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Perceptions of recent rainfall changes in Niger: a comparison between climate-sensitive and non-climate sensitive households

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Abstract Understanding public perceptions of changes in local weather patterns is fundamental to both climate science and policy, especially in sub-Saharan Africa where adaptation will be crucial to reduce the projected impacts of climate change. In this study, a nationally-representative sample of households in Niger is used to document how perceptions of 2007–2011 rainfall changes vary across households depending on their socio-economic characteristics and their location within the latitudinal rainfall gradient of the country. We further characterize the complex relationship between perceived rainfall trends and rainfall data derived from satellite data. We found that over the last five years, most people perceive less rainfall (76 %), worse distribution of rainfall in the year (78 %), more frequent droughts (83 %) and a rainy season delayed (71 %) and also finishing earlier (80 %). These perceptions are consistent with an observed worsening of rainfall conditions as seen from satellite data. Our results demonstrate that smallholders, commercial farmers, pastoralists and sedentary agro-pastoralists living in rural dry areas have a higher level of awareness of local changes than other respondents. Indeed, perceptions of these climate-sensitive households are more consensual and more closely related to observed local changes. We found that climate-sensitive households are able to detect very accurately changes in the beginning of the rainy season and to a lesser extent changes in rainfall distribution and drought frequency.

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1 Introduction

The perception of changes in local weather patterns — including changes in average conditions, in seasonality, in spatial patterns and variability — is an important driver of adaptation (Howe et al. 2014; Marx et al. 2007). In regions such as Africa, where vulnerability to climate variability and change is high, awareness of local change can motivate adaptation and lead to a reduction of vulnerability (Slovic 2000; Tschakert 2007). In Africa, rural households whose livelihood is heavily dependent on traditional rainfed agriculture and pastoralism are at risk of hunger and malnutrition. The underlying causes of such food insecurity are multiple – one of the most important being climate variability and extreme events such as droughts, excessive rains, changes in timing of the monsoon and floods affecting agricultural productivity (Haile 2005). A better understanding of people's perceptions of weather and climatic variability is required to enhance adaptive capacity and reduce this vulnerability through better design and distribution of adaptation tools such as index-based weather insurance and weather forecasts.

The understanding of climate perceptions and their determinants in the sub-Saharan African context has received a large amount of attention in recent years. For instance, a large-scale survey of agriculturalists in 11 African countries revealed a high awareness of temperature and precipitation changes over the last 20 years (Maddison 2007). Similar results were found throughout the literature and revealed a perception of decreasing rainfall shared by more than 70 % of households (Gbetibouo 2009; Bryan et al. 2009; Mertz et al. 2012; Silvestri et al. 2012). Relatively few studies have attempted to confront climate change perceptions with meteorological records and evidence is weak about whether people's perceptions of local weather patterns tally with quantitative measurements from meteorological stations or satellite rainfall estimates in Africa (Meze-Hausken 2004; Osbahr et al. 2011; Rao et al. 2011; Moyo et al. 2012; Mertz et al. 2012; Simelton et al. 2013; Sutcliffe et al. 2015). Various reasons have been given to explain this mismatch. For example, the perception of changing precipitation can reflect a change in seasonality or in the frequency of extremes instead of a change in total precipitation (Roncoli et al. 2002). In addition, meteorological data may represent a farmer's potential exposure to climate changes, while perceptions are more likely to be related to experienced climatic impacts (Reckien et al. 2012; Leclerc et al. 2013). Case studies have shown that crop failure or soil degradation perceptions are more easily used by farmers to gauge droughts (West et al. 2008; Osbahr et al. 2011). The concept of agronomic drought (Slegers 2008), which relates to meteorological drought, evapo-transpiration and soil-water deficiency illustrates this difference between exposure and impacts. As a result, comparing perceptions with meteorological measurement remains a major scientific challenge.

In this study, we examine how households in Niger perceive changes in rainfall, including changes in total rainfall, seasonality and distribution of rainfall over the past five years. A nationally-representative sample of 3967 households is used to document how perceptions vary across households depending on their socio-economic characteristics and their location within the latitudinal rainfall gradient of the country. Our hypothesis is that climate-sensitive households, who rely on a narrow range of resources and experience a higher level of exposure and impacts (Weber 2010; Reckien et al. 2012; Leclerc et al. 2013), have a greater awareness of local changes. We further characterize the complex relationship between perceived rainfall trends and rainfall data derived from satellite data. In particular, we examine how the matching between perceived rainfall trends and rainfall data varies across different rainfall indicators and different socio-economic characteristics.

