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# Malnutrition and conflict in East Africa: the impacts of resource variability on human security

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**Abstract** Changes in climate, along with anthropogenic pressures, impact vegetation productivity and related ecosystem services on which human security relies. The impacts of these climate changes on society will be experienced both through changes in mean conditions over long time periods and through increases in extreme events. Uncertainties remain on how short-term changes in ecosystems influence human security. Most studies analyzing the relationship between human security and climate are at the country level, ignoring fine-grained spatial heterogeneity in local climatic and socio-economic conditions. Here, we used detailed spatio-temporal information extracted from wide-swath satellite data (MODIS) to examine the impact of interannual variability in ecosystems on malnutrition and armed conflict in East Africa while controlling for other natural and socio-economic factors. The analysis was performed at a subnational and village scales. At the regional level, ecosystem variability was associated with malnutrition. This relationship was not statistically significant at the village level. At both levels of analysis, our results indicated that armed conflicts were more likely in regions with more vegetation. Results suggested that, in East Africa, increased levels of malnutrition were related to armed conflicts. They also showed the importance, in low-income countries, of local economic activity and accessibility to reduce the likelihood of malnutrition and insecurity.

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## 1 Introduction

There is an ever greater knowledge of how climate change, along with other socio-political factors, can impact livelihoods and threaten human security. In the past, research has focused on conflicts and famines, disentangling the economic and political impacts (De Waal 1997; Sen 1983). Now, with climate change, there is an additional layer of complexity which needs to be understood. Recently, studies have analyzed the impact of long-term changes in climatic means on food security (Parry et al. 1999; Schimel 2006; Schmidhuber and Tubiello 2007) and its influence on the onset of conflict (Raleigh and Urdal 2007). However, besides influencing the mean climatic conditions over long time periods, climate change will also impact society through increases in extreme events such as droughts, floods, and heat waves, with relatively small mean climate change in some cases (IPCC 2007). These short-term changes in climate increase the variability and decrease the predictability in ecological production and thus have the potential to influence human security (Barnett 2003). This may be especially true in regions where communities rely directly on goods and services provided by natural ecosystems. Moreover, the capacity of human societies to respond to and mitigate the effects of ecosystem changes, which depends on cultural, institutional, and technological mechanisms, will become more challenging with increasingly rapid climate-induced ecological change. The objective of this study is to improve our understanding of the complex interactions between the climate and human security through an empirical analysis, with a specific focus on the impacts of climate-related environmental variability on malnutrition and conflicts.

In the past decades, the theoretical models explaining famines and conflicts have moved beyond a Malthusian point of view, focusing more on the political roots and other social factors (Sen 1983; De Waal 1997). Environmental and climatic factors have also been introduced as potential causes of food insecurity and conflicts. A theoretical paradigm was developed to show how long term changes in climatic means increase migration and demands on natural resources which in turn lead to food shortages and conflict (Homer-Dixon 1991). This idea was supported by several empirical case studies (Percival and Homer-Dixon 1998; Howard and Homer-Dixon 1998) and coarse historical analyses (Zhang et al. 2007). In Darfur for example, the environmental root cause of the conflict was suggested by some prominent politicians and academics (Sachs 2006; Moon 2007). This perspective was however challenged by another group of political scientists who emphasized the social, ethnic, economic, and political roots to conflicts and stress the role of conflict management institutions (Theisen 2006; Nordås and Gleditsch 2007; Kevane and Gray 2008), pointing also to methodological weaknesses and theoretical shortcomings (Gleditsch 1998). One important aspect of climate change, which is often omitted from this discussion, is the impact of climate variability on food security and conflicts. Thus the primary impetus for this case study was to investigate the interactions between short-term changes in climate and malnutrition and armed conflicts based on regional scale empirical data.

Until now, most studies analyzing statistically the impacts of changes in environmental conditions and other socio-political factors on human populations relied on country-level data using aggregate figures such as GDP and casualty counts, therefore ignoring local conditions. The level of economic development within a country plays an important role as a mediating factor (De Waal 1997). Moreover, ecosystem changes impact regions unequally, depending on their economic and political status. Thus, to improve our knowledge about the impacts of climate variability on society, more fine-grained, sub-national scale analyses are needed (Barnett 2003; Nordås and Gleditsch 2007). Data extracted from satellite imagery can prove very beneficial as they provide spatially explicit information on changes in land surface attributes. High-temporal resolution time series of satellite data have the potential to improve our understanding of the links between the natural environment and humans by providing detailed information on spatial and temporal variations in vegetation activity (Linderman et al. 2005).

