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RESEARCH PAPER

Climate Variability and Environmental Stress in the Sudan-Sahel Zone of West Africa

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Abstract Environmental change in the Sudan-Sahel region of West Africa (SSWA) has been much debated since the droughts of the 1970s. In this article we assess climate variability and environmental stress in the region. Households in Senegal, Mali, Burkina Faso, Niger, and Nigeria were asked about climatic changes and their perceptions were compared across north–south and west–east rainfall gradients. More than 80% of all households found that rainfall had decreased, especially in the wettest areas. Increases in wind speeds and temperature were perceived by an overall 60–80% of households. Contrary to household perceptions, observed rainfall patterns showed an increasing trend over the past 20 years. However, August rainfall declined, and could therefore potentially explain the contrasting negative household perceptions of rainfall trends. Most households reported degradation of soils, water resources, vegetation, and fauna, but more so in the 500–900 mm zones. Adaptation measures to counter environmental degradation included use of manure, reforestation, soil and water conservation, and protection of fauna and vegetation. The results raise concerns for future environmental management in the region, especially in the 500–900 mm zones and the western part of SSWA.

Keywords Climate variability · Perceptions · Adaptation · Environmental management · Rainfall · Sahel

INTRODUCTION

Since the droughts of the 1970s and early 1980s in the Sudan-Sahel zone of West Africa (SSWA), there have been numerous attempts at understanding how humans and the natural environment have been affected by and adapted to the variable climate and weather patterns in the region (Mortimore and Adams 2001; Hiernaux et al. 2009; Nielsen and Reenberg 2010a). From the dramatic drying scenarios experienced in the 1970s and 1980s (Hulme 2001) to the apparent 'greening of the Sahel' (Rasmussen et al. 2001; Mortimore and Turner 2005; Olsson et al. 2005), there is little doubt that the Sahelian environment is sensitive to both human and natural driving forces, but the relative weight of these drivers and the nature of the impacts themselves on human populations and the natural environment are still contested (Mbow et al. 2008).

While there is no doubt that the region has experienced a dramatic change in climate over the past 30–40 years as annual rainfall has declined, recent trends show a more nuanced picture where a recovery is found in the central Sahel (between longitudes 7°W and 2°E) but not in the western Sahel (west of 7°W), leading to a proposed superimposition of an west–east gradient onto the already well-known north–south gradient of annual rainfall (Lebel and Ali 2009). The uncertainties surrounding the SSWA system are also clear from the IPCC Fourth Assessment Report as there is little consensus in the models regarding future rainfall patterns in the SSWA (Christensen et al. 2007).

Most studies looking at environmental change in the SSWA have analyzed specific environmental parameters at various scales. These range from assessments at local level (Mbow et al. 2000; Lykke et al. 2004; Wezel and Lykke 2006) to regional scale remote sensing based analyses (Olsson et al. 2005; Hein and de Ridder 2006)—whereas no studies have assessed the local perceptions of environmental stress across the whole region. Local perceptions of environmental change—combined with secondary data on observed changes—are important as they may capture factors and driving forces of change (Mertz et al. 2009, 2010), which may not appear in more narrowly designed analysis of specific environmental parameters. Perceptions may of course not be a completely true representation of actual changes, but as was found in Burkina Faso, they can often be corroborated by observed data (West et al. 2008) and they can be expected to determine human actions as people are likely to act according to their perceptions.

The objective of this article is to take the local approach by West et al. (2008) to a more regional scale and link local perceptions of change in climate factors and environmental stress for 15 sites across the SSWA. Focus is on farmer and pastoralist perceptions of climate variability and change during the past 20 years and the consequences thereof for natural resources. We also compare the local perceptions with observed rainfall data during the same period.

STUDY SITES AND METHODS

The 15 sites in Senegal, Mali, Burkina Faso, Niger, and Nigeria cover three main agro-ecological zones and stretch from 400 to 900 mm of annual precipitation (Fig. 1). The sites were selected to represent both an east–west and a north–south rainfall gradient and all sites had been previously studied by one of the research partners. This was essential to facilitate access to the villages and build on long-standing trust which is essential for obtaining valid information. From November 2007 to June 2008, 1249 household questionnaires were implemented by research assistants, who asked the questions to the household head (Table 1).

The households were asked to state changes during the past 20 years with respect to precipitation, temperature, winds, and dust storms. More specifically, they were asked about changes in the amount of annual rainfall, the length of the rainy season, the length of dry spells, the intensity of rainfall events, inundations of fields and villages, the intensity of temperatures during dry and wet seasons, the length of dry and cold periods, the frequency and duration of strong winds in both seasons and the intensity of dust

Table 1 Field sites and number of households (HH) sampled with indication of location according to north–south rainfall zones and west-east gradients

Site	Location according to rainfall zone	West–Central–East location	HH sampled
Burkina Faso			
Bidi-2	400–500 mm	C	41
Yomboli	400–500 mm	C	40
Dano	700–900 mm	C	105
Tougou	500–700 mm	C	98
Ziga	700–900 mm	C	99
Mali			
Dianguirdé	500–700 mm	W	106
Gogui	500–700 mm	W	99
Nankorola	700–900 mm	C	100
Niger			
Banizoumbou	400–500 mm	E	86
Guidan Roumji	400–500 mm	E	71
Mountseka	400–500 mm	E	93
Nigeria			
Chingowa	400–500 mm	E	45
Kalalawa	700–900 mm	E	50
Zangon Buhari	700–900 mm	E	47
Senegal			
Barkedji	400–500 mm	W	45
Kaffrine	500–700 mm	W	124
Total			1249