2 Study area and methods

2.1 Study area

Located at the heart of West Africa, Niger is a landlocked country with three quarter of its territory covered by the Sahara desert. Niger's climate is mostly arid, with a rainfall gradient ranging from 100 to 700 mm of annual rainfall (Fig. S.1) and it is one of the least developed countries in the world, ranking 186th according to the Human Development Index (Human Development Report 2013). The vast majority of its population (82 %) is living in rural areas and the country is highly dependent on agriculture, which contributes 38.2 % of GDP (World Bank 2012). Agriculture is predominantly rainfed and yields rely on one rainy season, from May to September. Although increasing in productivity, agriculture has been strongly affected in recent decades by several crises partly or entirely due to extreme weather events (World Bank 2013). Major shocks due to drought have been observed during the years 1996, 1999, 2003 and 2008. Floods occurred in 2008 and 2010, where heavy rains in July and August displaced nearly 200,000 residents and caused a sharp increase in the incidence of waterborne disease in addition to crop production loss.

2.2 LSMS-ISA Niger

This study draws from a survey of household perceptions from the Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS-ISA). LSMS-ISA Niger is a large-scale, multi-purpose survey which draws on a representative sample of 3967 households. The survey was implemented by the *Niger National Institute of Statistic* with the technical assistance of the World Bank LSMS-ISA team. Households were selected for the survey through a random two-stage process (Niger National Institute of Statistic 2013). In the first stage, 270 Enumeration Areas were selected with Probability Proportional to Size using the 2001 General Census. In the second stage, 12 (or 18) households were chosen randomly in each urban (or rural) Enumeration Area. Data on climate change perceptions were collected in the post-harvest questionnaire, from November 2011 to January 2012. Datasets are publicly available at http://go.worldbank.org/OQQUQY3P70.

In the post-harvest agricultural module, the section 8 was related to climate change. Household heads were asked if "*over the past five years*, *they have noticed the following changes*" followed by a list of climatic events: total rainfall, rainfall distribution throughout the year, more frequent droughts, more frequent floods, delay in the start of the rainy season (on a five-year time scale, as well as for the last rainy season), early ending rainy season and heatwave frequency. Here, we only focus on rainfall events and therefore we excluded questions on floods and heatwaves from the analysis (see Tab. S.2). The survey made the choice of a relatively short time scale (five year, one year) to collect perceptions. This choice contrasts with the literature, where the time scale used to collect perceptions generally varies from 40 years (Meze-Hausken 2004) to 20 years (Bryan et al. 2009; Fosu-Mensah et al. 2012; Tambo and Abdoulaye 2012).

From the household survey (section 4 of the LSMS-ISA survey), we used the household head's main employment during the last 12 months (Section 4 of the Household survey) to distinguish two categories of households: climate-sensitive households and non-climate-sensitive households. Climate-sensitive households are those whose livelihood is related to natural resources and highly dependent on rainfall: smallholders, cultivating less than 5 ha/year (5 %), commercial farmers (24 %), pastoralists and sedentary agro-pastoralists (14 %) and other rainfall dependent activities (4 %). Overall, climate-sensitive households account for 56 % of Niger households. Non climate-sensitive households are those whose main occupation is related to trade or craftworks (53 %), administration (25 %), independent activities (6 %) or without main occupation (16 %).

2.3 Rainfall indicators

As for rainfall data, we use the daily rainfall estimates 2.0 (RFE2) from FEWSNET, available at a 0.1 degree resolution for Africa. At this latitude (4°N), a pixel represents approximately 100 square km. RFE2 combines different satellite estimates using the maximum likelihood estimation method (Xie and Arkin 1997) and is calibrated on available station data (over 1000 stations across the continent). Those rainfall estimates are freely available in real time, at a daily time interval, which would ease the implementation of potential insurance, early warning, forecasts and dissemination schemes based on such data. We matched the clusters of Niger LSMS-ISA (N = 268) survey by attributing to every cluster the daily rainfall estimated in the pixel in which it is located and a value of rainfall was attributed to each of the 3967 households. It corresponds to 169 different pixels with distinct dates of survey, which makes 253 different values of indices computed from rainfall estimates (with low variations among each of the 169 pixels since all households were interviewed during the same year). It corresponds to an average number of 23.5 households interviewed per pixels (median of 18, standard deviation of 39.42, with only three pixels with more than 50 households interviewed), with a minimum of four and a maximum of 444. The southern part of the country, with much higher density of population and number of households, is thus over-represented, leading to a low number of observations in the northern (and arid, Saharan climate) part of the country and thus in the lower rainfall gradients.