Here we present a study of the geographical distribution of malnutrition and armed conflicts in Eastern Africa and more specifically in Sudan, Ethiopia, and Somalia. This region is characterized by unstable governments, weak states and widespread poverty. Recently, these countries ranked 126th (Ethiopia), 173rd (Sudan), and 180th (Somalia) out of 180 countries on the 2008 Corruption Perceptions Index by Transparency International (available at www.transparency.org), and ranked 146th (Sudan—Medium), and 169th (Ethiopia—Low) on the Human Development Index (HDI). Somalia is not listed on the HDI (UNDP 2007). Droughts, floods, famines, and violence have affected the region in the past decades. In sub-Saharan Africa, changes in natural ecosystems have the potential to influence human security along with many socio-economic factors. However, causal mechanisms of conflicts and malnutrition are known to be very complex and multiple. In this study, we investigate statistically whether there is a regional-scale association between spatio-temporal variations in ecosystem attributes and the occurrence of malnutrition and conflicts, while controlling for other important factors. Contrary to a widely held view, our results suggest a positive association between ecosystem productivity and conflicts. Furthermore, this analysis does not show any association between short-term land degradation, and both conflicts and malnutrition.

## 2 Study area

This study focuses on three countries in eastern Africa that have suffered from food insecurity, environmental change, and various conflicts during the past decades (Fig. 1). In the Republic of Sudan, from the early 1980's until recently, the Sudan People's Liberation Army (SPLA) fought the government in Khartoum for more autonomy in southern Sudan, causing migration, increased mortality, and land changes. To the west, in the Darfur region, a war is currently opposing Arab militia to different local non-Arab communities. Some authors have suggested that drought, desertification and overpopulation has pushed the nomads further south searching for land and water and thus occupying land used by local non Arab people (UNEP 2007).

In neighbouring Ethiopia, environmental changes are also a key concern. Land degradation, population growth, and drought threaten food security in the area. Extreme weather-related events appear to have already influenced the country's social and political situation (Comenetz and Caviedes 2002). Regional and international armed conflicts have also impacted the population in this country. Ethiopian troops were also involved in an insurgency in Somalia, which is currently facing one of the worst humanitarian crises on the African continent. Plagued with droughts, locust invasions, and floods, Somalia has not had a permanent national government

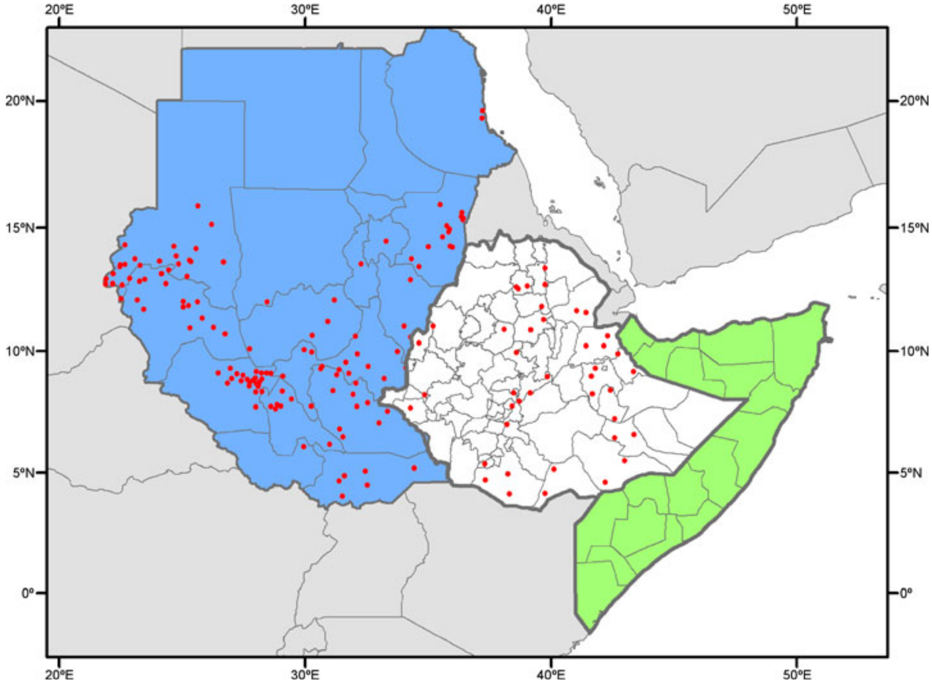


**Fig. 1** Study area showing the different administrative units and the villages (in *red*) used in this multi-scale study

since 1991. There are a large number of clans and warlords fighting for control over land and resources. In the centre of the country, islamist militias are fighting the internationally recognized, transitional federal government for dominance. This has led to an increase in food insecurity and a large number of refugees.

