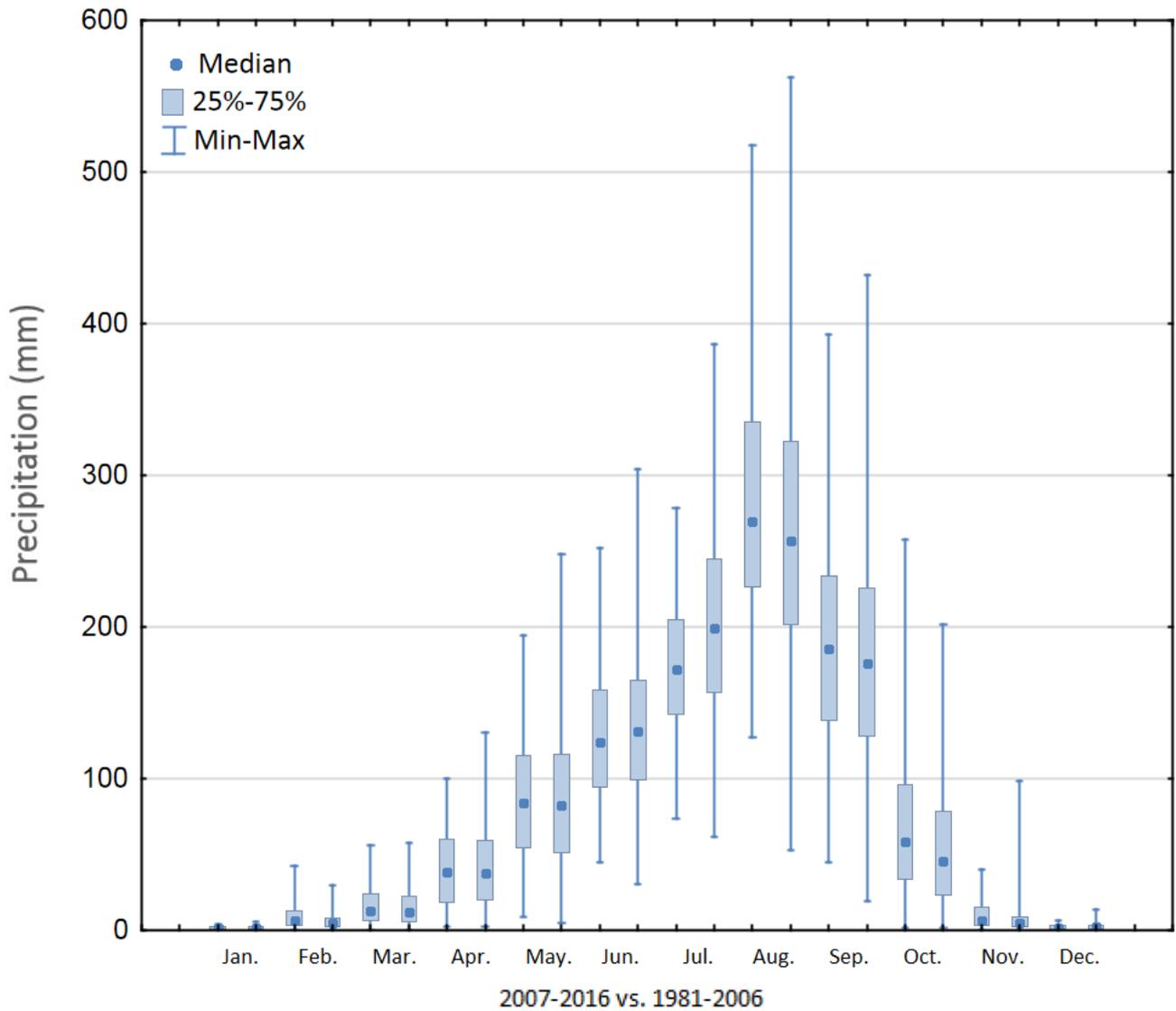


Figure 2. Box-whiskers plot comparison (top) of monthly precipitation for the first 25 years of the time series versus the last 10 years (2007-2016 vs 1981-2006). On the bottom, the results of the Seasonal Mann-Kendall (MK) test for detecting significant increasing or decreasing trends (Kendall Score) in the precipitation patterns for each of the areas taken into consideration in this study. The MK test was conducted using the observed precipitation records of the most recent time period (2007-2016) and the full time series available (1981-2016). The test performed did not highlight statistically significant (significance threshold p -value < 0.010) increasing or decreasing trends in the analysis of the two precipitation time series.