We selected a set of climate indicators describing the rainfall characteristics in Niger (Tab. S.1). Six rainfall indicators were computed at each household's location and for each year from 2002 to 2011: seasonal rainfall amount, onset, cessation and length of the rainy season, number of dry spells and standard deviation of daily rainfall. Standard deviation of daily rainfall computed each year is used a measure for temporal variability of the rainy season. To determine the onset and cessation dates of the rainy season, we used the criterion defined by Liebmann and Marengo (2001) which has recently been used by Boyard-Micheau et al. (2013) in Sub-Saharan Africa. Since this criterion is based on accumulated rainfall anomalies and not on rainfall threshold, the same definition can be applied for the whole country. This method is based on a quantity A called "anomalous accumulation" which is defined at each location such as:

$$\mathrm{A(day)} = \sum_{\mathrm{n=1}}^{\mathrm{day}} \left[\mathrm{R(n)} - \overline{\mathrm{R}}\right]$$

Where $R(n)$ is the daily precipitation and R is the climatological annual daily average. The calculation can be started at any time but we choose to start the accumulation on

May 1st each year which corresponds to a typical early onset in the wettest part of Niger (Marteau et al. 2011). For an anomalously wet day, relative to the long-term mean, this difference *A* is positive. An anomalously dry period is then shown as continuously declining accumulated anomalies. Across each season, the day on which these anomalies reach a minimum defines the onset. On the other hand, the day of the maximum of an anomalously wet period with continuously rising accumulated anomalies *A* defines the cessation date of the rainy season. Dry spells were defined as a period of at least seven consecutive days receiving less than 1 mm/day.

Table S.1 summarizes such rainfall characteristics in Niger. In order to contrast rainfall change perceptions with measurements during the five last years, we computed for each indicator the difference between the five years preceding the survey 2007–2011 and the preceding five-year period 2002–2006.

2.4 2.3 data analysis

First, we assessed the level of consensus of respondents' perceptions within a specific area experiencing the same local rainfall change. To do so, we used the consensus index originally developed by Tasle and Wierman (2007). Building on Shannon entropy, the index utilizes a probability distribution and the distance between categories. It is computed for every pixel (N = 169) representing an area of approximately 10 × 10 km as so:

$$\mathrm{Consensus}\ (X) = 1 + \sum_{n=1}^{n} p_i \log_2\left(\frac{|X_x - \mu_x|}{d_x}\right)$$

Where μ_x is the mean of *X* and d_x is the width of *X*. A lack of consensus within a pixel of 10 × 10 km generates a value of 0, while a complete consensus of opinion yields a value of 1.

Second, we performed the Mann–Whitney U test to investigate the relationship between perceptions and observations of changing rainfall. As an example, for the question "*Over the past five years, have you noticed more frequent droughts*?" (8A.1.1), we computed the difference in the number of dry spells between the five years preceding the survey 2007–2011 and the period 2002–2006 for each household's location. We then performed a Mann–Whitney U test where the null hypothesis specifies that this difference is similarly distributed between the "*Yes*" and "*No*" responses; perceptions being thus independent of the local observed rainfall change. By opposition, the alternative hypothesis is that the observed number of dry spells observed tends to be larger when people answer "*Yes*" than when people answer "*No*". *P*-values lower than 0.01 and 0.05 were chosen to reject the null hypothesis of independence and to identify a significant association between the perception and an observed local change. When relevant, we performed a Mann-Whitney U test with several rainfall indicators since some perceptions can be related to various rainfall indicators. For instance the perception "*Less rainfall*" could be associated with less rainfall amount, more dry spells or a shorter rainy season (with a delayed onset and/or an early cessation of rainfall). We thus test independently the association between the perceptions of "*Less rainfall*" with each of the latter indicators.

Finally, perceived and observed rainfall changes were contrasted using Pearson's residuals following the methodology proposed by Leclerc et al. (2013). First, rainfall indicators were ranked in ordered categories of equal size (lower, middle and upper), as shown in Table S.3. Pearson's residuals were then calculated for each type of perception. The procedure measures the deviation of the observed frequency (proportion of households perceiving a delayed onset or more drought for instance) from the frequency that would be expected from random answers. For each row *i* and each column *j* of the contingency table, the Pearson's residual for a cell (*Cij*) is given as:

$$C_{ij} = \frac{\text{observed}_{ij} - \text{expected}_{ij}}{\sqrt{\text{expected}_{ij}}}$$

Although the Chi-square test globally assesses whether households' declarations are independent from rainfall categories, the Pearson's residual allows identifying which cells individually contribute to reject the independence. When Pearson's residuals are positive, a positive association is observed while the association is rejected when Pearson's residuals are negative. For intermediary situations, a fuzzy picture (close from 0) should be observed. High residuals values can be interpreted as consensual answers.

Two conditions should be observed to demonstrate the matching between perceived and observed rainfall changes perceptions: (*i*) a higher level of consensus should be expected for extreme climatic events (lower and upper categories) than for intermediary situations (middle category) and (*ii*) Pearson's residuals should increase (or decrease) steadily with the rank of rainfall categories. All statistics were performed with *SAS 9.1* and *R* software.