The study region covers more than 4 million km$^2$, is host to many pastoralist communities, counts for over 132 million people (Central Intelligence Agency 2008), and includes three of the world's poorest countries (UNDP 2007). The number of refugees and internally displaced people (IDP) in 2006 in the region was well above 7 million, with more than 5 million IDP's alone in Sudan (Central Intelligence Agency 2008).

## 3 Data and method

### 3.1 Nutrition indicator

A commonly used nutrition indicator was applied to characterize the health situation in this region (Table 1). The Global Acute Malnutrition (GAM) indicator for the children under the age of 5 was used to measure nutritional status (Guha-Sapir et al. 2005). Theoretically, malnutrition covers both under and overnutrition but, in emergency situation, malnutrition is often used to identify undernutrition. A shortage of nutrients at the early stages of life can have disastrous effects. During

**Table 1** Summary of all the data used in this study

| Variables | Availability | Characteristics | Spatial scale | Temporal scale | Thresholds |
|---|---|---|---|---|---|
| Global acute malnutrition (GAM) | http://www.cedat.be | Weight-over-height ratio < 2 standard deviations from average ratio | Different administrative levels | Variable (>2,000 surveys available) | Village or admin. unit set to 1 if at least three surveys were available and the majority of these surveys had a value of GAM>15 |
| Armed conflict | http://www.prio.no | Interstate, extrastate, internal, and internationalized internal armed conflicts with at least 25 battle deaths annually, between two or more organized parties, of which at least one is the government of a state | Center of conflict with radius (in 50 km intervals) indicating the largest geographic extent of the conflict zone | 1946–2005 | Village or admin. unit within the region of conflict was set to 1 if malnutrition surveys available |
| Vegetation variability (SCV) | Rowhani et al. (2010) | Measure of interannual changes in total photosynthetic activity and in phenology (based on MODIS data) | 1 km | Since 2000 | Village: mean over years where GAM available Admin. unit: 80% percentile over unit |
| Ecosystem productivity (iEVI) | Rowhani et al. (2010) | Measure of total photosynthetic activity and used as proxy to measure total annual vegetation activity and the abundance of natural resources (based on MODIS data) | 1 km | Since 2000 | Village: mean over years where GAM available Admin. unit: average |
| Land degradation (trend in iEVI) | Rowhani et al. (2010) | Downward trend in iEVI (from 2000–2005) over at least 5 of the 6 years of observation, with a difference between the first and last year of at least 20% (based on MODIS data) | 1 km | Since 2000 | Village: percentage of degraded land Admin. unit: degraded if > 2% land decreased in iEVI |
| Roads | ESRI | All roads were used | Vector format | 1993 | Mean road density |
| Economic activity | http://gecon.yale.edu | Geophysically based economic dataset based on the concept of Gross Cell Product (GCP), which is similar to the Gross Domestic Product (GDP) | 1° | 2000 (1990, 1995 also available) | Mean Purchasing Power Parity (PPP) cell value over admin. unit/village |

health surveys (see below), information on three variables is collected for every child from 6 to 59 months: height/length, weight and age. The ratio weight-over-height measures Acute Malnutrition, which is then compared to expected values from reference tables. The GAM indicator represents the proportion of children below 2 standard deviations from the average ratio. The z-scores of this indicator at the village level as well as at the different administrative levels over Eastern Africa from 2001–2006 were obtained from the Complex Emergency DATabase (CE-DAT—http://www.cedat.be). This project of the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters (CRED) is a compilation of survey results carried out among conflict-affected populations. These nutritional surveys are recurrently undertaken by principally non-governmental organizations (NGOs) working in the field and are reported to CE-DAT. An analysis of the data has shown that the quality of the nutrition indicators has improved over the last years and is adequate for comparative analyses (Degomme and Guha-Sapir 2007).