Figure 2. Box-whiskers plot comparison 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-Kendall test performed did not highlight significant (p value < 0.010) increasing or decreasing trends in the analysis of the two precipitation time series.



10 years (2007-2016) Mann-Kendall trend test for monthly precipitation time series

	Country	Region	Kendall Score (S)	p-value (two tailed test)	Statistical significance
1	Benin	Banikoara	-49	0.2045	Non Significant
2	Benin	Pehunco	-42	0.2782	Non Significant
3	Benin	Karimama	-21	0.5821	Non Significant
4	Benin	Kounde	-36	0.3526	Non Significant
5	Benin	Kerou	-40	0.3014	Non Significant
6	Burkina Faso	Tansarga	-10	0.7885	Non Significant
7	Burkina Faso	Bottou	46	0.2142	Non Significant
8	Burkina Faso	Diapaga	18	0.6371	Non Significant
9	Niger	Parc W	43	0.247	Non Significant
10	Niger	Kirtachi	26	0.4584	Non Significant
11	Niger	Tamou	66	0.073	Non Significant
12	Niger	Boboye	12	0.7501	Non Significant

Full time series (1981-2016) Mann-Kendall trend test for monthly precipitation time series

	Country	Region	Kendall Score (S)	p-value (two tailed test)	Statistical significance
1	Benin	Banikoara	259	0.3083	Non Significant
2	Benin	Pehunco	349	0.17	Non Significant
3	Benin	Karimama	-74	0.768	Non Significant
4	Benin	Kounde	421	0.0978	Non Significant
5	Benin	Kerou	397	0.1185	Non Significant
6	Burkina Faso	Tansarga	321	0.1949	Non Significant
7	Burkina Faso	Bottou	78	0.7526	Non Significant
8	Burkina Faso	Diapaga	324	0.1964	Non Significant
9	Niger	Parc W	112	0.6458	Non Significant
10	Niger	Kirtachi	-149	0.5298	Non Significant
11	Niger	Tamou	79	0.7466	Non Significant
12	Niger	Boboye	-132	0.5952	Non Significant

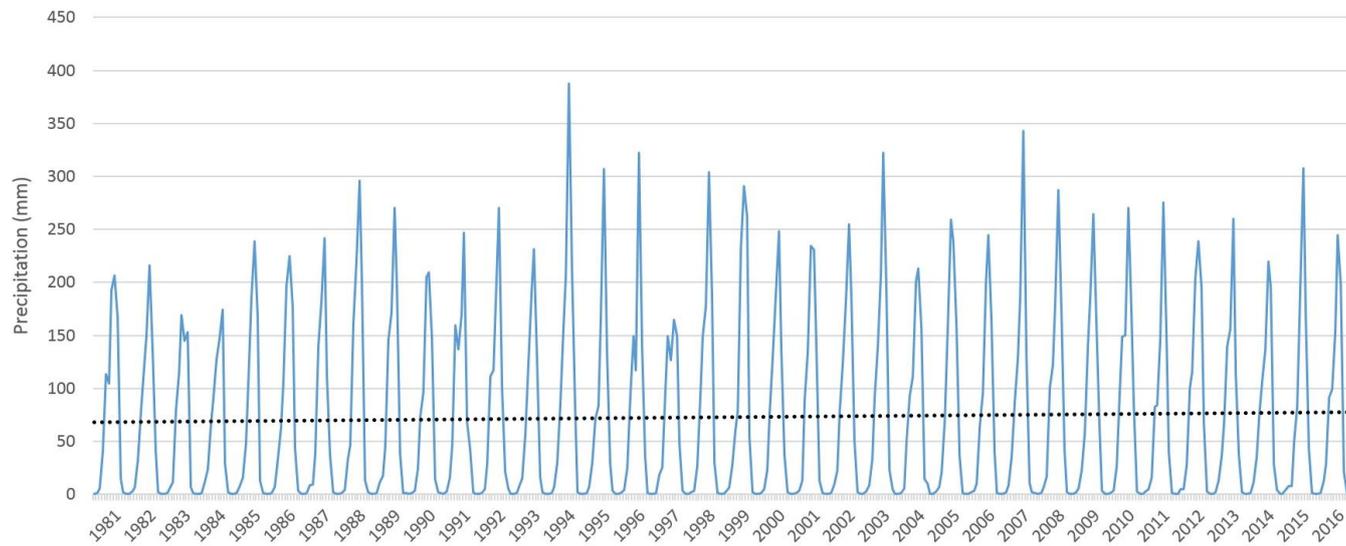
Last 10 years (2007-2016)

id	country	region	Mann-Kendall trend test for monthly environmental time series by Regions				Seasonal Sen's slope and intercept	
			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)