3 Results

3.1 Recorded changes of the rainy season characteristics

Figure 1 shows the interannual variations of the six rainfall indicators in average over all households' locations in Niger for the 10-year period preceding the LSMS-ISA survey. While there is a high year-to-year variability, several indicators show less favorable climate conditions during the last five years 2007–2011 compared to the preceding five-year period 2002–2006. Indeed, the mean seasonal rainfall amount is decreasing from 387 mm/year to 362 mm/year during the two periods (Fig. 1a). In addition we can see from Fig. 1b, c and d that the timing of the rainy season has also changed during the two periods with shorter rainy seasons (91 days in 2002–2006 compared to 82 days in 2007–2011) characterized by a late onset and an early cessation of rains. However, none of the differences in the mean rainfall characteristics between the two periods 2002–2006 and 2007–2011 pass a student test at 95 %. This is likely due to the occurrence of the exceptional wet year 2010 whose rainy season characteristics (high total rainfall amount, early onset and late cessation of the rains) contrast with the ones of the other rainy seasons of the five-year period 2007–2011.

3.2 Perceived changes of the rainy season characteristics

More than 75 % of respondents indicated that they perceived a decrease in rainfall amount and a worsening of rainfall distribution with 83 % of respondents reporting more frequent droughts

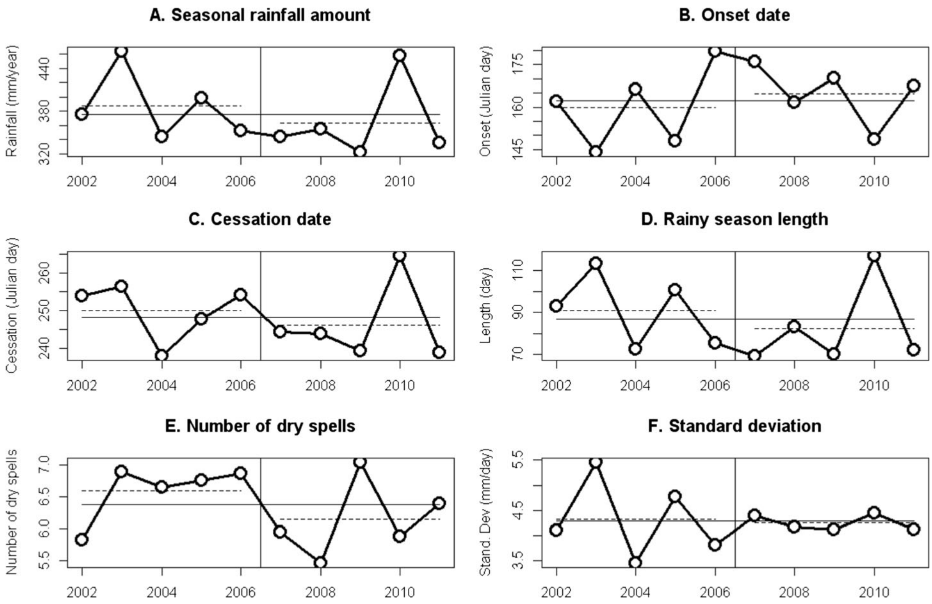

Fig. 1 Time series of rainfall indicators in Niger. All rainfall indicators are averaged over the 3967 households' locations in Niger. The solid horizontal line represents the 2002–2011 average while the two dashed lines represent the 2002–2006 and 2007–2011 average

(Table 1). In addition, a large proportion of respondents reported changes in seasonality of the rainy season which was reported to start later (71 %) and finish earlier (80 %). Perceptions of rainfall changes are very similar between climate-sensitive and non-climate-sensitive households, exhibiting only slight differences between answers. The only significant difference between both livelihood types concerns changes in total rainfall, where 80 % of climate-sensitive households observe a decrease, and only 71 % of other households do.

Several socio-demographic and environmental variables had significant effects on the perceptions of rainfall change (Tab. S.4 and S.5). Indeed, we found that mean rainfall usually experienced by the respondents (here represented by the total annual rainfall averaged over the period 2002–2011) has an effect on their perceptions of rainfall changes; detrimental changes (less rain, more frequent droughts, shorter rainy seasons) being more frequently perceived by people living in drier areas (less than 400 mm per year) than in the more humid areas ($p < 0.01$). Pastoralists and sedentary agro-pastoralists who rely on grazing to feed animals and who usually live in the driest regions, tend to favour even more negative patterns of rainfall changes compared to other climate-sensitive populations (significant at the 1 % level of confidence for most of the rainfall changes mentioned in the survey). Their perception may reflect their high exposure to rainfall fluctuations and an increasing lack of pasture, which may not be entirely due to rainfall. Other socio-demographic characteristics do not show such large differences between categories. Contrary to other studies where farming experience (highly correlated to age) appears as a determinant of perceptions (Maddison 2007; Gbetibouo 2009), the age of the respondents has no significant effect on the perceptions of local changes.