### 3.2 Conflict data

The geo-referenced Armed Conflicts dataset (Version 4–2006) and the corresponding Conflict Site extension, developed by the Centre for the Study of Civil War (CSCW) at the International Peace Research Institute, Oslo (PRIO) and Uppsala University, was used (http://www.prio.no/cscw/armedconflict). This dataset covers interstate, extrastate, internal, and internationalized internal armed conflicts with at least 25 battle deaths annually, between two or more organized parties, of which at least one is the government of a state (Strand et al. 2005). The dataset spans from 1946 until 2005, giving the geographic coordinates of the center of the conflict as well as the radius covering the affected area. The radius indicates the largest geographic extent of the conflict zone from the center point during the course of conflict and is measured in 50 km intervals. The database also provides conflict parameters such as the year of observation, the start of the conflict, the parties involved in the conflict, the type of conflict, and its intensity. This dataset was used to determine small-to-large scale violent conflicts. However, it does not take into account smaller violent conflicts which do not necessarily lead to direct human casualties but can degrade livelihoods.

### 3.3 Environmental change indicators

Environmental variables were measured using the 1 km resolution, collection 4, Nadir Bi-directionally Adjusted Reflectance (NBAR) MOD43B4 product from the MODIS sensor aboard the Terra platform (Schaaf et al. 2002) for the period from February 2000 to December 2006. To measure interannual variability in land-surface attributes we used the “Sum of the absolute values of the change vector” (SCV; Fig. 2), a metric based on the Enhanced Vegetation Index (EVI) which measures changes in total photosynthetic activity and in phenology (Linderman et al. 2005). The SCV was linked to climate variability and also to agricultural land use, fires, and other anthropogenic disturbances (Rowhani et al. 2010).

Climate variability intertwined with poor economic conditions can lead to population displacement. People may be forced to move to more fragile ecosystems. The consignment of poor populations in these marginal lands may cause environmental

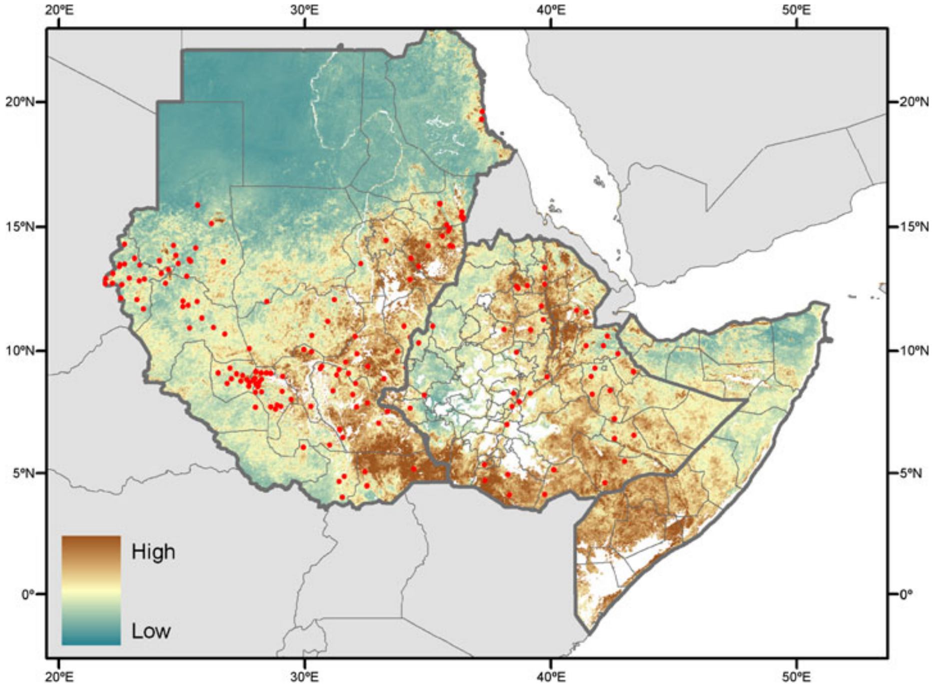


**Fig. 2** The spatial distribution of vegetation variability as measured by the SCV over the study area. The SCV was measured at 1 km resolution using MODIS data. Some areas were masked out (in *white*) due to unreliable (cloud cover, missing data; Rowhani-et al. 2010) satellite data

degradation (Homer-Dixon 1991). This ecological marginalization of poverty also increases the risk of malnutrition and conflict. Furthermore, while in some cases it is resource scarcity that may trigger conflicts, in other cases it is the abundance of natural resources, especially if these generate substantial income (Barnett 2003; Collier 2007). Here, the downward trend in ecosystem productivity was included as a proxy variable characterizing one specific aspect of land degradation (Fig. 3). The annual integrated EVI (iEVI) values, measuring total photosynthetic activity, are used as a proxy to measure total annual vegetation activity and the abundance of natural resources. Land degradation was calculated as a continuous decrease in iEVI over at least 5 of the 6 years of observation, with a difference between the first and last year of at least 20%.

