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ORIGINAL PAPER

Rainfall variations and child mortality in the Sahel: results from a comparative event history analysis in Burkina Faso and Mali

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Abstract Over the last 40 years, the Sahel has seen a long-term downward trend in rainfall. The importance of ecological variables as factors affecting child survival in rural subsistence societies has already been emphasized, but little empirical evidence has been gathered to support this. This paper presents a comparative event history analysis aimed at understanding how rainfall variations may influence child mortality in two neighbouring countries, Burkina Faso and Mali. These countries are similar in terms of population dynamics, economy, livelihood, child mortality and rainfall conditions (i.e. strong south–north decreasing rainfall gradient). Individual data for both countries came from two detailed nationally representative retrospective surveys conducted in 2000. Rainfall data for the 1960–1998 time period were obtained from the Climatic Research Unit. This study shows that child survival in each country is related to specific patterns of rainfall variation across livelihood regions, highlighting the complex nature of environmental causality of child mortality.

Keywords Child mortality · Rainfall variations · Burkina Faso · Mali · Event history analysis

Introduction

Health conditions in Sub-Saharan Africa continue to be the worst of all developing regions, with under-five mortality rates averaging 136 deaths per thousand births, compared with 72 per thousand across less developed regions as a whole (United

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Nations 2011). Mosley and Chen (1984) were amongst the first to conceptualize the environmental factors, such as intermediate biomedical factors, which affect child mortality. They labelled these factors ‘proximate determinants’ (Mosley and Chen 1984). In developing countries, as in the developed world, water-related diseases are clearly associated with rainfall conditions, as shown by Drayna et al. (2010) in their study in the USA. In rural subsistence societies in particular, ecological factors are known to have a strong influence on child survival through malnutrition (Kiros and Hogan 2000), energy expenditure (Jaffar et al. 2000), income reduction (Paul 1998) and the development of water-related diseases (Dyson 1991).

Despite the emphasis that has been placed on the important effect of rainfall factors on child survival, there has been little empirical evidence gathered on this topic. This is partly due to the multiple factors related to mortality: rainfall is only ever one of several factors, and its real effect is therefore difficult to isolate. Often, the statistical significance of this effect disappears once other variables are added to the equation. Other factors in the environment may also act to neutralize the effect of rainfall. In addition, and perhaps most importantly, the relationship between rainfall factors and health may be more complicated than a simple relationship between two dichotomous variables. In the literature, the few studies dealing with this issue either used coarse classifications of rainfall or an indicator determining the season (Balk et al. 2004; Dyson 1991; Jaffar et al. 2000).

Given that a recent study showed that, in Burkina Faso, there are specific patterns in the relationship between rainfall variation and child mortality in each agro-climatic region (Dos Santos and Henry 2008), this paper presents a comparative event history analysis of Burkina Faso and a neighbouring country, Mali. The aim of the paper is to provide solid empirical evidence of the influence of rainfall variation on child survival in the Sahel. After introducing the conceptual framework, we describe the context of the study. We then briefly discuss the data and the statistical methods used before presenting the results. Finally, we discuss the limitations of our approach, along with possible future improvements.

Conceptual framework

According to the World Health Organization (2010), 23 % of deaths in Africa can be attributed to environmental risk factors. In the literature, several climatic factors have separately been found to influence child health and mortality. Figure 1 attempts to sum up the direct and indirect impacts of these factors, although the causality scheme is very complex.[1] Three main characteristics define climate conditions in the literature on this topic. Until now, the easiest way of scientifically measuring the impact of climate on child survival has been to compare risk of child mortality depending on agro-climatic region with risk of child mortality overall (Balk et al. 2004; Curtis and Hossain 1998).

Rainfall factors influencing child survival include quantity and distribution of rain. More precisely, climatic variability, such as irregular rainfall distribution,

[1] See Sutherst (2004) for a discussion on global change and vector-borne diseases.

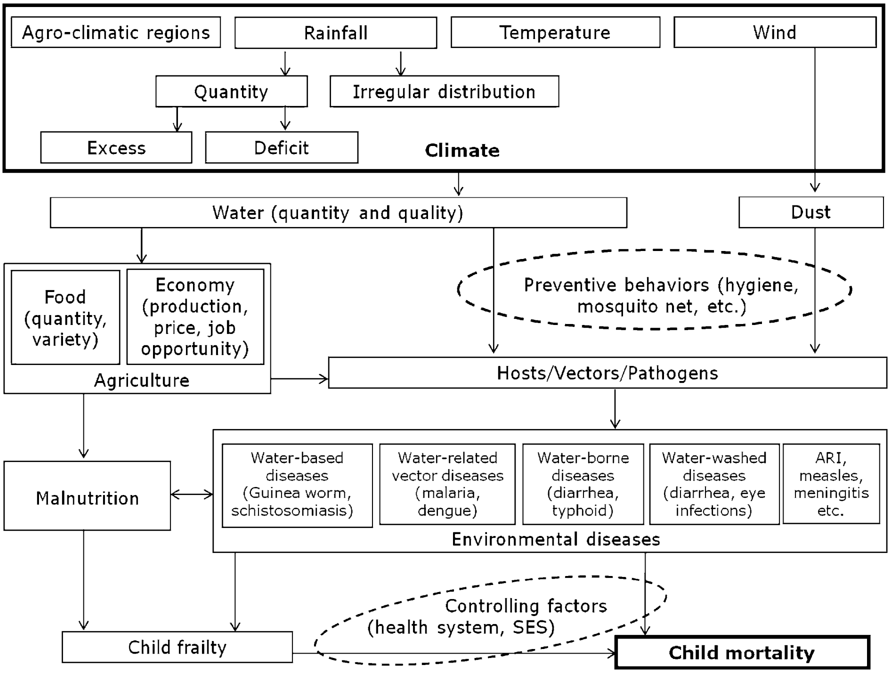

Fig. 1 Impacts of climate on child survival

probably has a greater impact on societies than mean climate values (Katz and Brown 1992), particularly in the vulnerable Sahel region (Kandiji et al. 2006). The effect of rainfall on mortality each month may be highlighted where accurate, precise data are available (Besancenot et al. 2004; Dos Santos and Henry 2008; Jaffar et al. 2000; Kynast-Wolf et al. 2002). As seen in a study conducted in Burkina Faso by Dos Santos and Henry (2008), an excess of water may cause higher mortality than a deficit, probably due to increases in vector development.

Temperature is another climatic factor that may be having an impact on child mortality. Not only do high temperatures lead to increased vector numbers—by favouring vector breeding, maturation and survival (McMichael 2003)—increased incubation rates of pathogens within vectors (McMichael et al. 2003) and increased transmission of vector-borne diseases (Bunyavanich et al. 2003), they also influence water availability through drier conditions (Tsai and Liu 2005).

In desert-prone regions, wind and sandstorms influence levels of desert dust and contribute to poorer air quality. A number of adverse health effects have been associated with dust, including respiratory diseases (including asthma and pneumonia), cardiovascular diseases (such as ischaemic heart disease and cerebrovascular disease), cardiopulmonary diseases (such as chronic obstructive pulmonary disease), intracerebral haemorrhagic stroke and, more rarely, conjunctivitis and allergic rhinitis (see the literature reviews of Besancenot et al. 2004; De Longueville et al. 2012; Mbaye et al. 2009). The association between the Harmattan and meningococcal disease is one of the most widely recognized examples of the influence of season on infectious diseases (Sultan et al. 2005). Birth season, and more precisely birth month, is also an important factor affecting child mortality, since epidemics of acute respiratory infections, meningitis and measles remain common and show perfectly regular seasonality (Ferrari et al. 2008; Fargues and Nassour 1992).