The highest level of consensus in the perceived rainfall changes is found in responses of climate-sensitive households which tend to be more consensual within a pixel than responses given by other households (Fig. 2a and b). This is mainly the case for breeding activities and for other climate-sensitive households. At the exception of rainfall variability, climate-sensitive

Table 1 Frequency of rainfall change perceptions. Percentages are given the main occupation of the household's head

	Climate-sensitive households (n = 2202)	Non-climate-sensitive households (n = 1765)	Total
Rainfall measure			
Less rain	79.8	70.7	75.7
No change	6.1	11.2	8.3
More rain	14.1	18.2	15.9
Distribution of rainfall in the year			
Worse distribution	77.8	78.5	78.1
No change	6.2	11.3	8.5
Better distribution	15.9	10.3	13.4
More frequent droughts			
Yes	82.6	83.1	82.8
No	17.9	16.9	17.2
Delay in the start of the rainy season			
Yes	72.4	68.7	70.7
No	27.6	31.3	29.3
Rainy season finished earlier			
Yes	81.2	78.8	80.1
No	18.8	21.2	19.9
Beginning of the last rainy season (2011)			
Early	11.5	11.3	11.4
On time	37.4	36.5	37
Late	51.1	52.1	51.5

households are more consensual within a pixel than other households. In contrast, less consensus in perceived local change is found among other livelihoods categories, who are mostly urban and sedentary (Fig. 2d). A clear relationship is observed with the rainfall gradient: the less abundant rainfall is, the more consensual responses are. The highest level of consensus is obtained in locations where rainfall is less than 200 mm/year.

We found that three types of perception of rainfall changes are consistently associated to changes in observed rainfall (Table 2). A late start of the rainfall season perceived by households tends to be observed as such, either on a five year time scale ($p < 0.05$) and for the last rainy season ($p < 0.01$). A perceived "*worse distribution*" of rainfall tends to correspond in the observations to a decrease of seasonal rainfall ($p < 0.01$), a shortening of the rainy season ($p < 0.01$) and an early cessation of the rains ($p < 0.05$). Besides, the standard deviation, which measures the deviation from the mean and is therefore expected to be a good indicator of rainfall variability, has no association with the perceived rainfall variability. A perceived increase of the frequency of droughts tends to correspond in the observations to a larger number of dry spells as well as a delayed onset ($p < 0.01$). Two types of perceptions remained without association with observed rainfall indicators: "*less rainfall*" and "early end of the rainy season".

Pearson's residuals were computed to assess the relationship between observed rainfall and perceived changes and perceptions (Fig. 3). We found that climate-sensitive households generally have a more accurate perception of the beginning of the rainy season (Fig. 3a). Indeed, the high positive residuals for upper onset categories (late onset) imply that the number