### 3.4 Control variables/socio-economic data

During events of resource shortages, accessibility is of utmost importance for relief assistance (Rosegrant and Cline 2003). Supplies and aid need to reach the affected population quickly to reduce human casualties. Road maps were downloaded from the Digital Chart of the World server (ESRI 1993) to estimate the average road density per administrative unit. The economic activity of a country mediates the

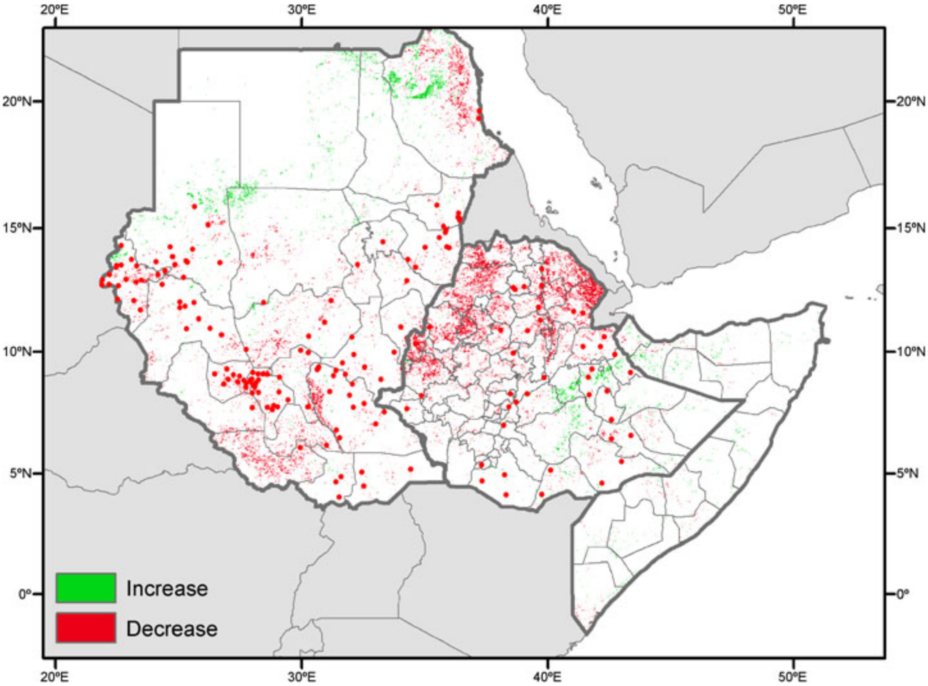


**Fig. 3** The spatial distribution of land degradation as measured by a continuous decrease in iEVI (a proxy variable for ecosystem productivity) over the study area using MODIS data

impacts of resource variability on human security (Homer-Dixon 1991; Barnett 2003). In particular, disparities between richer urban areas and poorer rural regions within a country are quite important. To assess the economic activity per administrative unit, we used the G-Econ database which measures global economic activity at a 1°x1° resolution (Nordhaus 2006). This geophysically based economic dataset is based on the concept of Gross Cell Product (GCP), which is similar to the Gross Domestic Product (GDP) but at the resolution of the cell. The data include the Market Exchange Rate (MER) and Purchasing Power Parity (PPP) cell GDP values. This latter, purchasing-power-corrected 1995 US dollars GCP was used in this study.

### 3.5 Statistical model

We tested two logistic regression models with, as dependent variable, respectively the global acute malnutrition indicator and the armed conflicts, and with the above-mentioned socio-economic and environmental data as independent variables. This statistical analysis was performed at two spatial scales. Firstly, all the variables were aggregated at different administrative levels. Due to the constantly changing administrative situation in Sudan and Somalia, the analysis in these countries was focused on the first administrative level (states in Sudan and regions in Somalia). In Ethiopia, the analysis was conducted over the second administrative level, the 68 zones. For each year, both environmental change indicators were aggregated at the corresponding administrative level by taking the mean iEVI value to capture the general vegetation status over the unit and the 80% percentile of SCV to capture the most extreme vegetation variability. Both these variables were then averaged over the 2000–2006 time period. At this level, a unit was characterized as affected by land degradation if more than 2% of its area was undergoing an annual decrease in iEVI. For the model explaining malnutrition, each administrative unit or village was assigned a value of 1 if, over the 2001–2006 period there had been at least three surveys and that the majority of these surveys showed a value of GAM superior to 15—a threshold commonly used to characterize critical emergency situations. This reduced the number of administrative units to 38. Similarly, for the model explaining conflict, those spatial units for which malnutrition values were available and which fell within the conflict zone (as defined by the center point and the radius in the PRIO dataset) over the 2000–2005 period were assigned a value of 1. All other units were assigned a value of 0. Thus, this analysis was performed over a total of 71 administrative units.