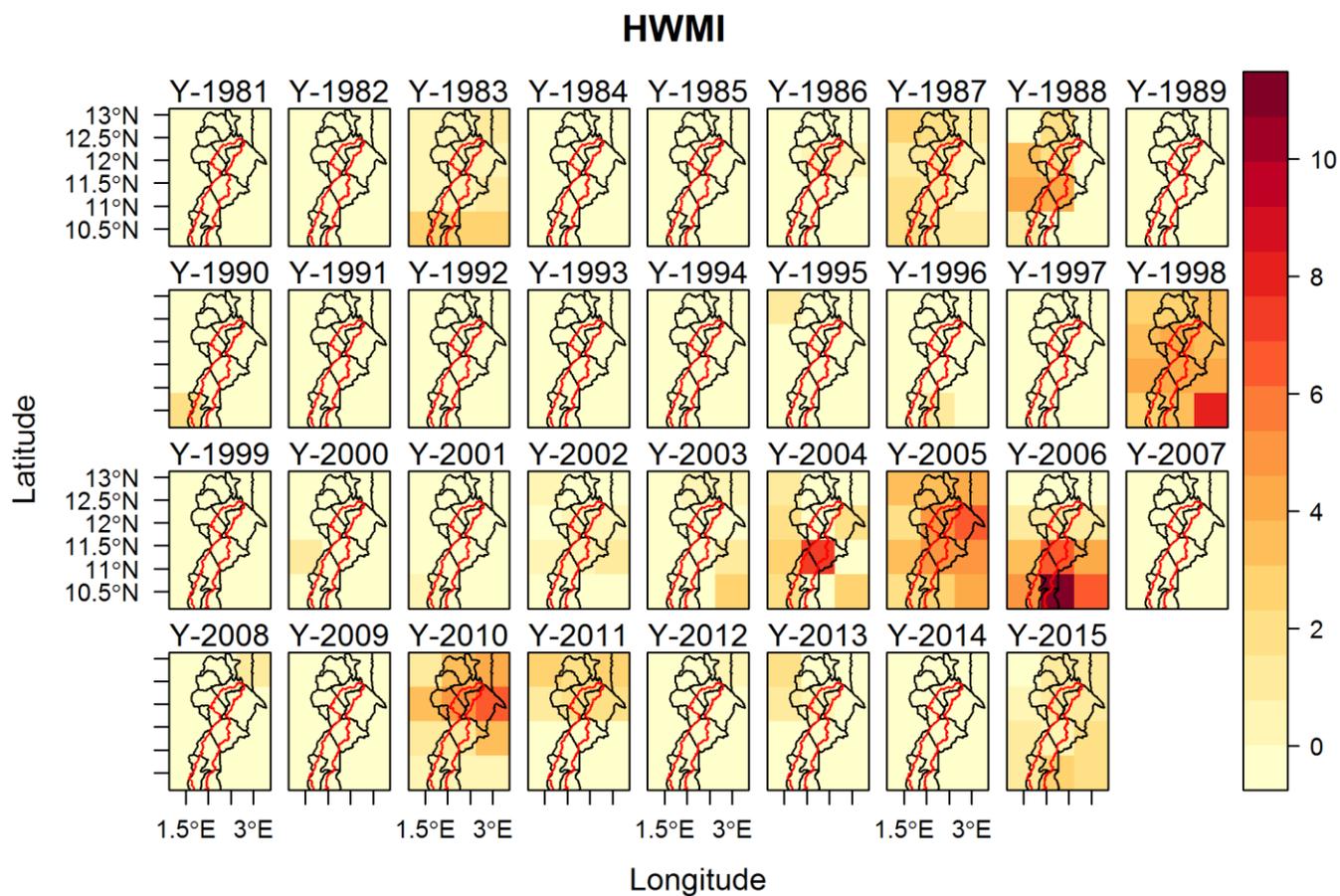
id	country	region	Mann-Kendall trend test for monthly environmental time series by Regions				Seasonal Sen's slope and intercept	
			Kendall Score (S)	variance of S	two-sided p-value	Kendall's tau statistic	value of Sen's slope	intercept
1	Benin	Banikoara	259	64624.3300	0.3083	0.0344	0.00052	31.010
2	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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Figure 4. HWMI index computed for 1981 to 2015 on the Mékrou