Climate also affects childhood mortality through indirect routes, notably through water resources, which influence agriculture and environmental diseases, often leading to malnutrition. In agriculture, climatic conditions influence the quantity and quality of the water available for vegetation to mobilize. A lack of water therefore affects the quantity and the variety of food crops produced. The consequence for the population is a deterioration in nutrition and therefore an increase in cases of malnutrition, especially in regions that are already facing shortages of clean water and food (Haile 2005). In terms of child survival, the groups most vulnerable to malnutrition are pregnant women (by reducing birth weight), breast-feeding mothers (by influencing the quantity and the nutritional quality of breast milk) and children. In Niakhar (Senegal), malnutrition was found to be at the origin of 60 % of deaths amongst children aged 1–60 months (Garenne et al. 2000). Diseases spread easily amongst malnourished people due to the weakening of immune systems, and children are the most at risk because their immune systems are not yet fully developed (Besancenot et al. 2004; Kiros and Hogan 2000). Ecological factors may also influence child survival indirectly by affecting economic factors. They may reduce income (by reducing food production and causing rises in food grain prices) and influence the availability of income-generating work (Paul 1998). In Zimbabwe, for example, food prices increased by 72 % during the 1991–1992 drought (Stern 2006). For very poor households who spend 80 % or more of their disposable income on food, seasonal variability in income and/or food prices may lead to seasonal swings in mortality due to malnutrition.

In addition to malnutrition, water resources may modify the quantity of hosts, vectors and pathogens present in surrounding areas, leading to various environmental diseases. According to Bradley's widely used classification (1977), there can be said to be four types of water-related disease: (i) water-based diseases transmitted by a host (such as a worm), (ii) water-related vector diseases, transmitted by a vector (such as an insect), (iii) water-borne diseases, where water is a passive transporter for pathogens and (iv) water-washed diseases due to lack or insufficient use of water for hygiene (Besancenot et al. 2004; Mbaye et al. 2009; Tsai and Liu 2005).

Evidence for seasonal transmission of water-related vector diseases in West Africa does exist (e.g. for malaria, see Nahum et al. 2010; Hamad et al. 2002; Koram et al. 2003), but there is no absolute pattern. For example, the effect of season differs depending on the vector. In a literature review, Sullivan (2010) found that the densities of two different malaria parasites are inversed during the dry season: when *P. falciparum* densities decrease, *P. malariae* densities increase. For dengue, the relationship with the season depends on the vector density during the wet season (Sriprom et al. 2010; Strickman and Kittayapong 2002) or the hot dry season (Tsuzuki et al. 2009), depending on the context. The density of some vectors depends on the type of agriculture (see Koudou et al. (2005) for the density of the malaria vector in a rice-based crop system in comparison with vegetable gardens).

Water scarcity, especially during the dry season, is associated with higher prevalence of diarrhoea, due to increased consumption of unsafe water and reduced hygiene practices, which lead to both water-borne and water-washed diseases (Bandyopadhyaya et al. 2012; Fewtrell et al. 2005). Drought also affects levels of diarrhoea indirectly, since stunted children are more vulnerable to diarrhoeal diseases. But, again, the effect of rainfall and temperature variation depends on the aetiological agent. Kale et al. (2004) found that bacterial diarrhoea is more frequently associated with the warm wet season while rotavirus infections occur more commonly during the cold season.

For water-based diseases, evidence shows the effect of climate on peak patency and the transmission, but through different routes. In the case of the dracunculiasis (Guinea worm disease), this relationship depends on the context. In wet areas, cases of the diseases are more prevalent during the dry season, when vectors are more concentrated in water, while in the drier savannah, peak prevalence occurs during the wet season (Watts 1994). A documented epidemic of human intestinal schistosomiasis in the Okavango Delta in Botswana in the early 1960s revealed a statistically significant correlation between prevalence and flow, but only when a lag period of 5–6 years was introduced (Appleton et al. 2008), highlighting the issue of latency between climate variables and health outcome.

Any one of these environmental diseases may lead to child death under certain circumstances. Amongst the most important of these are a weak health system, low socioeconomic level of the household, and a low level of education, or no education, for the mother (Emch et al. 2010). Malnutrition can lead to an increase in environmental diseases, and childhood diarrhoeal diseases in particular (Bern et al. 1992), which, in turn, could aggravate the nutritional status of the child. Finally, within this web of channels, two major sets of controlling variables must be mentioned (circled in Fig. 1): preventive behaviours (e.g. use of mosquito nets and hygiene practices) and certain socioeconomic variables at both the national level (health system) and the household level (socioeconomic status).

Context

Burkina Faso and Mali are worth comparing since they present similar contexts in terms of economy, livelihood, population dynamics and rainfall conditions. Burkina Faso (population 17 million) and Mali (population 16 million) are amongst the poorest countries in the world: according to the Human Development Index, the former ranked 181st and the latter 175th out of 183 countries (UNDP 2011). The gross national income per capita is similar in both countries: 1,141 $US and 1,123 $US, respectively (UNDP 2011). Both countries are rural subsistence societies with more than 70 % of their population living in rural settlements: 83 % in Burkina Faso (INSD and ORC Macro 2004) and 73 % in Mali (DNSI and ORC Macro 2002). The economies of both countries depend heavily on the agricultural sector, with 90 % of the population in Burkina Faso (INSD 2000) and 80 % in Mali engaged in these activities (DNSI and ORC Macro 2002).

In terms of population dynamics, the fertility levels of both countries are very high, with a total fertility rate of 5.2 (INSD and ORC Macro 2004) and 6.6 (DNSI and ORC Macro 2002) children per woman in Burkina Faso and Mali, respectively. A comparison of life expectancy at birth also reveals high levels of mortality in both countries: 55.4 and 51.4 years, respectively. Both countries also experience high levels of child mortality compared to their West African neighbours (WHO 2004) (81 per thousand and 96 per thousand for Burkina Faso and Mali, respectively) with high geographical disparity within each country. In Burkina Faso, the child mortality rate is 150 per thousand in the central region while it is over 250 per thousand in the Sahel and the Northern regions (INSD and ORC Macro 2004). Marked regional differences in under-five mortality have also been observed in Mali. For example, under-five mortality rate ranges from 219 per thousand live births in the Koulikoro region to 291 per thousand live births in the Mopti region (DNSI and ORC Macro 2002).

Amongst children below the age of five, the four most frequent causes of death are malaria (17 % in Mali, 20 % in Burkina Faso), diarrhoeal diseases (18 % in Mali, 19 % in Burkina Faso), pneumonia (24 % in Mali, 23 % in Burkina Faso) and neonatal complications (26 % in Mali, 18 % in Burkina Faso). The percentage of children below the age of five who are underweight was 38 in Burkina Faso in 2003 and 33 in Mali in 2001. As is the case with their African neighbours, these two Sahelian countries have a weak health system: 0.06 physicians and 0.08 physicians per 1,000 inhabitants in Burkina Faso and Mali, respectively, in 2004, and, more generally, 0.85 health workers per 1,000 inhabitants in both countries, as compared to an average of 2.63 per 1,000 inhabitants in Africa as a whole in 2002. Finally, immunization coverage amongst 1-year-olds was 78 % (Burkina Faso) and 75 % (Mali) for measles and 88 % (Burkina Faso) and 76 % (Mali) for DTP3 in 2004 (WHO 2006).

In terms of environmental context, the Sahel has a long history of droughts and related famine (Haile 2005). The region is characterized by a long-term downward trend in rainfall (Nicholson 2001; Niemeijer and Mazzucato 2002). During the period between 1971 and 1990, rainfall had decreased by on average 180–220 mm in West Africa in comparison to the period between 1950 and 1970, with 1970 being a pivotal year (Lebel et al. 2000).

In addition, these two Sahelian countries are characterized by a strong south–north decreasing gradient of average annual rainfall (Fig. 2). In both countries, three distinctive farming systems are largely determined by rainfall patterns: (1) *Pastoral systems* with a high incidence of severe poverty and low potential for poverty reduction, (2) *Agro-pastoral millet/sorghum systems* with a high incidence of severe poverty but with a high potential for poverty reduction and (3) *Cereal-root crop mixed systems* with a lower incidence of poverty but also with a high potential for agricultural growth. Most agricultural production is concentrated within the short rainy season. Consequently, climate events affecting the distribution or quantity of rain during the rainy season have historically had a significant impact on food production.