Secondly, the statistical analysis was performed at the village level, for Sudan and Ethiopia as malnutrition levels were only available at the village scale in these countries. Our sample included 282 villages. A 15 km buffer zone was created around each village within which all variables were measured. The two environmental change indicators were averaged over these zones for each year. The temporal resolution of the study was also increased. Instead of using the average SCV and iEVI over the entire study period, we used these variables only for those years when a malnutrition survey was available. The percentage of degraded land was also measured over these zones.

All explanatory variables were checked for multi-collinearity and transformed when necessary to satisfy the condition of normal distribution. Explanatory variables were kept in the full model if they decreased the Akaike's Information Criterion (AIC) value (Burnham and Anderson 2002). The logistic regression model provides coefficient estimates and odds ratio (Hosmer and Lemeshow 1989). Values of the pseudo-$R^2$, a measure of goodness-of-fit in logistic regression, between 0.2 and 0.4 represent a very good explanatory power of the model. The Receiver Operating Characteristic (ROC) curve measures how accurately the model classifies observations. Good models have an area under the ROC curve above 0.7. The model chi-square test measures the improvement in fit that the explanatory variables make compared to the model with just a constant.

## 4 Results

### 4.1 Malnutrition

An equal number of administrative units showed high levels of malnutrition (19 units) and a GAM value below 15 (19 units). Out of the 38 administrative units used in this analysis only 14 presented important land degradation as measured by a declining trend in iEVI. The model had a good overall explanatory power (Table 2). It classified the observations rather accurately (area under ROC over 0.81). The model chi-square test was significant, rejecting thus the null hypothesis. The variable "land degradation" was not significant and did not lower the AIC.

Similarly, ecosystem productivity (measured by the iEVI) did not influence the presence of malnutrition. At this scale, both of these variables were therefore removed from the model.

Three variables were included in the model at the level of administrative units (Table 2). The variable representing interannual variability in land surface attributes (SCV) was significant with a positive coefficient and a very high odds ratio. At this level, units with variable vegetation productivity had thus an increased likelihood of acute malnutrition. By contrast, both road density per administrative unit and the level of economic activity had negative coefficients. The odds of finding malnutrition in a rich administrative unit were 0.028, i.e. malnutrition was 35.7 times more likely to be found in a poor area with a low GCP. The likelihood of observing malnutrition in an administrative unit decreased with road density. Infrastructure, access to markets and a healthy economy thus decreased the likelihood of malnutrition whereas interannual variability in ecosystem productivity increased the odds of malnutrition.

At the village scale, 109 villages had a GAM value less than 15 and 173 villages were affected by a high level of malnutrition. In the models (Table 2), none of the environmental change indicators were statistically significant. Only the economic activity was related to malnutrition at the village level. Thus, environmental change and infrastructure only influence food insecurity at the regional level whereas the economic situation is key at the regional and local scales.

The direct relationship between malnutrition and conflict was also analyzed. At the administrative unit level, the two variables were correlated (Pearson's correlation coefficient = 0.50, significant at $p < 0.001$). The logistic regression model analyzing the likelihood of malnutrition in conflict areas (Table 3) showed statistically significant results (pseudo-$R^2$ = 0.19, model chi-square = 0.0008). The observations were fairly accurately classified by the model (area under ROC = 0.74). The model showed that the nutritional status in this region is associated with the level of violent conflicts. In East Africa, GAM values over 15 were 11.7 times more likely to be found in areas affected by armed conflicts. However, no relationship was found between malnutrition and conflict at the village scale.