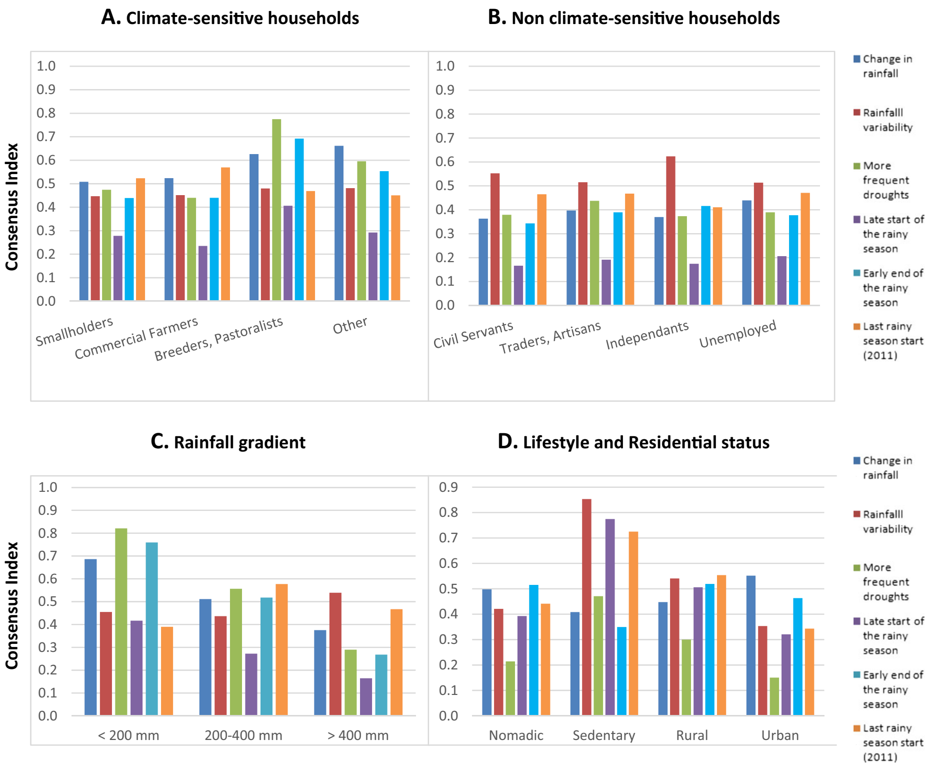

Fig. 2 Consensus in perception of local changes across questions and socio-economic characteristics. Data are sorted according to the economic livelihood **a** and **b**, annual rainfall **c** and residential status **d**. The index ranges from 0 to 1. A low value of the consensus index indicates that respondents can have very different perceptions of local changes within the same location. In contrast, a high value indicates a high degree of consensus within a particular area

of households reporting a late start of the rains is significantly higher than expected under the null hypothesis. Conversely, for the lower onset categories (early onset), the association is clearly rejected by respondents (residuals close to −30). The same agreement is found with the 2011 rainy season onset which occurred less than 6 months before the survey (Fig. 3b). We did not find such agreement between observed and rainfall changes when considering respondents with non-climate-sensitive livelihoods. The residuals are both negative for the earliest and latest onset dates whereas the intermediary situation is highly positive. For the onset of the year 2011, the perception of non-climate-sensitive households was even reversed between observations and perceptions.

We also found that a perceived worsening of rainfall distribution in the climate-sensitive households matches with an observed decrease of seasonal rainfall, a shortening of rainy season and an early cessation of the rains (Fig. 4). The rainy season length seems to be the leading indicator for a perceived worsening of rainfall distribution with the highest Pearson's residuals. Among non-climate-sensitive households, the consistency between perceived and observed changes was less clear, especially for intermediary rainfall situations where absolute values of Pearson's residuals should be lower than for the upper and lower rainfall categories.

The climate-sensitive households' perception of droughts matches well with local changes in the number of dry spells (Fig. 5). Although slightly less clear, perceptions of non-climate-sensitive

Table 2 Heat diagram showing significant *P*-values between climate change perceptions (lines) and meteorological indicators (columns). Dark green is used for statistically significant results at the 1 % significance level, light green at the 5 % level, orange for non significant results and grey when there was no relationship expected

	Less Rain	Higher standard deviation of rainfall	More frequent dry spells	Late onset of the rainy season	Late onset of the rainy season (2011)	Early end of the rainy season	Shorter rainy season
Less Rain	orange	orange	orange	orange	grey	orange	orange
Worse rainfall distribution	dark green	orange	orange	orange	grey	light green	dark green
More frequent droughts	orange	dark green	dark green	dark green	grey	orange	orange
Late start of the rainy season	grey	light green	light green	light green	grey	grey	grey
Late start of the last rainy season (2011)	grey	grey	grey	grey	dark green	grey	grey
Early end of the rainy season	grey	grey	grey	grey	dark green	grey	grey

households were also consistent with rainfall observations. Indeed the proportion of households reporting more frequent droughts increased steadily in areas recording a higher number of dry spells and an observed delayed onset of the rains (climate-sensitive households only).

4 Discussion

In the context of a changing climate, a better understanding of people's perception of weather and climatic variability is required to enhance adaptive capacities. Although detrimental changes tend to be overestimated in such a survey in other contexts in Sub-Saharan Africa (Gbetibouo 2009; Bryan et al. 2009; Mertz et al. 2012; Fosu-Mensah et al. 2012; Silvestri et al.