Mali, however, differs from its neighbour in its geography. Livelihood in Mali is influenced by the presence of the Senegal and Niger rivers that run through the

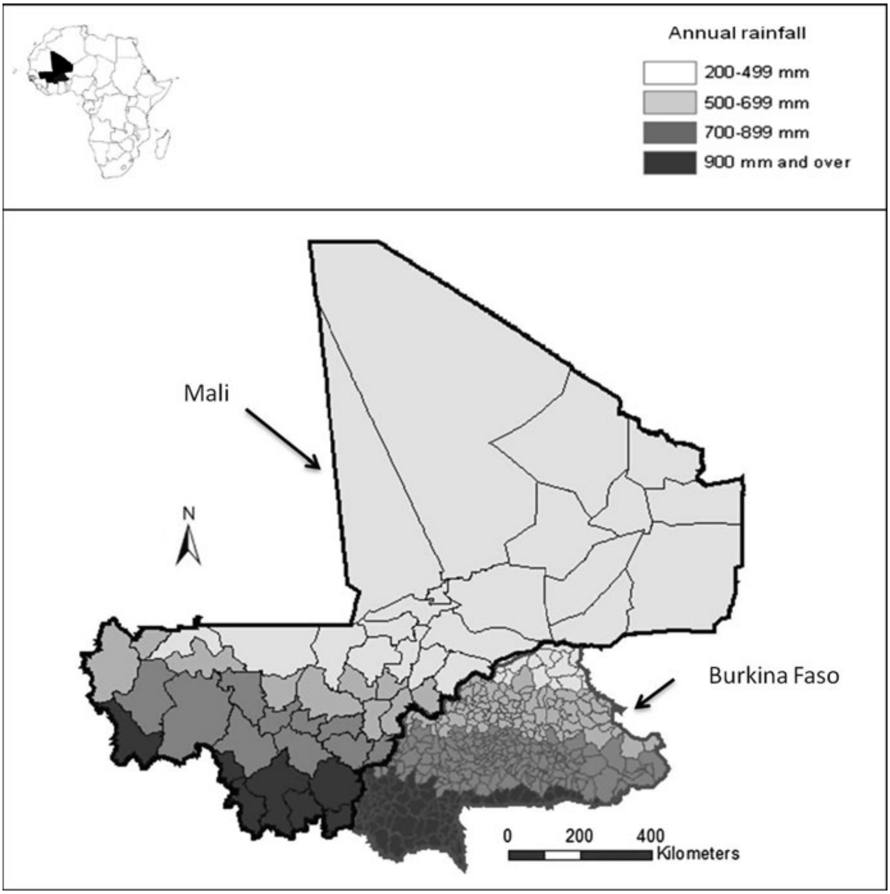

Fig. 2 Long-term average rainfall in Mali and Burkina Faso, with the 1970–1998 administrative boundaries (*Source* New et al. 2000)

country. The delta and the bend in the Niger River allow activities such as fishing, flood cropping and cattle herding. These activities are not present at the same latitudes in Burkina Faso.

Data

One of the original aspects of this study was the use of reliable and comparable multi-source data to look at how rainfall variations influence child survival in Burkina Faso and Mali.

Socio-demographic data

Individual and household data were provided by two nationally representative detailed retrospective life history surveys. These surveys used a comparable design, and both were conducted in 2000. The first of these surveys, *Enquête sur les Dynamiques Familiales et l'Education des Enfants au Mali* (EDFEEM), was conducted in Mali by the Sociology Department of the University of Laval and the CERPOD (Marcoux et al. 2002). In total, 3,152 women aged 30–54 at the time of the survey were surveyed. During the period between 1970 and 1998, 9691 live births and 1,071 child deaths were recorded amongst these women. The survey covered the whole country except for the northern parts of the Kidal, Gao and Tombouctou regions, which represents less than 10 % of Mali's total population (DNSI and ORC Macro 2002). Logistic problems prevented this Saharan region located in the extreme north of the country from being surveyed.

The second survey, *Enquête Migration, Insertion Urbaine et Environnement au Burkina Faso* (EMIUB), was conducted in Burkina Faso by the ISSP of the University of Ouagadougou, the Demography Department of the University of Montreal, and the CERPOD (Poirier et al. 2001). In total, 3,751 women aged 15–64 at the time of the survey were investigated throughout the entire country. During the period between 1970 and 1998, 8,735 live births and 1,153 child deaths were recorded amongst these women.

These two surveys followed the same methodology and are therefore comparable. Household questionnaires included questions on the individual characteristics of the different members and on their housing conditions. Detailed biographic questionnaires covered family origins, migration, employment, and matrimonial and fertility histories.

Concerning fertility histories, for each live birth, each woman was asked for the date of birth and the survival status. Recording the age at death for deceased children was nevertheless done quite differently in the two surveys. The Burkina Faso survey, following standard practice, recorded age at death in months if the child had died within 24 months of birth, and in completed years if the child had died between the age of two and five. In Mali, women were asked for the year and month of the death.

Since the data used in this study do not come from a continuous longitudinal survey but from a retrospective survey, it contains several biases,[2] notably selection bias, that must be addressed. Because the data are nationally representative, we can assume that there are no differences between the characteristics of women who participated in the survey and women who did not. By definition, retrospective data imply a selection bias, since the fertility histories of mothers who had died or migrated abroad at the time of the survey are not known (Guest 1998). For these individuals, it must be assumed that the children of these individuals had the same histories as those of the women interviewed.

Rainfall data

The data for the 1960–1998 time period were obtained from the global monthly precipitation dataset produced by the Climatic Research Unit at the University of East Anglia (New et al. 2000). This data were interpolated from a network of

[2] For information on data quality and other selection bias, please refer to Dos Santos and Henry (2008).

stations at a spatial resolution of 0.5 degrees latitude and longitude and have been linked to the socio-demographic data.

Livelihood data

A livelihood indicator provided by FEWS (2009) helps to describe how people in a given area will be affected by different hazards such as drought, market failure, floods, etc. (Fig. 3). A livelihood zone is defined as an area within which people broadly share the same livelihood patterns, including access to food, income and markets. Based on primary key informants (focus groups, including field staff from government and non-government offices, market traders and researchers) as well as on published and unpublished documents, the FEWS indicator attempts to evaluate how households secure their food and income.

Methods

Event history methods were used to estimate the impact of rainfall on child survival, controlling for relevant variables related to the child (such as gender, rank and generation), to his/her mother (such as education level, age at the child's birth, migratory status and standard of living) and the dominant type of livelihood of its zone of residence.

Socio-demographic data are especially suitable for this study because it allows us to link the residential history of each mother (and her exact place of residence over time) with the survival of her children. Since both surveys include a complete event history component of residential history, they allow for a dynamic analysis of our key independent variables—rainfall variables. Traditional studies, particularly those using DHS surveys, are only able to consider rainfall variables for the mother's residence at the time of the survey, when it is used as a determinant of earlier child mortality. However, if, for example, rainfall conditions change due to a residential move from a location where rainfall conditions are favourable to a location where rainfall conditions are unfavourable, then it can be assumed that the child's exposure to the risk that is related to contextual conditions also changes. Event history data are used to account for these changes over time.

Because of the availability of rainfall data, we have focused on births between 1970 and 1998. The first month of life is excluded from the analysis because birth deaths are more often linked to endogenous factors, such as congenital malformations or hereditary diseases. Each child that born in a rural area[3] was therefore followed from his/her first month until he/she reached 5 years of age, until his/her death, or until the end of the survey period.[4] Table 1 shows the different case studies in the population at risk. Children who were still alive at the end of the year 1998, but who were not yet 5 years old, children who had moved from rural areas to a city

[3] Defined as <10,000 inhabitants on the day of birth (Beauchemin et al. 2002).

[4] Censoring "means that information on events and exposure to the risk of experiencing them is incomplete" (Guillot 2003, p. 326).