See actual locations in Fig. 1

Dry zone: 400–500 mm; intermediate zone: 500–700 mm; wet zone: 700–900 mm

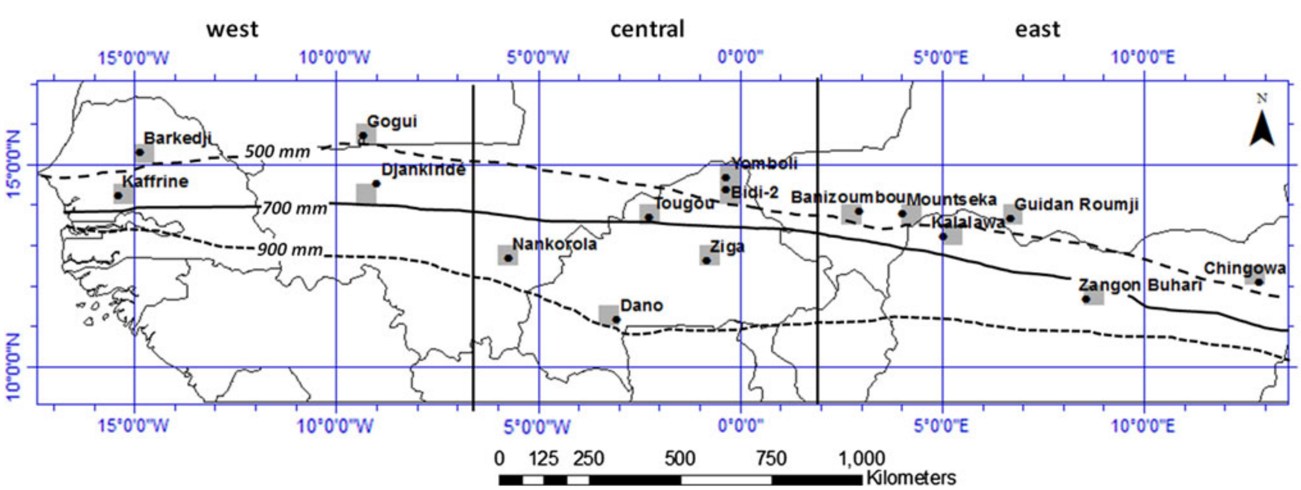

Fig. 1 The location of the 15 sites in West Africa, with indication of isohyets and the rainfall data grid cells used

storms. Finally, households were asked to assess positive and negative impacts of climate factors on soils, water resources, vegetation and fauna as well as the adaptation measures implemented to counter these. All frequencies of responses were tested for significance using a χ^2 test.

Focus group interviews were carried out in Kaffrine, Senegal, Tougou, Ziga, and Dano, Burkina Faso, Tourourou, and Nankorola, Mali, and Mountséka and Guidan Roumdji, Niger. The interview guide for group interviews focused first on open questions and discussion regarding general positive and negative aspects of village life before issues of climate and broader perceptions of environmental change were discussed. This was done in order not to influence the answers of respondents.

We are aware that household and focus group perceptions of climate factors during the past 20 years will not provide an accurate or even correct representation of actual changes. However, households are likely to act upon their perceptions (Vedwan 2006; Slegers 2008) and in order to guide strategies for adaptation and development it is therefore important to link such perceptions to observed changes. For a further discussion on the use of perceptions, see also Mertz et al. (2010).

Household perceptions on climatic changes were compared with climatologically observed changes. Due to limited or no data availability for most parameters, this was only possible for rainfall trends, and more specifically only for rainfall amounts and dry spells. The rainfall data were extracted from a database of 0.5° latitude–longitude gridded 10-day (hereafter called decades) rainfall amounts for the period 1982–2006. The data originate from a network of 266 ground stations and were extrapolated by applying regression kriging to obtain the grid (Lebel and Ali 2009). For the SSWA located south of 15°N and west of 11°E, the coverage of rainfall stations was optimal for minimizing measurement errors (Ali et al. 2005). In a study comparing global products and using the rain gauge network as a reference, Ali et al. (2005) found that the ground products remained, in this region, superior to the blended products. To characterize magnitudes of dry spells, the deviation of rainfall of a

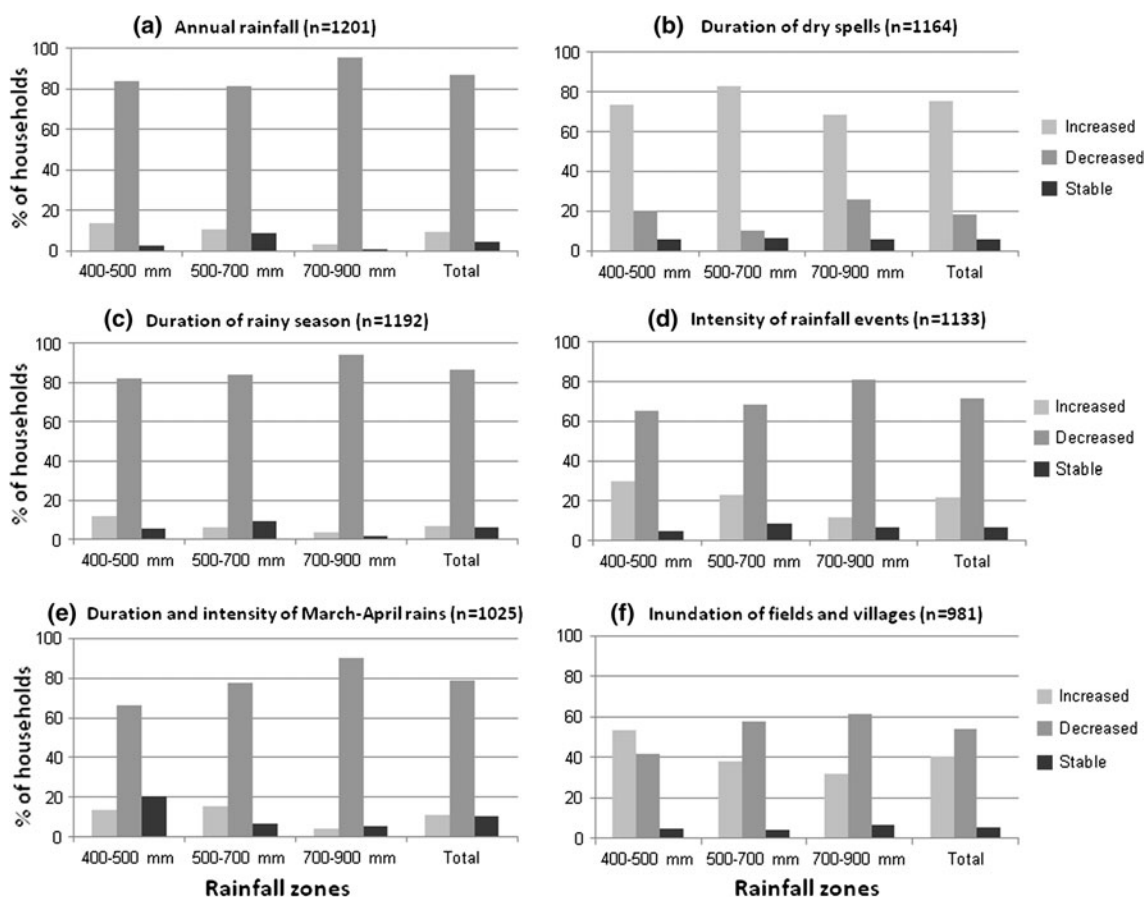

Fig. 2 Household perceptions of changes in **a** annual rainfall, **b** duration of dry spells, **c** duration of rainy season, **d** intensity of rainfall events, **e** duration and intensity of March–April rains, and **f** inundations of fields during the past 20 years. Data presented along a north–south gradient according to different rainfall zones

particular 10-day period from the long term period mean was calculated using z scores (Lebel and Ali 2009):

$$\text{Anomaly} = \frac{\text{Period rainfall} - \text{long term mean period rainfall}}{\text{Standard deviation of long term mean period rainfall}}$$

A period was categorized as dry if the anomaly was equal to or lower than −0.75.