**Table 2** Multivariate logistic regression model results using global acute malnutrition (GAM) as the dependent variable

| Variable | Parameter estimate | | Standard error | | *p*-value | | Odds ratio | |
|---|---|---|---|---|---|---|---|---|
| | Admin. unit | Village | Admin. unit | Village | Admin. unit | Village | Admin. unit | Village |
| Intercept | 22.61 | 7.36 | 9.85 | 2.06 | 0.0217 | 0.0003 | – | – |
| $\log_{10}$GCP | −3.57 | −0.87 | 1.36 | 0.258 | 0.0089 | 0.0007 | 0.0283 | 0.419 |
| Roads | −53.55 | | 25.28 | | 0.0341 | | $5.5 \times 10^{-24}$ | |
| SCV | 17.38 | | 8.66 | | 0.0446 | | $3.55 \times 10^{07}$ | |

At the administrative unit level (38 observations), the model performs relatively well with a pseudo-$R^2$ equal to 0.26 and the area under ROC = 0.81. Statistically significant explanatory variables include economic activity ($\log_{10}$GCP), roads, and interannual variability in land surface attributes (SCV). However, at the village level (282 observations), the model is less efficient (pseudo-$R^2$ = 0.04 and area under ROC = 0.64) and the only statistically significant variable remaining is $\log_{10}$GCP. At the administrative unit level, SCV represents the 80% percentile of SCV over the unit averaged over the 2000–2006 period. At the village level, it represents the average SCV over the 15 km buffer at the year of the survey. Here, the square-root transformation has been used. Parameter estimates and their corresponding odds ratio are shown

**Table 3** Multivariate logistic regression model results at the administrative unit level, measuring the relationship between global acute malnutrition (GAM; dependent variable) and the presence of armed conflict (Conflict) (pseudo-$R^2 = 0.19$, area under ROC = 0.74)

| Variable | Parameter estimate | Standard error | $p$-value | Odds ratio |
|---|---|---|---|---|
| Intercept | −1.71 | 0.77 | 0.0266 | – |
| Conflict | 2.46 | 0.88 | 0.0052 | 11.7 |

Parameter estimates and their corresponding odds ratio are shown. No relationship is found at the village level

## 4.2 Violent conflict

According to the PRIO dataset, from 2000 to 2005, armed conflicts with more than 25 battle deaths happened primarily in southern and western Sudan, and in the border region between Somalia and Ethiopia. This affected 39 of the 71 analyzed administrative units. The remote sensing data showed that a declining trend in iEVI impacted half of the units (36 out of 71). At the level of administrative units, the variables characterizing interannual variability in ecosystem productivity, land degradation, and road density were not significant and did not lower the AIC (Table 4). They were thus removed from the full model. Ecosystem productivity and economic activity, as measured by the iEVI and the GCP, were significant explanatory variables in the model explaining armed conflicts. Both variables improved the fit of the model compared to the null model (model chi-square = 0.012) but the model's overall fit was weak (pseudo-$R^2 = 0.08$). The area under the ROC equalled 0.71, showing a fairly good classification of the observations. The results showed that, in the study area, regions with a better economic situation were less likely to be subject to armed conflict (Table 4). The increase by 10 units in GCP reduced the likelihood of war by a factor of 3. On the contrary, armed conflicts were more likely in areas with more vegetation.

At the village level, around 160 villages were found in conflict areas during the malnutrition surveys. The model performed slightly better than at the administrative unit level (pseudo-$R^2 = 0.13$ and area under ROC = 0.74) and iEVI was the only statistically significant variable remaining in the model. As with the model at the

**Table 4** Multivariate logistic regression model results analyzing the spatial distribution of conflict (PRIO)

| Variable | Parameter estimate | | Standard error | | $p$-value | | Odds ratio | |
|---|---|---|---|---|---|---|---|---|
| | Admin. unit | Village | Admin. unit | Village | Admin. unit | Village | Admin. unit | Village |
| Intercept | 7.235 | 2.108 | 4.08 | 2.63 | 0.0762 | 0.01 | 1,387.06 | 8.23 |
| $\log_{10}$GCP | −1.089 | | 0.548 | | 0.0471 | | 0.3366 | |
| iEVI | $3.6 \times 10^{-05}$ | $5.73 \times 10^{-05}$ | $1.50 \times 10^{-05}$ | $1.16 \times 10^{-05}$ | 0.0163 | $8.04 \times 10^{-07}$ | 1.00004 | 1.00007 |

At the administrative unit level, the model's pseudo-$R^2$ equals 0.08 and the area under ROC = 0.71. Statistically significant explanatory variables include economic activity ($\log_{10}$GCP) and ecosystem productivity (iEVI). At the village level (282 observations) the model performs slightly better (pseudo-$R^2 = 0.13$ and area under ROC = 0.74) and iEVI is the only statistically significant variable remaining in the model. At the administrative unit level, iEVI represents the average iEVI over the unit from 2000–2006. At the village level, it represents the average iEVI over the 15 km buffer at the year of the survey. Parameter estimates and their corresponding odds ratio are shown level of administrative units, armed conflicts were more likely in regions with more vegetation (Table 4).