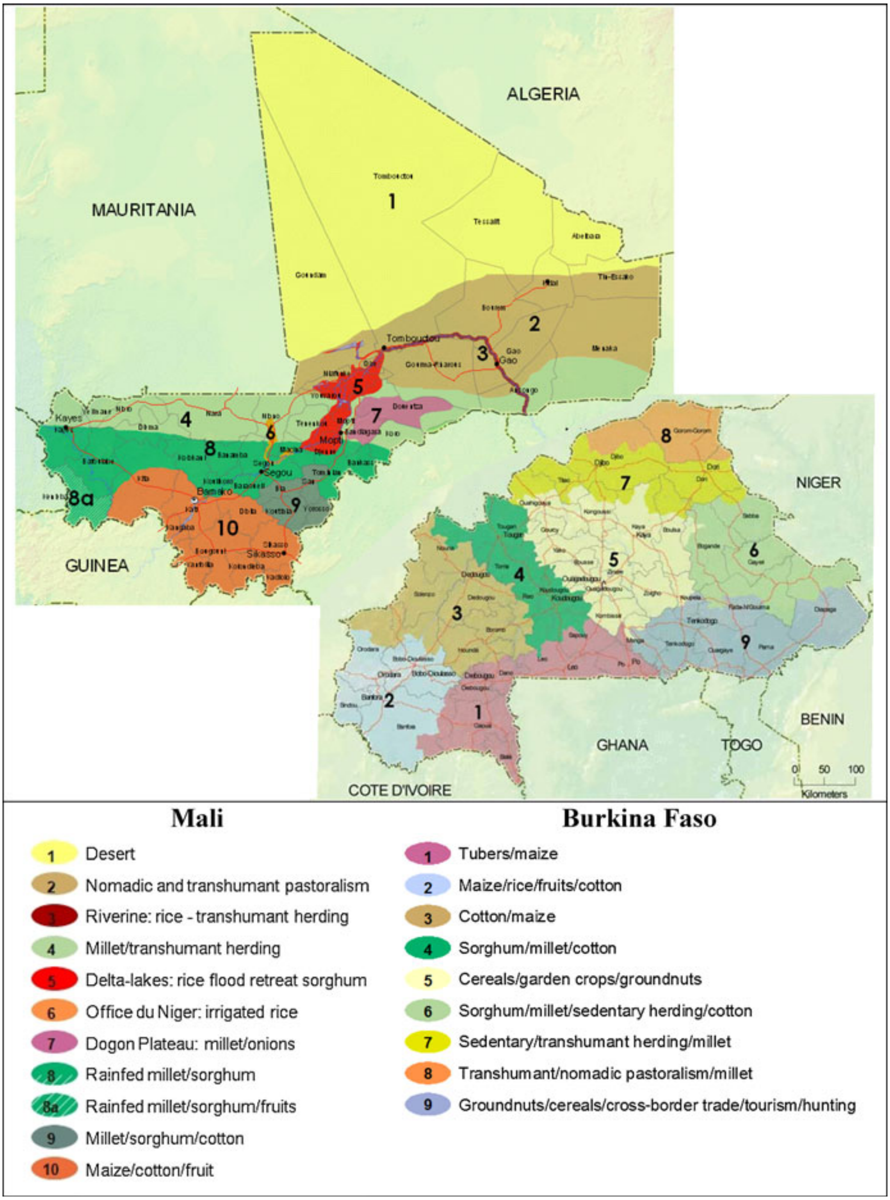

Fig. 3 Livelihood zones in Mali and Burkina Faso (*Source* FEWS 2009)

or another country, and children who had left their mother's residence before the age of 5 because of fostering were right censored. In total, the database contains 8,230 children in Burkina Faso and 9,691 in Mali.

The data were organized as a child-period data file in which each line represents a 1-month period. The dependent variable indicates when a death has occurred for

Table 1 Number of children who died, were censored, or survived during the period of observation

	Population at risk Mali	Population at risk Burkina Faso
Died	1,071	1,153
Right censored	1,954	2,211
Survived	6,666	4,866
Total	9,691	8,230

each month-long interval. Overall, the sample consists of a total of approximately 370,000 child-periods for Burkina Faso and 475,000 child-periods for Mali.

Event history methods were used to estimate the impact of various rainfall conditions on child survival, controlling for relevant variables related to the child and his/her mother. The event history approach allows us to take time-varying explanatory variables into account. Binary logistic regression methods were used to estimate discrete-time event history models (Allison 1984). The statistical model used is shown below:

$$\log\left(\frac{p_{ti}}{1-p_{ti}}\right) = \alpha_t + \beta' \cdot X_{ti} \tag{1}$$

where p_{ti} is the conditional probability that child i experiences the event (death) at age t, given that the event has not already occurred; α_t represents the baseline hazard function; and $\boldsymbol{X}_{ti}$ is a vector of child, mother and rainfall covariates. Both time-constant and time-varying covariates are included in the models. Children that were still alive (no death) were treated as the reference category. In the model, the standard errors of the regression coefficients are adjusted for maternal clustering accordingly using Huber–White standard errors (Hox 2002).

Explanatory variables

Table 2 shows the categorization of the variables used in the models.

Variables related to the child and to the mother

A number of bio-demographic variables have been shown to consistently affect the probability of child death. Our models include the child's gender, birth order, multiple births, period of history (generation) and the age of child as the baseline hazard of child death. In addition, we included variables that might determine the mother's health knowledge and behaviour, such as socio-economic factors (education level and age of mother). All of these variables are time-constant covariates.[5]

[5] We did not include contextual household variables such as access to water or type of latrine, which are usually included in such models, despite the fact that these variables were time-varying in our database, because the different modalities did not allow for making relevant distinctions in rural contexts, which meant that these variables were not sufficiently discriminating.

Table 2 Descriptive statistics of the sample from the first month of life

	Mali		Burkina Faso	
	Person-time	% of sample	Person-time	% of sample
Child variables				
Age				
≤6 months	57,095	12	47,783	13
7–17 months	98,763	20.8	79,703	21.6
18 months and over	319,002	67.2	240,830	65.4
Gender				
Boy	252,620	53.2	188,123	51.1
Girl	222,240	46.8	180,193	48.9
Birth order				
1	82,919	17.5	66,631	18.1
2–5	289,438	61	210,742	57.2
6 and over	102,503	21.5	90,943	24.7
Generation				
1970–1979	95,759	20.2	89,168	24.2
1980–1989	221,505	46.7	148,697	40.4
1990–1998	157,596	33.2	130,451	35.4
Multiple birth				
No	465,007	97.9	361,093	98
Yes	9,853	2.1	7,223	2
Mother variables				
Mother's age at birth of child				
<20	34,61	7.	30,566	8.3
20–29	223,950	47.2	182,624	49.6
30 and over	216,291	45.6	155,126	42.1
Education				
No education	458,625	96.6	354,511	96.2
Primary and over	16,235	3.4	13,805	3.8
Rainfall variables				
Monthly deviation				
<85 %	51,772	10.9	49,408	13.4
85–94 %	85,658	18	54,523	14.8
95–104 %	100,200	21.1	69,476	18.9
105 and over	61,362	12.9	82,877	22.5
Dry season	175,868	37	112,119	30.4
Season of birth				
Harvest season	244,877	51.6	195,680	53.1
Hungry season	229,983	48.4	172,636	46.9
Long-term average rainfall				
<500 mm	96,883	20.4	42,861	11.6
500–699 mm	138,163	29.1	114,158	31

Table 2 continued

	Mali		Burkina Faso	
	Person-time	% of sample	Person-time	% of sample
700–899 mm	159,937	33.7	138,257	37.6
900 mm and over	79,877	16.8	73,040	19.8
Yearly deviation				
<85 %	93,349	19.7	42,604	11.6
85–94 %	180,899	38.1	108,894	29.6
95 % and over	200,612	42.2	216,905	58.9
Sample size	474,860	100	368,316	100