RESULTS

Household Perceptions

North–South Gradient

The results in this section are divided into three ecological zones based on average annual rainfall over the past 20 years at the study sites. The zones are: 400–500 mm (dry zone), 500–700 mm (intermediate zone), and 700–900 mm (wet zone). In all these zones there was generally a pessimistic perception of changes in climate factors over the past 20 years. It was of course difficult to account for the 'golden past' effect, but the response patterns were in many cases so clear that they—as a minimum—reflected a great concern with a changing and very variable climate. χ^2 tests showed that all differences between groups were significant at $P < 0.01$.

The overall perceived *precipitation* patterns (Fig. 2) were viewed most negatively by households in the wet zone. Almost 100% of respondents in this group stated that overall rainfall in the rainy season had declined. They were less negative on the length of dry spells than the other zones, but still almost 70% of respondents stated dry spells had increased. The intensity of rainfall events and inundations had generally decreased, according to their perception. The dry zone was the only area to perceive the frequency of inundations to have increased and about 30% of respondents found rainfall events to be more intense. The intermediate zone was in most responses intermediate between the two extreme zones except on dry spells where they had the highest response rate of all groups with more than 80% stating an increase.

The response patterns regarding *temperature* (Fig. 3) showed for the intermediate and wet zone that more than 60%—and in some cases up to 90%—of households stated that temperatures and the length of hot spells had increased. This was also the case for the dry zone, though responses were somewhat mixed. Regarding the length of cold spells, there was more disagreement—in the dry and wet zones a majority found these to have decreased whereas in the intermediate zone, 60% perceived an increase. Finally, perceptions of changed *wind* patterns (Fig. 4) showed that households found the frequency of strong winds in both dry and rainy season to have increased as well as the intensity of dust and sand storms. The intermediate zone had the most pronounced negative view with more than 80% stating an increase in wind in all three response categories.

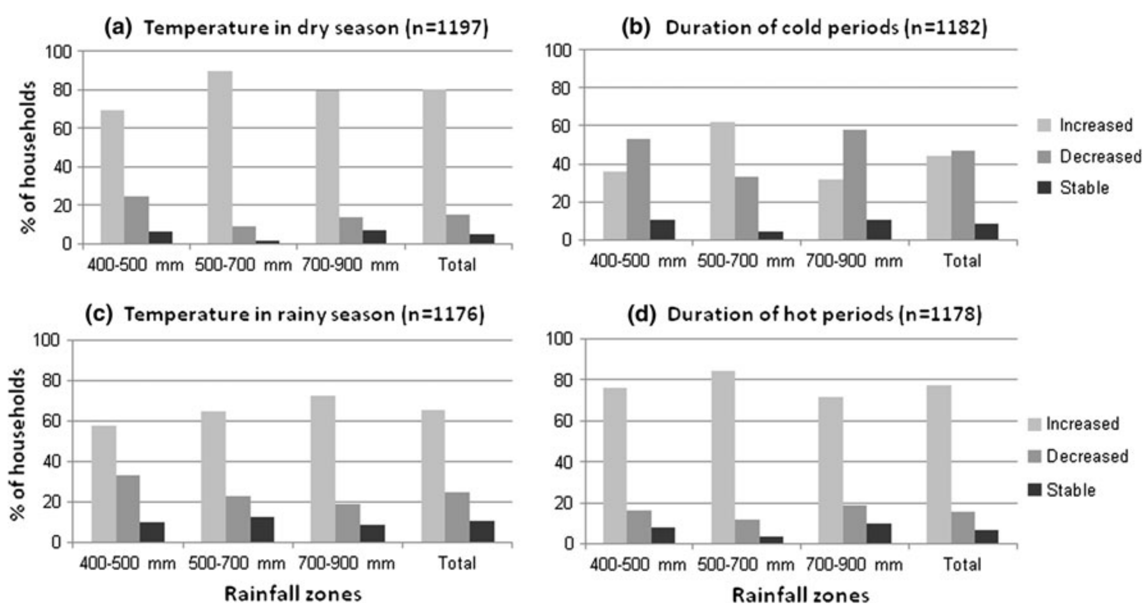

Fig. 3 Household perceptions of changes in temperatures in **a** rainy and **b** dry seasons and in the duration of **c** cold and **d** hot periods during the past 20 years. Data presented along a north–south gradient according to different rainfall zones

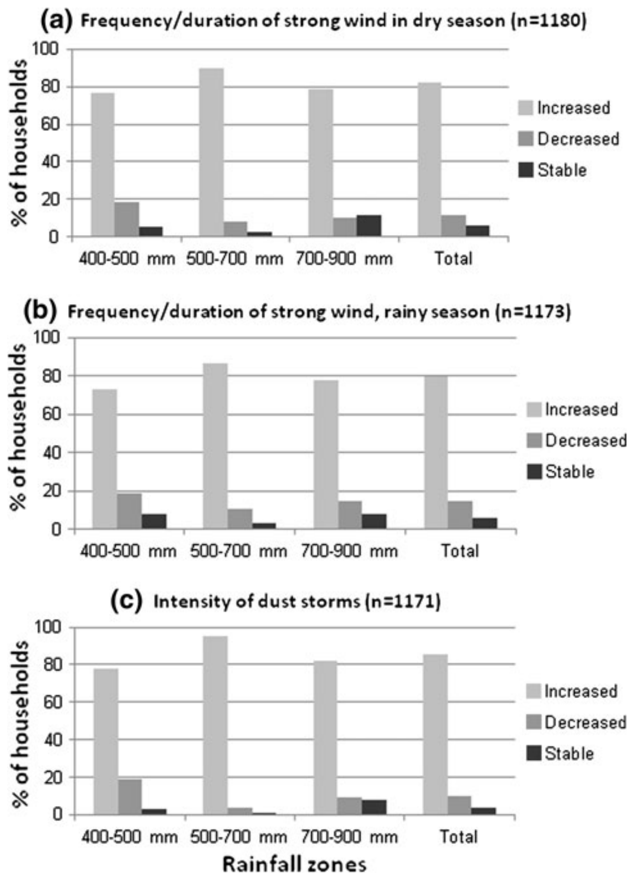

Fig. 4 Household perceptions of changes in the frequency and duration of strong winds in **a** the rainy season and **b** the dry season and in **c** the intensity of dust storms during the past 20 years. Data presented along a north–south gradient according to different rainfall zones