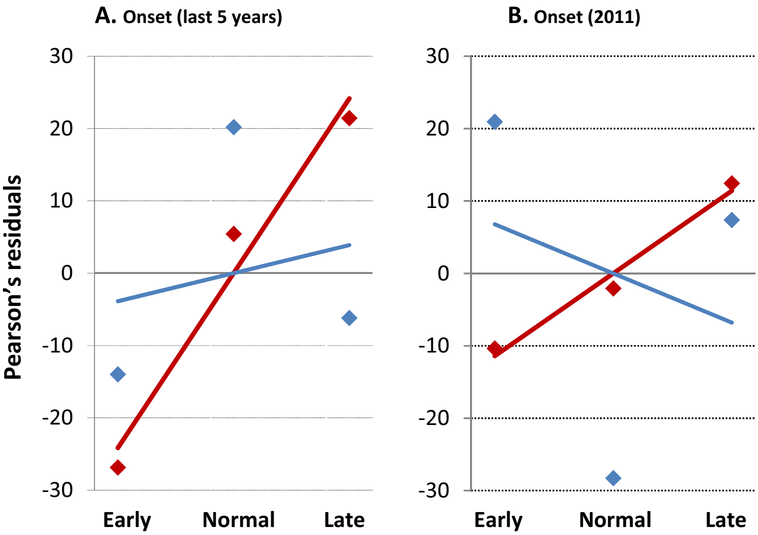

Fig. 3 Proportion of households perceiving a late onset over the last five years **a** and in 2011 **b** compared to observed changes in the onset dates. The red color is used for climate-sensitive households' perceptions, whereas non-climate-sensitive households' perceptions are represented in blue

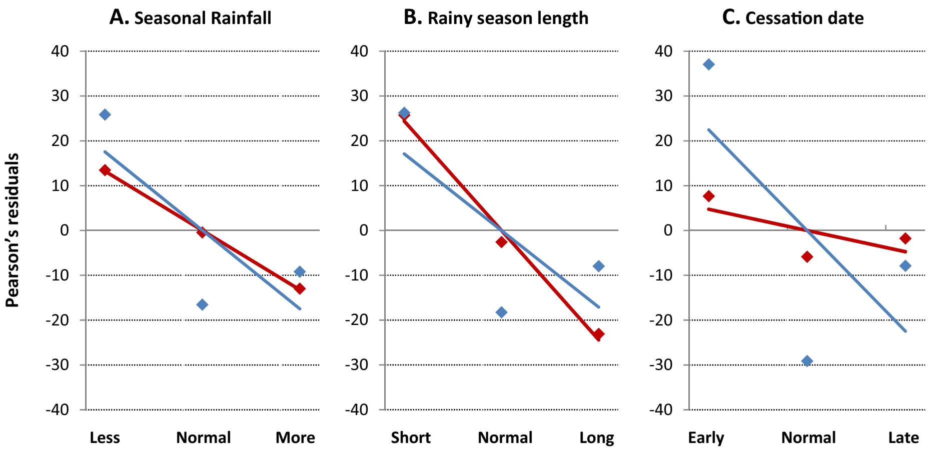

Fig. 4 Proportion of households perceiving a worse rainfall distribution compared to observed changes of seasonal rainfall **a**, rainy season length **b** and cessation date **c**. The red color is used for climate-sensitive households' perceptions, whereas non-climate-sensitive households' perceptions are represented in blue

2012; Comoé and Siegrist 2013), we found an overall perception of a worsening of rainfall conditions which is consistent with the recent changes of rainfall observed from satellite data. This consistency between perceptions and meteorological data, particularly clear when considering climate-sensitive households are in contrast with previous studies in Africa which show on the opposite that perceptions are inconsistent with observed rainfall changes (Meze-Hausken 2004; Osbahr et al. 2011; Rao et al. 2011; Moyo et al. 2012; Simelton et al. 2013; Sutcliffe et al. 2015). While recognizing that the determinants of human perceptions are context-specific, we argue that this conflicting result may be explained by differences in research settings. First, while existing studies are based on case-studies, to our knowledge this study is the first to use a

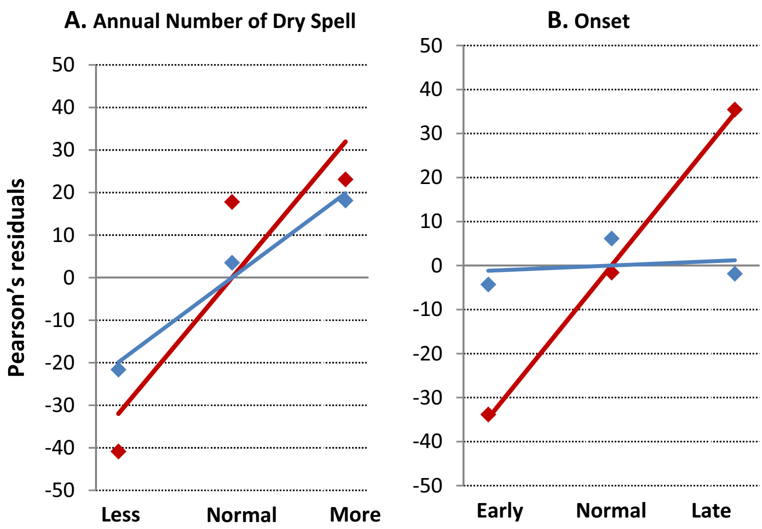

Fig. 5 Proportion of households perceiving more frequent droughts compared to observed changes of the annual number of dry spells **a** and of the onset date **b**. The red color is used for climate-sensitive households' perceptions, whereas non-climate-sensitive households' perceptions are represented in blue