	Mali	
	Person-time	% of sample
Residency variables		
Livelihood zone		
(L3) Riverine: rice-transhumant herding	77,988	16.4
(L5) Delta-lakes: rice flood retreat sorghum	27,437	5.8
(L7) Dogon Plateau: millet, onions	17,417	3.7
(L8) Rainfed millet, sorghum	143,889	30.3
(L9) Millet, sorghum, cotton	68,961	14.5
(L10) Maize, cotton, fruit (R)	138,492	29.2

	Burkina Faso	
	Person-time	% of sample
Residency variables		
Livelihood zone		
(L1) Tubers, maize	43,487	11.8
(L2) Maize, rice, fruit, cotton	8,539	2.3
(L3) Maize, cotton (R)	50,358	13.7
(L4) Sorghum, millet, cotton	67,980	18.5
(L5) Cereal, garden crops, groundnuts	85,633	23.3
(L6) Sorghum, millet, cotton, sedentary herding	26,323	7.2
(L7) Sedentary, transhumant herding and millet	37,563	10.2
(L8) Transhumant, nomadic pastoralism and millet	4,410	1.2
(L9) Groundnuts, cereals, cross border trade, tourism, hunting	44,018	12

Variables related to the place of residence

A livelihood indicator was introduced to the models to characterize areas within which people broadly share the same livelihood patterns. Nine livelihood regions are recognized in Burkina Faso, and 7 in Mali (FEWS 2009). This indicator has been extracted by GIS at the department level. We include this indicator[6] in our models to control for any effects it might have on child mortality. The nomadic and transhumant livelihood zone in Mali was removed because of the small number of observations recorded in this region.

Rainfall variables

Three variables extracted at the department level were used to capture three dimensions of the potential impact of rainfall on child death. These were (1) the mean annual precipitation over the 1960–1998 time period (long-term average rainfall), (2) the per cent of normal precipitation over the year (yearly deviation) and (3) the per cent of normal precipitation over the month (monthly deviation). All of these rainfall variables are time-varying covariates and will be linked to the child's life history by the child's department of residence.[7]

The first variable, the annual mean of precipitation over the 1960–1998 period (long-term average rainfall), is considered a good indicator of agricultural productivity and vulnerability to drought. Four categories were compared: less than 500, 500–699, 700–899 mm per year and over 900 mm per year (Fig. 2). These categories correspond to the agro-climatic regions, which are the areas where crops with similar yield responses to water are cultivated (Doorenbos and Kassam 1987).

Because this long-term annual rainfall variable is closely associated with the livelihood variable (Cramer's V equal to 0.70 in Mali and Burkina Faso), we included these two variables in separate models.

The second variable (yearly deviation) indicates the extent to which rainfall in the department throughout the year differed from long-term rainfall conditions in the department. The measure of the variable is the ratio of the mean rainfall over the 12 months prior to the child observation to the mean annual rainfall over the 1960–1998 time period. Three categories were compared in the models: less than 85, 85–94, and 95 % and over.[8]

Overall, it was expected that the risk of child death would increase if the year was unfavourable in terms of rainfall conditions (excessively dry or wet). More specifically, the influence of drought on the risk of death was expected to be higher in drier agro-climatic regions than in wetter regions, and the effect of rainfall surplus was expected to be higher in wetter agro-climatic regions than in drier regions where an increase in rain could provide farm production inputs and a source of water (Balk et al. 2004). Two interaction terms were therefore introduced to the separate models: yearly deviation x livelihood region and yearly deviation x long-term annual rainfall. The third variable (monthly deviation) indicates the extent to which rainfall in the department differed over the month in which the child observation was made from the long-term rainfall conditions in the department for

[6] Note that this indicator is not time-varying.

[7] Rainfall variables have a spatial resolution of 0.5° but have been constructed by department. It is worth noting that the administrative division in Burkina Faso changed with each Population Census. This study used the 1996 department boundaries, no matter when the event occured.

[8] This categorization was arbitrarily defined but several tests were performed. The criterion of having a sufficient number of observations in each category was determining.

that month. The measure of the variable is the ratio of the rainfall over the month in which the child observation was made to the mean monthly rainfall over the 1970–1998 time period. Five categories were compared in the models: less than 85, 85–94, 95–105, 105 % and over, and the dry season. Because rainfall may be very low in the dry season (1 mm or less), the indicator is calculated only for months during the rainfall season, defined as the months with a monthly rainfall mean of at least 20 mm over the 1970–1998 time period. With this definition, we controlled for the difference in the onset of the rainfall season across regions in the two countries. AGRHYMET[9] defines the onset of the rainfall season as being when 20 mm of water falls in 1 or 2 days without a dry period occurring during the following 30 days (AGRHYMET 1992).

These three variables are time varying. This is the chief advantage of our databases: to be able to consider the rainfall conditions in the place where the child lived when he/she was 0–5 years old, and not the place where his/her mother was surveyed. This fact is particularly relevant in Burkina Faso, which is well known for its high levels of internal mobility (Cordell et al. 1996). In this database, 20 % of the children were not born and had never lived in the village where their mother had lived during the survey. One quarter of the children had known one or more residential changes before the age of 5.

Several lagged time periods (0, 1, 3, 6 and 12 months) for the monthly deviation variable have been considered in order to measure the capacity of populations to cope with rainfall irregularities. For periods of drought, an increase in mortality due to lack of income and/or food availability is expected in the months that follow. For periods of excess rain, an increase in mortality due to malaria is expected in the months that follow because of the time taken for the malaria parasite to complete its life cycle. A longer time window was considered to be irrelevant because of the low resilience of children. It was expected that the risk of child death would increase if rainfall over the three preceding months differed greatly from normal conditions (higher or lower).

Finally, in the literature, birth season is often used as a proxy for climatic influence (Blacker 1991). This variable was introduced as a control variable. Two seasons were compared: the harvest season, defined as the period between January and June and the hungry season, defined as the period between July and December (Jaffar et al. 2000). The risk of death was expected to be higher during the hungry season.

Presentation of the models

To investigate the net effect of rainfall variations on mortality between the ages of 1 and 59 months, we estimated logistic regressions. Tables 3 (Mali) and 5 (Burkina Faso) show the multivariate results including child, mother, livelihood and rainfall characteristics. Seven models are presented for each country.

Because of their close association, livelihood (Models 1–4) and long-term average rainfall (Models 5–7) have been included in separate models. Model 4

[9] Regional centre of agronomy, hydrology and meteorology, working on Burkina Faso, Cape-Verde, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, Senegal, and Chad.

Table 3 Event history model of child, mother, residency and rainfall effects on risk of death in Mali, by period of childhood (odds ratio)

	Model 1 (1–59 m)	Model 2 (1–23 m)	Model 3 (7–23 m)	Model 4 (1–23 m)	Model 5 (1–59 m)	Model 6 (1–23 m)	Model 7 (7–23 m)
Child variables							
Age	0.98**	0.96+	1.05	0.96+	0.98**	0.96+	1.05
Age^2	1.00**	1.00	1.00	1.00	1.00**	1.00	1.00
Gender							
Boy (R)	1	1	1	1	1	1	1
Girl	1.13*	1.19**	1.29**	1.19**	1.14*	1.19**	1.29**
Birth order							
1 (R)	1	1	1	1	1	1	1
2–5	1.70***	1.68***	1.78***	1.68***	1.71***	1.68***	1.78***
6 and over	3.15***	2.99***	3.12***	2.99***	3.10***	2.94***	3.07***
Generation							
1970–1979 (R)	1	1	1	1	1	1	1
1980–1989	0.60***	0.58***	0.57***	0.57***	0.61***	0.58***	0.57***
1990–1998	0.36***	0.36***	0.38***	0.36***	0.37***	0.37***	0.38***
Multiple birth							
No (R)	1	1	1	1	1	1	1
Yes	1.40+	1.87***	2.02**	1.87***	1.43*	1.89***	2.02**
Mother variables							
Mother's age at birth of child							
<20 (R)	1	1	1	1	1	1	1
20–29	0.86	0.76**	0.75+	0.76**	0.85	0.75**	0.74*
30 and over	0.55***	0.48***	0.49***	0.48***	0.53***	0.47***	0.48***
Education							
No education (R)	1	1	1	1	1	1	1
Primary and over	0.98	0.78	0.75	0.78	0.96	0.76	0.73
Residency variables							
Livelihood zone							
(L3) Riverine: rice-transhumant herding	1.56***	1.54***	1.74***	1.19			
(L5) Delta-lakes: rice flood retreat sorghum	2.27***	2.50***	2.89***	2.26**			
(L7) Dogon Plateau: millet, onions	1.55**	1.11**	1.58	1.47			
(L8) Rainfed millet, sorghum	1.51***	1.54***	1.65***	1.66*			
(L9) Millet, sorghum, cotton	0.94	1.07	1.26	1.39			
(L10) Maize, cotton, fruit (R)	1	1	1	1			