West–East Gradient

An even clearer pattern could be observed when analyzing household perceptions along a west–east gradient. The boundaries for, respectively, the western, central, and eastern part of the SSWA for the purpose of this study are indicated in Fig. 1. Here χ^2 tests also showed that all differences between groups were significant at $P < 0.01$. Households in the western part of the SSWA were consistently more negative than those in the central or eastern part about climate trends in the past 20 years. Those in the eastern part consistently had the most positive impressions. Overall, over 80% of household found that total annual *rainfall* amounts had decreased over the past 20 years. However, in the western part of the SSWA more than 90% of households perceived a decrease whereas this was significantly lower in central (85%) and eastern SSWA (75%), see Fig. 5. Similar observations were made for the other parameters. The contrast between perceptions in the western and eastern part became particularly clear for the length of the dry spells as about 90–95% of households in the western part perceived an increase against only about half of the households in the eastern part.

A much higher percentage of households in the west experienced an increase in *temperatures* during the dry season than in the central and in particularly in the eastern part of the SSWA (Fig. 6). Similarly, a higher percentage of household experienced an increase in temperatures and in the length of cold spells in the western and central part than in the eastern part. With regards to the length of hot spells, still a higher percentage of western households experienced an increase but there was almost no difference between the percentages of households in the central and eastern part. The clear west–east gradient was also present in the perceptions of changes in *wind* patterns (Fig. 6).

Perceptions of Impact of Climate Change and of Environmental Stress

Few households mentioned positive *impacts* of climate change and variability on soil, water, vegetation, and fauna, especially in the intermediate zone, where less than ten households listed positive impacts on all four environmental parameters. Households were most positive in the wet zone, especially with regard to soil and water resources. Generally, the households did not provide details on the nature of impacts other than, for example, that water availability had increased or decreased, vegetation had increased or degraded and so on.

Relatively few adaptation measures to impacts on environmental resources were mentioned except for soil resources (Fig. 7a). The main adaptation strategy for the declining quality of soil resources was manure application and other types of soil fertilization. In the intermediate zone, fallow was also mentioned as important, probably because it is very difficult to find fallow land in that area due to agricultural expansion (Mertz et al. 2010). The other measures were of minor importance, though various types of soil and water conservation were common. Adaptation to declining water resources was very uniform across the rainfall zones: various types of water points had been developed and improved (Fig. 7b). Soil conservation and water harvesting were also mentioned, however. For vegetation and fauna (Fig. 7c, d), reforestation and protection of vegetation and fauna were the most important strategies, and the importance of vegetation for fauna protection was recognized. Reforestation is in most cases related to either establishment of community woodlots for firewood or wider tree planting actions on degraded forest lands and abandoned agricultural land. The latter is often promoted by externally funded projects. Fattening of livestock was also an adaptation measure to declining fauna as a response

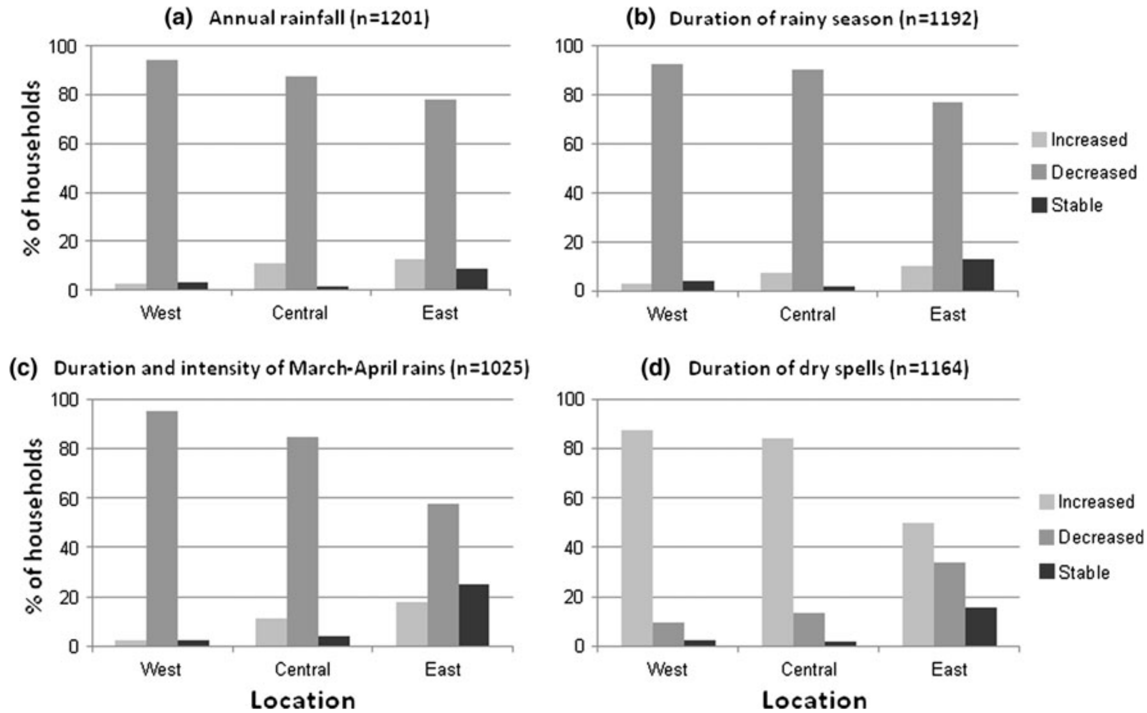

Fig. 5 Household perceptions of changes in **a** annual rainfall, **b** duration of dry spells, **c** duration of rainy season, and **d** duration and intensity of March–April rains during the past 20 years along a west–east gradient

to declining availability of bush meat for consumption and sale.

In the focus group discussions, positive aspects mentioned by groups included good access to agricultural land and proximity to water resources, but these were not caused by environmental factors. However, several of the negative comments indicated environmental stress: poor soils were mentioned by groups in seven sites and increased evaporation from water bodies was mentioned in three sites. Direct climate drivers such as 'poor rainy seasons' and higher temperatures were also mentioned in this part of the interview where the climate issue had not yet been discussed with the group. The condition of the natural vegetation was also mentioned directly when 'the bush' was perceived to be less green due to the lack of rain, but also indirectly in one site by the lack of firewood.