nationally-representative survey. Indeed, large scale datasets offer the advantage of encompassing a high diversity of rainfall changes. Second, this study used fuzzy logic and Pearson's residuals to match perceptions with observations. In the context of the analysis of indigenous knowledge, fuzzy logic is particularly relevant in matching (imprecise) human perceptions with (precise) scientific measurements (Berkes and Kislalioglu Berkes 2009; Leclerc et al. 2013). Third, by focusing on short-term perceptions (five years or the previous season), a choice which contrasts with the literature, we believe that memory biases are likely to be limited in our study (Beegle et al. 2011; Mertz et al. 2012). Fourth, the comparison between climate-sensitive and non-climate sensitive households contributes to our understanding of the topic by providing evidence that the latter have more accurate perceptions. This result suggests that households' climate sensitivity should be taken into account when studying human perceptions of rainfall changes.

It is important to recognize some inherent limitations of this study. First, the formulation of survey questions is an important point when collecting local change perceptions. An oriented question, such as "*During the last 5 years*, *have you noticed more frequent droughts*?" may favour affirmative answers. Neutral questions, such as "*During the last 5 years*, *have you noticed a decrease*, *increase or no change in drought frequency*?" are more likely to deliver a clearer picture of perceptions. In the LSMS-ISA survey, questions on droughts, start of the rainy season and end of the rainy season were collected through oriented questions, while questions on rainfall amount, variability and last rainy season starts were neutral (Table S.2). Second, there was no "*Do not know*" response category and households without an opinion may have given a random or a fuzzy answer. Third, in several local languages, words may be lacking for the description of some climate parameters. For instance, Tschakert (2007) demonstrates that the word climate leads to a plurality of definitions in Wolof, Senegal's dominant language. As in Senegal, Niger is composed of a multiple ethnic groups with different languages.

Another limitation of this study is the use of rainfall estimates instead of meteorological stations data which were not available to us at the time of the study. Indeed, the RFE2 rainfall estimates dataset is specifically designed and used for monitoring rainfall conditions across Africa as part of famine early warning surveillance and not intended to be used for detecting inter-annual precipitation trends in onset and cessation of rainfall. Yet, this dataset has already been successfully used to document recent trends of rainfall in sub-Saharan Africa (Diem et al. 2014). Moreover several studies compared rain gauge and satellite data for this zone (Thiemig et al. 2012; Gosset et al. 2013; Novella and Wassila 2013; Ramarohetra et al. 2003; Roca et al. 2010), showing the relatively high performance of such methods and their particular interest for areas that are poorly endowed with rain gauge infrastructure, as is the case for Niger. In addition, using the only rainfall station publicly available at Niamey Airport, we found a similar trend in the total rainfall and onset date as found in satellite retrievals and reported by the majority of people in Niger (Fig. S.2).

5 Conclusion

In this paper, we used an index of consensus and Pearson's residuals to understand whether perceptions of recent rainfall changes are consistent with rainfall observations in Niger. Our results demonstrate that climate-sensitive households are more consensual and more closely related to observed local changes than other respondents. Climate-sensitive households in Niger are particularly aware of rainfall changes related to the onset, rainfall distribution and droughts frequency.

The onset was found to be accurately perceived at various time scales and for different changing patterns. Such a result highlights the importance of the start of the rainy season for a number of agricultural and pastoral activities. In contrast, local changes of total rainfall did not match the households' perceptions. It confirms results from Roncoli et al. (2002) showing that the perception of changing precipitation is more drive by a change in seasonality or in the frequency of extremes instead of a change in total precipitation.

The apparent mismatch we found between observed and perceived local changes by households in urban areas may raise some concerns about the awareness of environmental changes in such areas. Being unable to notify local rainfall changes may lead to an underestimation of climatic risks. However, more relevant climate indicators in urban areas such as the occurrence of heatwaves and floods need to be further investigated.

A better understanding of household perceptions can add value to policy processes that strive to mitigate the effects of climate change especially in the context of developing countries. It might serve as a reliable basis for the design of relevant adaptation tools to support decision-making of farmers. For instance, our findings point out the importance of an indicator such as the onset of the rains for shaping adaptation-related tools such as seasonal forecasts and weather index-based insurance (Ingram et al. 2002; Roudier et al. 2012 and Roudier et al. 2014; Leblois et al. 2014). The diffusion and adoption rate of such tools depend heavily on the transparence and understanding of farmers (Patt et al. 2010), advocating more attention to indigenous knowledge and adaptation strategies in response to perceived changes in rainfall.

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