Table 3 continued

	Model 1 (1–59 m)	Model 2 (1–23 m)	Model 3 (7–23 m)	Model 4 (1–23 m)	Model 5 (1–59 m)	Model 6 (1–23 m)	Model 7 (7–23 m)
Rainfall variables							
Season of birth							
Harvest season (R)	1	1	1	1	1	1	1
Hungry season	0.88*	0.95	0.99	0.95	0.89*	0.95	0.99
Long-term average rainfall (v)							
<500 mm					1.09	1.03	1.14
500–699 mm (R)					1	1	1
700–899 mm					0.75***	0.71***	0.71**
900 mm and over					0.62***	0.65***	0.61***
Yearly deviation (v)							
<85 % (R)		1	1	1		1	1
85–94 %		0.96	0.92	0.91		0.97	0.93
95 % and over		0.98	0.94	1.01		0.98	0.94
Livelihood zone * yearly deviation (v)							
L3 * 85–94 %				1.57			
L3 * 95 % and over				1.36			
L5 * 85–94 %				1.26			
L5 * 95 % and over				1.06			
L7 * 85–94 %				0.83			
L7 * 95 % and over				0.57			
L8 * 85–94 %				0.97			
L8 * 95 % and over				0.86			
L9 * 85–94 %				0.73			
L9 * 95 % and over				0.72			

Significance level (two-tailed tests): *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$; + $p \leq 0.15$

R reference category, *v* time-varying covariate that value can change through the period at risk

clearly highlights the necessity of introducing an interaction term between 'yearly deviation' and 'livelihood', in order to better understand the specific patterns of rainfall variation and child mortality relationships in each livelihood region.[10] Tables 4 and 6 show the odds ratio of different categories created by combining the yearly deviation with the livelihood. Odds ratios are calculated to allow a direct comparison between livelihood regions within the yearly deviation categories (Tables 4A, 6A) and between yearly deviation categories within the livelihood regions (Tables 4B, 6B).

[10] We also tested a model with another interaction term (yearly deviation x long-term annual rainfall) but most of the categories were not significant (results not shown here).

Table 4 Results for interaction variables, model 4 (1–23 months) in Mali

A. Comparison of livelihood zone by yearly deviation

	L3	L5	L7	L8	L9	L10
<85 %	1.19	2.26**	1.47	1.66*	1.39	1
85–94 %	1.87**	2.84***	1.22	1.62**	1.01	1
95 % and over	1.61**	2.39***	0.84	1.43**	1.00	1

B. Comparison of yearly deviation by livelihood zone

	<85 %	85–94 %	95 % and over
L3	1	1.43	1.37
L5	1	1.15	1.07
L7	1	0.75	0.58
L8	1	0.88	0.87
L9	1	0.66	0.73
L10	1	0.91	1.01

(L3) Riverine: rice-transhumant herding; (L5) Delta-lakes: rice flood retreat sorghum; (L7) Dogon Plateau: millet, onions; (L8) Rainfed millet, sorghum; (L9) Millet, sorghum, cotton; (L10) Maize, cotton, fruit (R)

There is considerable evidence to suggest that the factors affecting child survival are not equally important throughout the entire period of childhood.[11] Three childhood periods were therefore investigated: age 1–59 months (Models 1 and 5), age 1–23 months (Models 2, 4 and 6) and age 7–23 months (Models 3 and 7). As was shown by Balk et al. (2004), younger infants are expected to be less vulnerable to climatic variations than older children, thanks to the protection afforded by breastfeeding. Children are more vulnerable after weaning, and more specifically after the age of 7–8 months (Fargues and Nassour 1992).

Due to this variable's lack of robustness, the monthly deviation effect was included in separate models, including mother and child characteristics only. Tables 7, 8, 9 and 10 show the sensitivity tests by time lag and childhood period.

Finally, the monthly and yearly deviation were excluded for the 1–59 month models because the age at death was recorded in years if the child had died between the ages of 2 and 5 for the Burkina Faso data.

Results

Of the 8,230 children in the Burkinabè database (9,691 in Mali), 1,153 died between the 1st and 60th month of life (1,071 in Mali).[12]

[11] See Cleland and van Ginneken (1988) for the effect of mother's education level and van Poppel and van der Heijden (1997) for the effects of water supply and other environmental factors.

[12] In Burkina Faso, as per usual practice, age at death was recorded in months if the child had died within 24 months of birth, and in completed years if the child had died between the ages of two and five. In Mali, women were asked for the year and month of the child's death.

Results for the child and mother effects (Models 1–7)

Our results are consistent with the literature on child and mother explanatory variables associated with child mortality.[13] In both countries, the effect of the socio-demographic characteristics of the child and his/her mother was unchanged by the introduction of rainfall variables (highly stable odds ratios).

Results for birth season (Models 1–7)

As has been observed in The Gambia (Jaffar et al. 2000), an insignificant effect of birth season on child death was found in Burkina Faso and Mali. However, this result contrasts with the highly significant seasonal effect identified in the Nouna district in Burkina Faso (Kynast-Wolf et al. 2002).

Results for livelihood (Models 1–4)

As expected, child survival was influenced by livelihood pattern. In both countries, living in some regions considerably increases the risk of death. In Mali (Models 1–4 in Table 3), areas near the Niger River or irrigated perimeters, which influences yields, income, food and more generally the livelihood of households, are particularly unfavourable for child survival. In Burkina Faso, children living in the 'Maize, rice, fruit and cotton' region have a higher risk of death than those living in other regions. In Burkina Faso, and to a lesser extent in Mali, age seems to increase the differences in mortality between livelihood regions. The 7–23 month age range is the childhood period most at risk (Model 3 compared to Model 2), which was expected due to the higher impact of exogenous factors.

Results for long-term average rainfall (Models 5–7)

In Mali, the risk of death is lower in the 700–899 mm region than in the 500–699 mm region (reference category) and lower still in the most abundant rainfall region (900 mm and over). In Burkina Faso, the long-term average rainfall variable is only significant for older children (7–23 and 11–23[14] month age ranges), with a reduced risk of death in the most abundant rainfall region.

Results for yearly deviation (Models 2, 3, 4, 6 and 7)

A rainfall deficit during the 12 preceding months alone does not influence child survival in Mali and Burkina Faso. The yearly deviation is only significant when we introduce an interaction term with livelihood (only in Burkina Faso).

Results for yearly deviation x livelihood (Model 4 in Tables 3, 5 and Tables 4, 6). In Mali, the significant effect of livelihood region noted above increased when a

[13] The non-significant result for the mother's level of education in Mali is also consistent with the literature. See Diarra and Tangara (1999, p. 41) for further explanations.

[14] Results for the 11–23 months are not shown here.