Groups in all eight sites reported warmer temperatures and less rain over the past 20 years, whereas longer dry spells and stronger winds were reported from six sites. "Rains start late" was more frequently mentioned in the western sites than in the eastern sites whereas the opposite was true for the comment "rainy season shorter". The impacts on the natural environment mentioned were mainly focused on a reduction in the vegetation in seven sites—fewer plants in the bush and deforestation. Loss of fauna due to the cutting of trees and increased hunting as well as movement of sand was another frequently mentioned problem.

There were relatively few adaptation measures focusing directly on environment, though some of the general adaptation measures such as migration and diversification of activities could also be a response to impacts of either climate variability or resource use on the environment. In five sites of the central–eastern part of the region reforestation was mentioned as a means to improve the bush but halting hunting as a means to increase the fauna in the bush was only mentioned in one site. Stopping the practice of bush fires was mentioned in two sites as a means to improve the bush.

Observed Changes in Rainfall

Observed decadal rainfall trends were analysed to compare them with the household perceptions of rainfall trends for all sites. Actual overall decadal rainfall amounts showed an increase over the last 20 years in all sites. There was, however, no clear trend along either the north–south or the west–east gradient (Fig. 8). Rainfall amounts at the beginning and end of the season seemed to remain the same in the western and the eastern part, but the central part saw a small decline in rainfall amounts at the beginning of the season. The rainfall pattern in the middle of the season

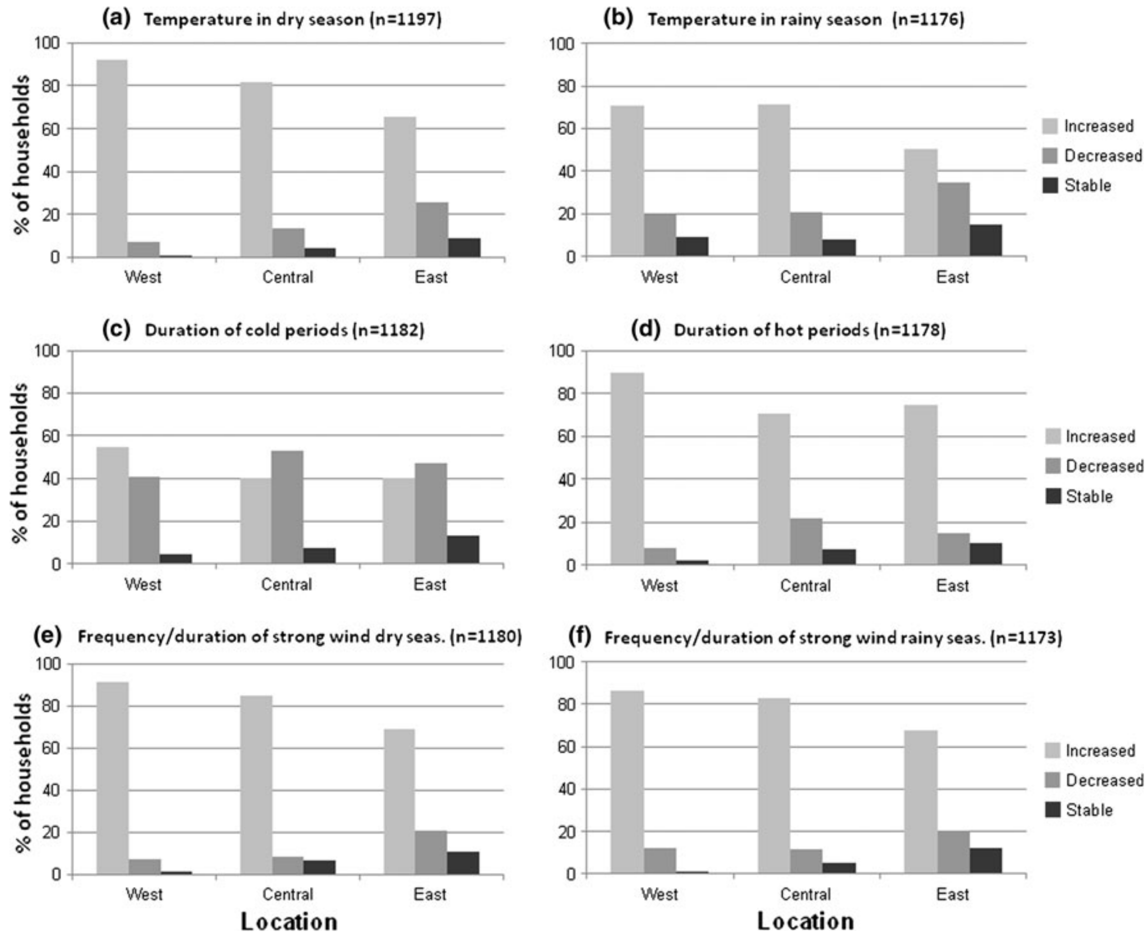

Fig. 6 Household perceptions of changes in temperatures in the **a** dry season and **b** rainy season, in the duration of **c** cold and **d** hot periods, and in changes in the frequency and duration of strong winds in the **e** dry season and **f** rainy season during the past 20 years along a west–east gradient

changed significantly over the years for all sites, and rainfall amounts for the period 1982–1986 were below those of the period 2002–2006, and this for practically the whole season. However, between 1992 and 2001, July and August rainfall amounts were, in most of the sites, higher than in either 1982–1986 or 2002–2006. This seemed especially pronounced for the 700–900 mm rainfall zone. In the eastern part of the region, and for the 700–900 mm sites in the central part, the peak of the rainfall season was later during the 2002–2006 period than during any of the previous periods.

No clear change in either the length or the frequency of dry spells could be observed over the years, although there were fewer dry spells in the period 2002–2006 compared to 1982–1986 for most sites. An example of the central zone is shown in Fig. 9—the figures for the western and eastern zone are very similar.

DISCUSSION AND CONCLUSIONS

Based on the perceptions by households and by the focus groups, a fairly clear picture of increasing environmental stress was painted across the region. Most of the climate factors were perceived to become more extreme (Figs. 2, 3, 4, 5, and 6), perhaps with the curious exception of the intensity of rainfall events, which in IPCC scenarios are expected to accompany climate change in the region. The perceived increase in temperatures is consistent across the region.

The perceptions of change in rainfall factors appeared to be in contradiction to the observed climate information over the past 20 years, where a recovery in rainfall has been seen in many parts of the SSWA (Fig. 8). Our data shows that the perceived shortening of the rainy season was not happening according to the 10-day period climate data.