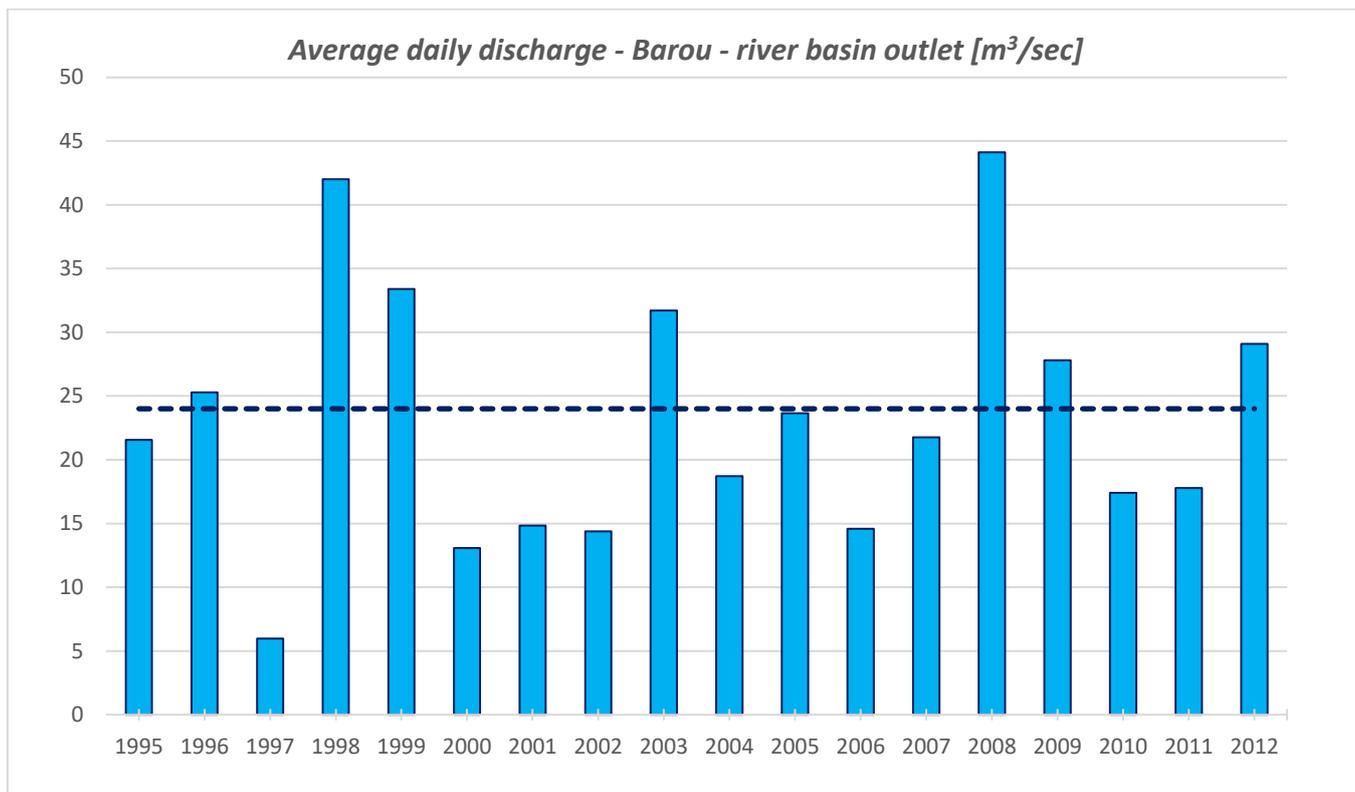


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Figure 5. Mékrou River daily average discharge at Barou station as modelled in SWAT in the period 1995-2012. Dashed line indicates the average of the total period under consideration.



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APPENDIX A.

QUESTIONNAIRE

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