Table 5 Event history model of child, mother, residency and rainfall effects on risk of death in Burkina Faso, by period of childhood (odds ratio)

	Model 1 (1–59 m)	Model 2 (1–23 m)	Model 3 (7–23 m)	Model 4 (1–23 m)	Model 5 (1–59 m)	Model 6 (1–23 m)	Model 7 (7–23 m)
Child variables							
Age	0.92***	1.04	1.61***	1.05	0.92***	1.04	1.60***
Age^2	1.00***	0.99***	0.98***	0.99***	1.00***	0.99***	0.98***
Gender							
Boy (R)	1	1	1	1	1	1	1
Girl	1.06	1.03	1.00	1.03	1.07	1.03	1.01
Birth order							
1 (R)	1	1	1	1	1	1	1
2–5	0.94	1.02	1.15	1.02	0.94	1.02	1.15
6 and over	1.31+	1.54*	2.01**	1.54*	1.30+	1.54*	1.97**
Generation							
1970–1979 (R)	1	1	1	1	1	1	1
1980–1989	0.80**	0.79*	0.62***	0.77*	0.80**	0.78*	0.61***
1990–1998	0.85+	0.86	0.79+	0.85	0.83*	0.84	0.78+
Multiple birth							
No (R)	1	1	1	1	1	1	1
Yes	2.05***	1.84**	2.11**	1.85**	2.05***	1.86**	2.08**
Mother variables							
Mother's age at birth of child							
<20 (R)	1	1	1	1	1	1	1
20–29	0.72**	0.69**	0.56**	0.70**	0.74**	0.71**	0.58**
30 and over	0.54***	0.50***	0.42***	0.51***	0.56***	0.52***	0.45***
Education							
No education (R)	1	1	1	1	1	1	1
Primary and over	0.56*	0.58+	0.44**	0.57+	0.55*	0.56*	0.43**
Residency variable							
Livelihood zone							
(L1) Tubers, maize	1.39**	1.47**	0.96**	5.01**			
(L2) Maize, rice, fruit, cotton	1.74**	2.03*	1.94*	8.21***			
(L3) Maize, cotton (R)	1	1	1	1			
(L4) Sorghum, millet, cotton	1.2	1.38*	1.71**	2.96			
(L5) Cereal, garden crops, groundnuts	1.43***	1.50***	1.74***	6.28***			
(L6) Sorghum, millet, cotton, sedentary herding	1.44***	1.47**	1.39+	4.99***			

Table 5 continued

	Model 1 (1–59 m)	Model 2 (1–23 m)	Model 3 (7–23 m)	Model 4 (1–23 m)	Model 5 (1–59 m)	Model 6 (1–23 m)	Model 7 (7–23 m)
(L7) Sedentary, transhumant herding and millet	0.96	1	1.08	2.88*			
(L8) Transhumant, nomadic pastoralism and millet	1.02	0.82	0.69	4.05**			
(L9) Groundnuts, cereals, cross border trade, tourism, hunting	1.37*	1.59**	1.25	1.29			
Rainfall variables							
Season of birth							
Harvest season (R)	1	1	1	1	1	1	1
Hungry season	0.92	1.10	1.06	1.10	0.92	1.09	1.06
Long-term average rainfall (v)							
<500 mm					1	0.85	0.70+
500–699 mm (R)					1	1	1
700–899 mm					1	1.09	1.03
900 mm and over					0.92	0.96	0.65**
Yearly deviation (v)							
<85 % (R)		1	1	1		1	1
85–94 %		0.97	0.91	3.01**		0.95	0.86
95 % and over		0.99	0.85	2.98**		0.98	0.82
Livelihood zone * yearly deviation (v)							
L1 * 85–94 %				0.27*			
L1 * 95 % and over				0.28*			
L2 * 85–94 %				0.27			
L2 * 95 % and over				0.20*			
L4 * 85–94 %				0.5			
L4 * 95 % and over				0.43			
L5 * 85–94 %				0.16***			
L5 * 95 % and over				0.23**			
L6 * 85–94 %				0.19***			
L6 * 95 % and over				0.32*			
L7 * 85–94 %				0.28*			
L7 * 95 % and over				0.35+			

Table 5 continued

	Model 1 (1–59 m)	Model 2 (1–23 m)	Model 3 (7–23 m)	Model 4 (1–23 m)	Model 5 (1–59 m)	Model 6 (1–23 m)	Model 7 (7–23 m)
L8 * 85–94 %				0.28+			
L8 * 95 % and over				0.10***			
L9 * 85–94 %				1.65			
L9 * 95 % and over				1.09			

Significance level (two-tailed tests): *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$; + $p \leq 0.15$

R reference category, *v* time-varying covariate that value can change through the period at risk

Table 6 Results for interaction variables, model 4 (1–23 months) in Burkina Faso

A. Comparison of livelihood zone by yearly deviation

	L1	L2	L3	L4	L5	L6	L7	L8	L9
<85 %	5.01**	8.21***	1	2.96+	6.28***	4.99***	2.88+	4.05**	1.29
85–94 %	1.35	2.22	1	1.49	1.02	0.94	0.82	1.15	2.14**
95 % and over	1.38+	1.68	1	1.27	1.45*	1.58**	1.02	0.42*	1.42

B. Comparison of yearly deviation by livelihood zone

	<85 %	85–94 %	95 % and over
L1	1	0.81	0.82
L2	1	0.81	0.61
L3	1	3.01**	2.98**
L4	1	1.52	1.28
L5	1	0.49*	0.69
L6	1	0.57*	0.95
L7	1	0.86	1.05
L8	1	0.86	0.31*
L9	1	4.97**	3.25**

(L1) Tubers, maize; (L2) Maize, rice, fruit, cotton; (L3) Maize, cotton (R); (L4) Sorghum, millet, cotton; (L5) Cereal, garden crops, groundnuts; (L6) Sorghum, millet, cotton, sedentary herding; (L7) Sedentary, transhumant herding and millet; (L8) Transhumant, nomadic pastoralism and millet; (L9) Groundnuts, cereals, cross border trade, tourism, hunting

rainfall deficit occurred. In Burkina Faso, these differentials across livelihood regions were even stronger than in Mali, particularly during a severe drought. In Burkina Faso, specific patterns of rainfall variation and child mortality relationships were found in each livelihood region[15] (Table 6B). In three regions (L5, L6 and L8), while the risk of death was reduced during a moderate drought or normal rainfall period as expected, we found a higher risk of death in region L3 (maize/cotton) and L9 (millet, groundnuts, sorghum, cross border trade, tourism and hunting) during a

[15] In Mali, the results were not significant (Table 4B).

Table 7 Effects of rainfall monthly deviation on risk of death between 1 and 23 months in Mali, after controlling for child and mother effects (odds ratio), by time lag (month of the observation, one month before, mean of the 1–3 months before, mean of the 4–12 months before and mean of the 1–6 months before the observation was made)

Monthly deviation (v)	M (0)	M (1)	M (1–3)	M (4–12)	M (1–6)
<85 %	0.69**	1.26	0.85	0.93	0.88
85–94 %	0.86	1.05	0.86	0.96	0.75***
95–104 % (R)	1	1	1	1	1
105 and over	0.65**	1.19	0.79*	0.9	1.01
Dry season	0.93	1.05	0.98	n.d.	0.93

Table 8 Effects of rainfall monthly deviation on risk of death between 1 and 23 months in Burkina Faso, after controlling for Child and Mother Effects (odds ratio), by time lag (month of the observation, one month before, mean of the 1–3 months before, mean of the 4–12 months before and mean of the 1–6 months before the observation was made)

Monthly deviation (v)	M (0)	M (1)	M (1–3)	M (4–12)	M (1–6)
<85 %	1.25	0.75	0.98+	1.33	1.31
85–94 %	0.9	0.83	0.83	1.18+	1.02
95–104 % (R)	1	1	1	1	1
105 and over	1.09	1.00	0.9	1.00	0.97
Dry season	1.10	0.91	0.94	n.d.	0.63*

moderate drought or normal rainfall period. The first result may be explained by the higher sensitivity of crops to environmental variations, and the latter by the fact that a rainfall deficit limits the development of pathogens. In Mali (Table 4B), yearly deviation had no significant effect, if each livelihood region is observed separately.