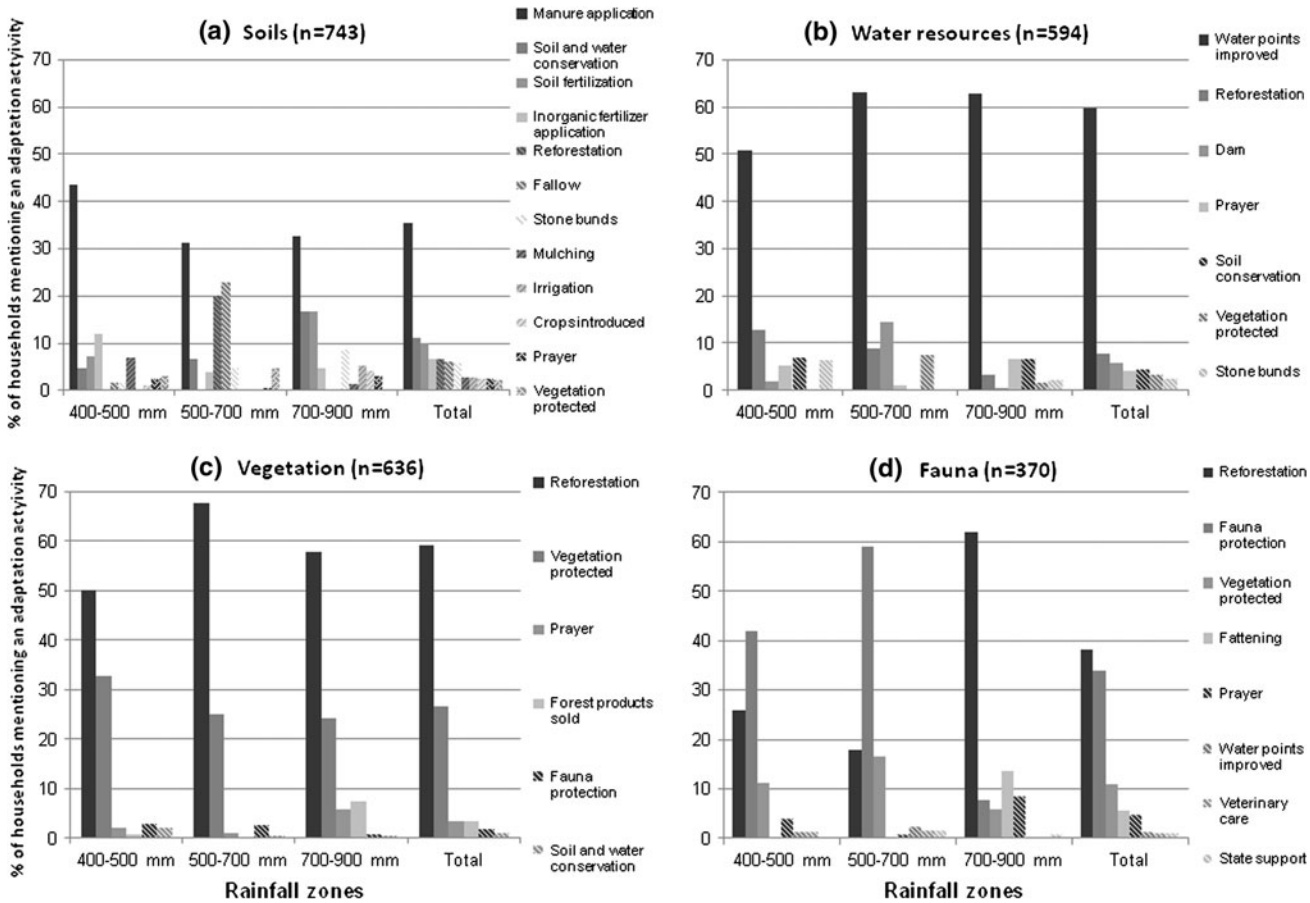

Fig. 7 Adaptation measures mentioned by households in response to negative impacts of climate factors on **a** soils, **b** water resources, **c** vegetation, and **d** fauna according to different rainfall zones

However, the perception of declining rainfall may represent a general discontent with the inter- and intra-seasonal variation of rainfall as observed elsewhere (West et al. 2008), and the observed rainfall data showed that July and August rainfall decreased in the 2002–2006 period compared to the 1990s across the region. The peak of the rainfall season also shifted backwards in time. August is a crucial month of fruiting for cereal crops, and dry spells (Fig. 9), extreme rainfall events or overall low/excessive rainfall in this month may strongly influence household perceptions of overall rainfall patterns. Additionally, a smaller number of rainfall events might also contribute to a mismatch between perceptions and rainfall data. For a small area in west Niger (Le Barbé et al. 2002) found that the "main change of rainfall regimes since the 1950s and 1960s is the dramatically smaller occurrence rate of rain events in August and September whereas the monthly averages of their point intensity did not change much." This would be in accordance with some households' perceptions of an increase in the intensity of the rainfall events.

Observed data on inundations, temperatures and windspeed were not available. The very strong negative perception of change in wind patterns in the intermediate zone (Fig. 4) may be due to the relatively high population density of this zone compared to the other zones in many of the countries. In 2000 in Burkina Faso, Mali, and Senegal, this zone had 30–50 inhabitants per km^2 or more compared to 10–30 inhabitants per km^2 in the dry zone whereas the wet zone was highly variable (Heinriggs and Perret 2009). The zone is close to the northern margin of agriculture and the high land use intensity coupled with a reduced forest cover may cause winds to be perceived stronger than they used to be. However, it may also be that winds speed and frequency of strong winds have indeed increased.

The pessimistic views on the impact of climate factors on the environment held by most households (Fig. 7) give some reason for concern for the coherence in answers, at least in the first category on soil fertility: the main physical reasons for reduced soil fertility is unlikely to be climate factors. Reductions in water resources, vegetation, and

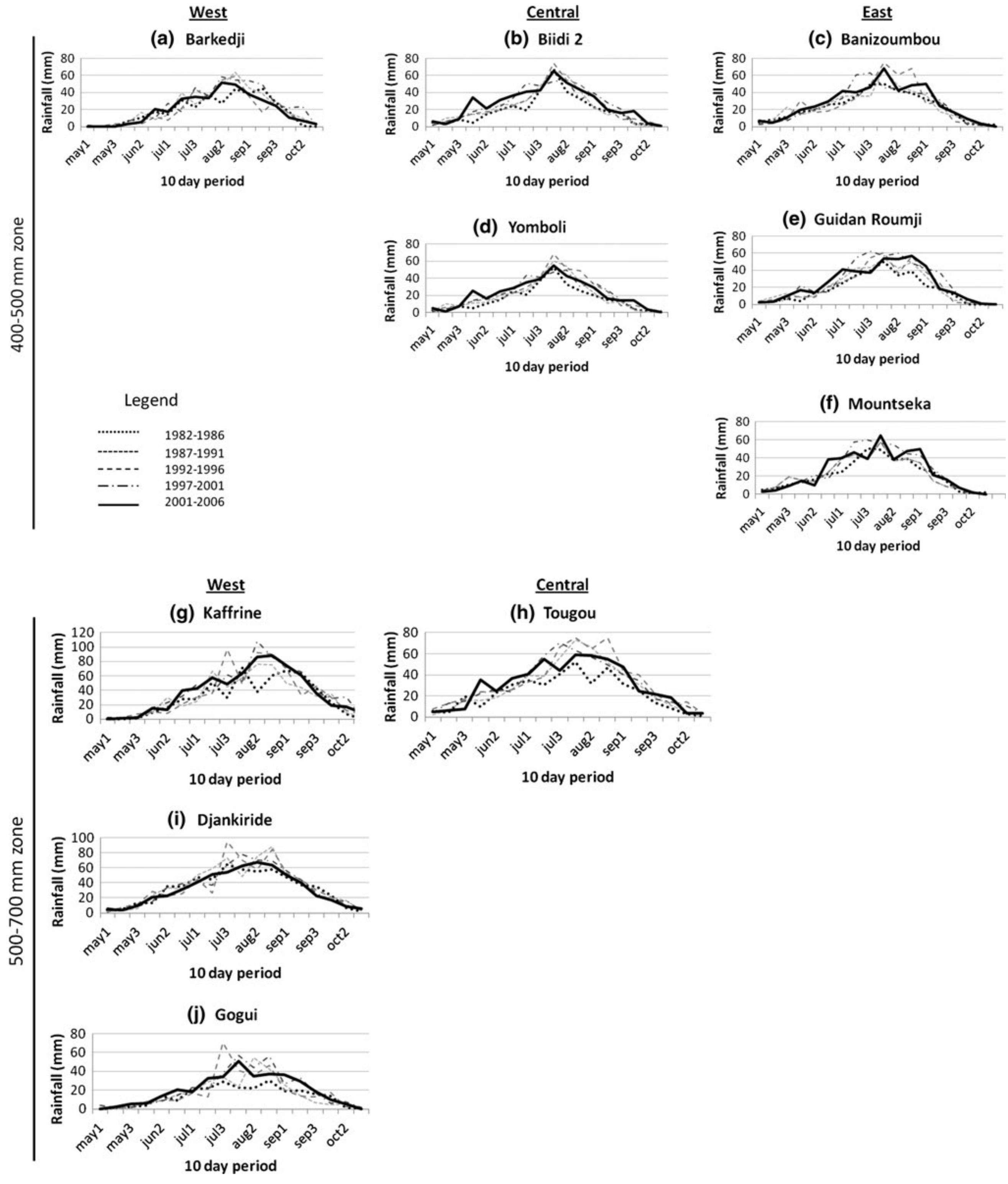

Fig. 8 Observed changes in decadal rainfall for all study sites for the period 1982–2006, divided into five periods of 5 years. **a**–**f** Study sites located in the 400–500 mm zone, **g**–**j** study sites located in the 500–700 mm zone, and **k**–**o** study sites located in the 700–900 mm zone

fauna were more consistent with the question. The suggested adaptation measures were not surprising and may indeed indicate adaptive responses to many other factors than just climate change (Mertz et al. 2010), e.g., projects on soil and water conservation that are also a response to declining crop yields (Reij et al. 2005). But it was