Results for monthly deviation (Tables 7, 8, 9, 10)

Results for this variable were unexpected and puzzling for both countries. Five methods for measuring the effect of a recent rainfall deficit on child death have been considered (month of the observation, 1 month before observation, mean of the 1–3 months before observation, mean of the 4–12 months before observation and mean of the 1–6 months before observation[16]). In Mali (Table 7), a reduced risk of child death was observed when rainfall differed greatly from normal rainfall conditions (M 0, M 1–3, and M 1–6). In Burkina Faso (Table 8), the only clear significant result revealed a reduced risk of death during the dry season. Several childhood periods were been tested using the model that included the mean of the 1–3 months before the child observation.[17] However, a reduced risk of child death

[16] We also included rainfall during the 1–3 and 4–12 months before the child observation was made in the same model. Results (not shown here) were not significant for either country.

[17] Because this time lag seems to us to be the most relevant in the Sahelian context.

Table 9 Effect of rainfall monthly deviation (1–3 months) on risk of death in Mali, after controlling for child and mother effects (odds ratio), by childhood period

Monthly deviation (v)	1–23	7–23	11–23
<85 %	0.85	0.88	0.70+
85–94 %	0.86	0.82	0.70*
95–104 % (R)	1	1	1
105 and over	0.79*	0.86	0.79
Dry season	0.98	1.08	0.92

Table 10 Effect of rainfall monthly deviation (1–3 months) on risk of death in Burkina Faso, after controlling for child and mother effects (odds ratio), by childhood period

Monthly deviation (v)	1–23	7–23	11–23
<85 %	0.97	0.83	0.86
85–94 %	0.83	0.66*	0.65+
95–104 % (R)	1	1	1
105 and over	0.9	0.79	0.61**
Dry season	0.86	0.78	0.76

was sometimes observed when rainfall differed greatly from normal rainfall conditions in Mali (Table 9) and in Burkina Faso (Table 10).

Conclusions and discussion

The aim of this study was to gain a deeper understanding of how rainfall variations may influence child survival in two Sahelian countries, Burkina Faso and Mali, based on reliable multi-source data in event history models. A previous analysis has already shown that child survival is related to specific patterns of rainfall variation in each region of Burkina Faso (Dos Santos and Henry 2008). Using similar data and methodology, this study has been extended and replicated in Mali, a comparable neighbouring country.

In Burkina Faso and Mali, the effects of the socio-demographic characteristics of the child and his/her mother were found to be consistent with the literature. Very few results concerning the effects on rainfall variables on child survival were statistically significant. Sensitivity analyses were made and whichever way the risk is computed, the stability of some rainfall results is noteworthy. The risk of death is lower in regions with high long-term average rainfall in Mali and in parts of Burkina Faso. As was previously found by Dos Santos and Henry (2008), the yearly deviation seems to have no direct effect on child mortality, but a rainfall deficit during the 12 preceding months increases the mortality differential across the livelihood regions in Burkina Faso and to a lesser extent in Mali.

More surprising is the effect of recent rainfall conditions on child survival. Unexpectedly, the effect of rainfall monthly deviation on the risk of death is unstable in Mali and Burkina Faso, depending on the time lag and the childhood period being considered. This means that in these kinds of environmentally heterogeneous countries, it is not relevant to suggest the same variable to measure the effect of recent rainfall on child survival. One tentative explanation could be the problem of pattern and scale, as suggested by Levin (1992) in his seminal ecological studies article on this issue. A deficit (or excess) of rainfall during the 1, 3 or 6 month(s) prior to the survey may affect child survival through three different mechanisms. It is therefore not surprising that different results should be obtained for each time period. In addition, these mechanisms could differ with childhood period and/or regions in both countries. Appleton et al. (2008) illustrated the variability in the conclusions drawn after using different time lags when studying the correlation between the prevalence of intestinal schistosomiasis and the presence of rivers in Botswana.

The most significant result concerned the effect of livelihood on child survival. This study highlighted huge mortality differentials across livelihood regions in both countries. One explanation could be the complexity of the relationship between environment, hosts/vectors/pathogens, and morbidity/mortality. For example, the density of some vectors depends on the type of agriculture, as stated by Koudou et al. (2005). Matthys et al. (2006) emphasized the limitations of using a broad classification of crop types to estimate the risk of malaria in a small region of Côte d'Ivoire. In our study, specific patterns were seen in Burkina Faso, as was the case in the study conducted by Dos Santos and Henry in 2008. In the northern livelihood regions, a deficit in rainfall increased the risk of death due to the sensitivity of crops, while in the southern regions, this deficit reduced the risk of death by limiting the development of pathogens (e.g. malaria). In Mali, these patterns could also be discerned. The odds ratios seemed to support this explanation but were not significant. Sample size is a factor that may have influenced the significance of the results. Even with these two large surveys (9,691 children in Mali and 8,230 in Burkina Faso), sample size directly influences the number of categories of control factors that can be allowed in the models. In some places, finer categories may be required.

The event history approach allows the environmental conditions of the child's first 5 years to be taken into account at different points in time, and not just at the time of the survey, as has generally been the case with previous studies. This means that any additional environmental variables must be time varying and multi-level, because factors at multiple levels may be important for understanding the causes of variability at the child level. For example, some of the unexpected results could be explained by specific differences in the health systems of these two countries, that is, geographical variations in access to health services, immunization rates and use of traditional medicine. Some of these factors were measured in the DHS but were not time varying. In addition, because the design of these surveys is not comparable to that used by our surveys, introducing DHS variables to our event history models seems to produce results that are not precise/accurate/reliable enough to contribute significantly to this issue.

This study is a good illustration of the difficulties encountered when investigating complex causal chains empirically. Rainfall variations are an underlying factor in child mortality in most cases. In the models presented above, some proximate drivers (e.g. malnutrition and household income reduction) were not introduced directly, while for some models we used the only indicators available, which were too broad (e.g. livelihood). The complexity of the many indirect and feedback mechanisms affects all aspects of climate-related child morbidity and mortality. No one factor can be considered in isolation, because of the many interactions between the different drivers of the risk of death. Persistent effects of drought can also be observed several years after the extreme weather events have taken place, because recovery in all its aspects (e.g. health, nutrition and economy) may take a long time, as was shown in Ethiopia by Dercon (2004). However, the latency between climate variables and health outcomes/death is variable. In this study, we tried as far as possible to take a holistic approach to mortality risk assessment. As suggested by this study, as well as by several others (Levin 1992; Matthys et al. 2006; Koudou et al. 2005), the complexity of the relationship between environment, vectors and morbidity/mortality means that great caution must be taken when attempting to draw conclusions.

This study used precise, powerful models and found that rainfall conditions do have an effect on child mortality. This method, however, while providing us with statistical results, does not explain the mechanisms behind those results, which would require further research. The resilience of households to the impact of rainfall variations and their specific health consequences still needs to be evaluated in rural regions. In-depth qualitative work may give information on household coping strategies, also known as household response to crisis, such as inter-household food exchanges or migrant remittances (Adams et al. 1998).

Given that extreme weather events and rainfall variability are expected to increase in Africa (IPCC 2001), this study gives valuable insights in terms of public health policy. Agriculture type seems to have a greater influence than rainfall conditions on child survival in these two Sahelian countries. Consequently, this study emphasizes the fact that there is no sense in developing or suggesting a single policy for combating child mortality across all regions. Local information on mortality patterns and specific tools, especially with regard to type of agriculture, are needed to be able to evaluate health hazards and plan public health activities. A better understanding of the way populations respond after a deficit or excess of rainfall is still required if an early warning system is to be implemented. This would require the investigation of other sources of data (qualitative and/or Demographic Surveillance System (DSS) data) and a focus on morbidity.

In conclusion, thanks to the use of individual retrospective event history data, this study succeeded in highlighting the specific causal relationships between rainfall and child death, at a fine temporal and spatial resolution across each livelihood region in Mali and Burkina Faso. In contrast to the current popular trend using macro-scale approach (i.e. covering West Africa or the Sahelian region), this study shows the importance of micro-analysis at fine resolution in order to tackle climate-health issues.

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