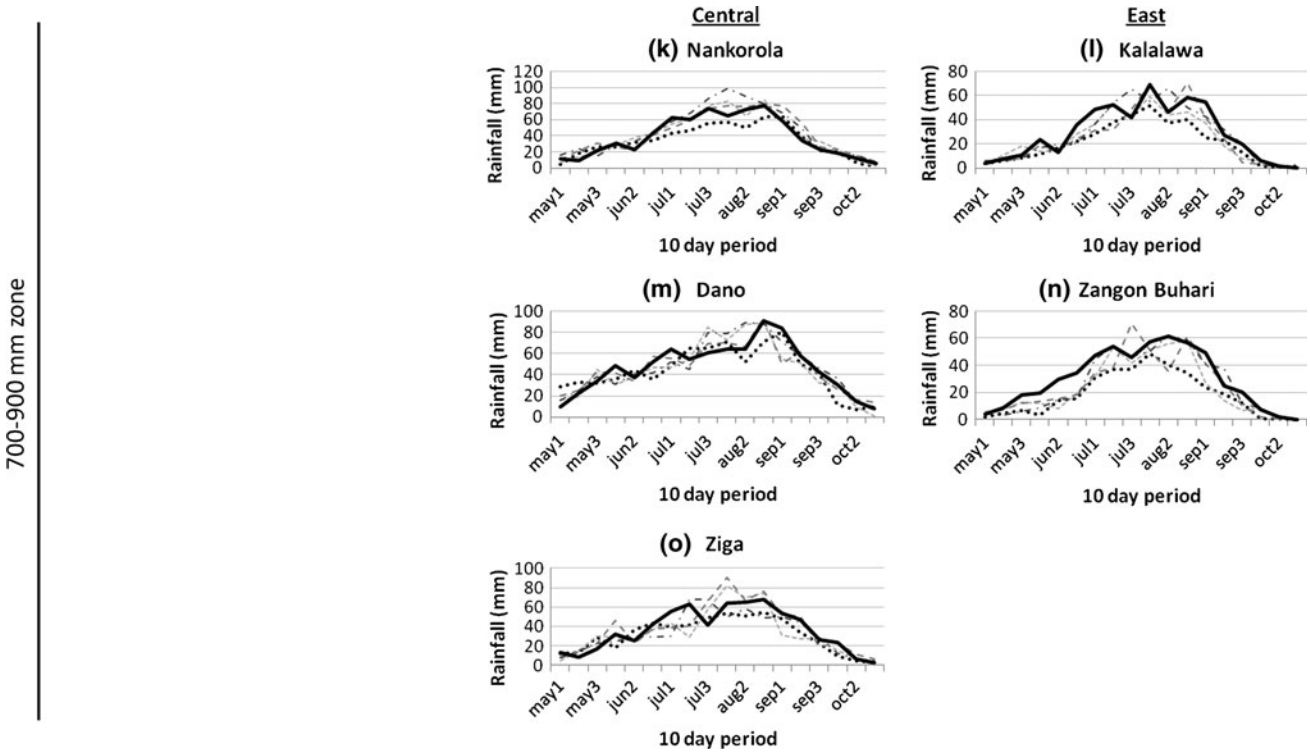

Fig. 8 continued

interesting that a fairly high percentage of respondents favoured protection of vegetation as a way to reduce deforestation and disappearance of fauna. Although the population at most of the sites consisted essentially of farming and livestock keeping communities, this underlines their strong concern with the natural environment as a source of income and subsistence as shown by others (Mertz et al. 2001; Lykke et al. 2002; Lykke et al. 2004). On the other hand, the pessimistic view of households on natural resources could be seen as being partly in contradiction to studies documenting a greening of the region (Olsson et al. 2005; Huber et al. 2011). There could be several reasons for this. First, the household focus on reforestation as one of their favoured adaptation strategies may in fact have contributed to a greening of their environment even though the natural vegetation may still be under pressure. Second, farming households are likely to focus their attention on the areas they use and these areas are likely to be diminishing given the increasing focus on migration and off-farm work as documented by many studies (Roncoli et al. 2001; Barbier et al. 2009; Nielsen and Reenberg 2010b; Mertz et al. 2011). Hence, they may not capture a broader greening trend in their region. Third, it should be noted that communities in the driest zone have a generally optimistic view on the development of natural pasture as a result of pastoral land reforms making these areas off-limits for agriculture (Mertz et al. 2010).

As indicated in "Study sites and methods" section, the perceptions mentioned in this article are not necessarily true representations of how the environment is changing as many people intuitively find the weather better and the forests greener in the past and the household heads responding to the questions may think that painting gloomy pictures of the environment could attract funding for local projects. Moreover, views may be strongly influenced by media stories that tend to focus on negative developments of the environment. Nonetheless, the overwhelming agreement for some of the response categories does call for concern about the environmental conditions. This is especially the case in the intermediate and wet zones that have higher population density and more pressure on land and other natural resources (Barbier et al. 2009; Mertz et al. 2010). Even though greening trends and rainfall were not easily correlated (Huber et al. 2011), the western part of the SSWA may require special attention to environmental protection if current rainfall trends continue as predicted by the IPCC (Christensen et al. 2007).

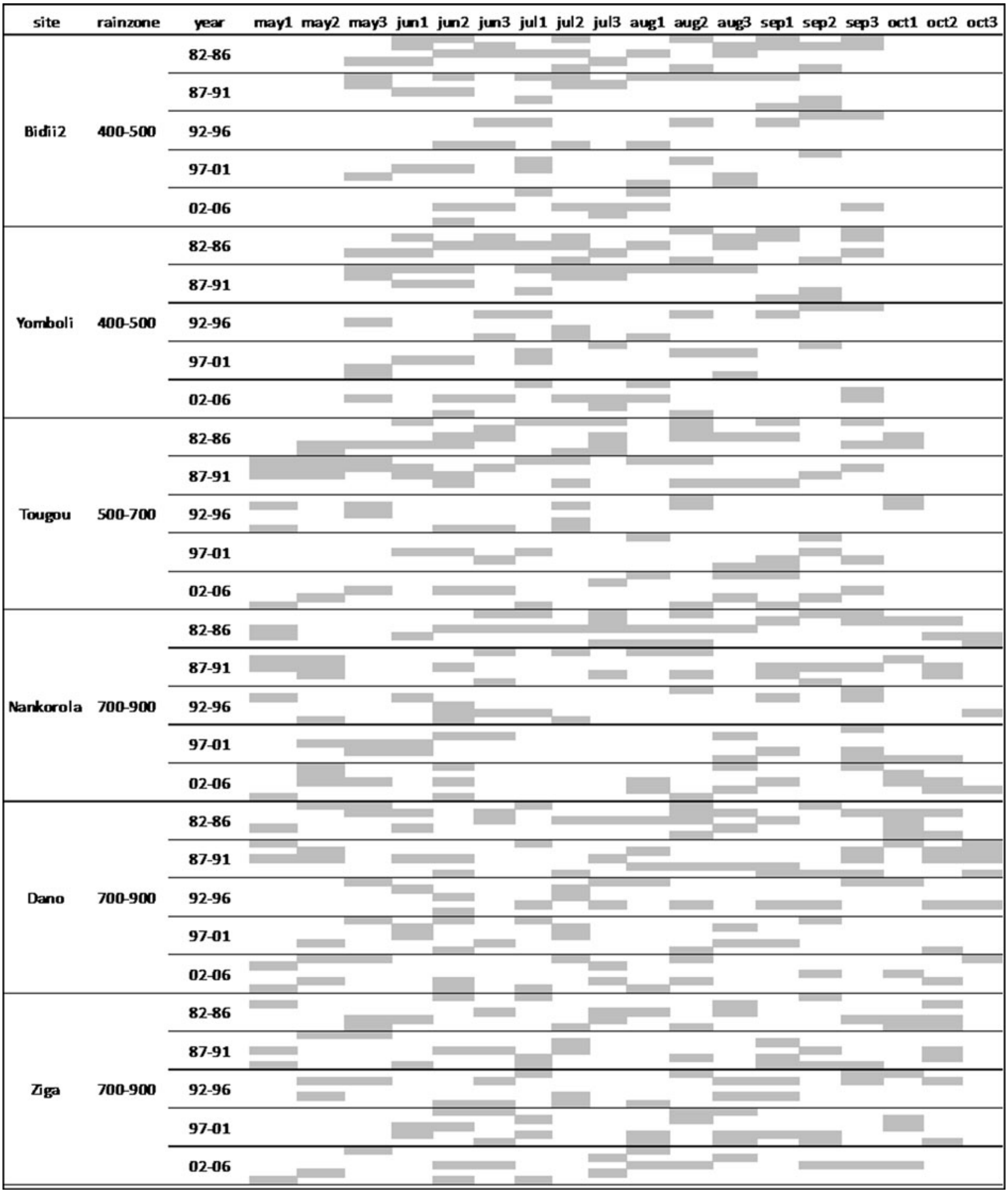

Fig. 9 Frequency and length of dry spells (*gray shading*) for the period 1982–2006, divided into five periods of 5 years, for each study site located in the central part of the study zone. The western and eastern zones show similar patterns

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