## 5 Discussion

Using detailed information extracted from remote sensing data, this study presented the influence of the climate-induced changes of ecosystem resources on malnutrition and armed conflict while controlling for other important factors. The results of our models do not imply strict causal mechanisms but rather associations between variables. However, our results highlight the important relationship between interannual variability in ecosystem production and malnutrition. As malnutrition is associated statistically with armed conflicts, ecosystem variability is also indirectly associated with violent conflicts. Our empirical study of vegetation variability as well as other historical examples of extreme climatic events (Battisti and Naylor 2008) impacting food security encourage more detailed research on the influence of climate volatility on society, especially in the wake of projected climate change (IPCC 2007).

Ecosystem variability, which is supposed to increase in the future, has been shown to be influenced by short-term variability in climatic conditions, land use and other disturbances (Rowhani et al. 2010). The main climatic factor explaining interannual variability in land surface attributes, as measured by the SCV, was rainfall variability. A previous study over Sub-Saharan Africa (Hendrix and Glaser 2007) showed that, at the level of a country, only a lagged interannual variability in rainfall was a more important factor in explaining the onset of conflict compared to long-term climate change and current year variability. The absence of a direct relationship between the SCV and armed conflicts in this study may be due to the different geographic region covered and the nature of conflict data. The PRIO dataset gives a centre point as well as a radius which approximately measures the area affected by the armed conflict with at least 25 battle deaths annually. The actual location of the fighting is not directly represented.

This study did not show a significant relationship between land degradation and either malnutrition or armed conflicts. In a widely held view, degradation of natural resources increases the probability of violence between competing groups (Homer-Dixon 1991). Land degradation can be associated with changes in mean climatic conditions and the ecological marginalization of poverty, leading to desertification. A previous study (Raleigh and Urdal 2007) showed that increasing levels of land degradation were positively related to conflict. Short-term land degradation (characterized here by a downward trend in ecosystem productivity over 6 years) was not associated with armed conflict in this study over Eastern Africa. Our analysis covers only a short time period (2000–2006) and declines in vegetation activity might be only temporary. Local communities have, over millennia, developed adaptation strategies to dry situations as the region has always been prone to droughts. Moreover, due to a lack of reliable land degradation maps, our land degradation metric only captures one aspect of degradation that is mostly related to declining rainfall. It tends to be much more conservative than other land degradation maps that are known for having overestimated the problem (UNEP 1992). Improved spatial and temporal metrics of land degradation, including soil moisture and quality, would be needed to better test the hypothesis linking degradation of natural resources to conflicts and human health.

As expected, economic activity is strongly associated with human security at the subnational scale. Previous studies had shown these relationships at the national level. The economic situation of a region thus influences also the impacts of resources variability on human security (Homer-Dixon 1991), especially in low-income states. This result shows that, at all scales, the economic activity plays a key factor in reducing malnutrition and conflicts. In wealthier regions, political institutions are able to respond to food shortages and to the effects of climate change. Economic wealth makes people less vulnerable to changes in ecosystem productivity, especially in regions where societies depend strongly on agriculture. This study also showed that accessibility decreases the impact of malnutrition. Roads allow food aid to reach affected areas. They also enable farmers to access markets, which will in turn increase their potential to improve their financial status and enhance the economic situation of the region.

The results also show that increased ecosystem productivity increases the likelihood of war in East Africa. There is a large nomadic, pastoralist community in this region. It has been shown that organized raids between pastoralists to steal livestock are more likely during the wet season, when grasses are high (Meier et al. 2007). The fact that violent conflicts in general are associated with more vegetated areas may also be a consequence of the population displacement that follows conflicts, which allows the vegetation to regrow around abandoned villages. In Darfur, livestock migration patterns have been significantly affected by the ongoing conflict, restricting grazing access for pastoralists (Young et al. 2005). In these cases, ecosystem state is a consequence rather than a cause of conflicts. At a national scale, the abundance of natural resources, if they generate high income, can also "trap" certain countries in poverty and conflict by worsening governance and promoting autocracies (Barnett 2003; Collier 2007), with adverse impact on the environment and increased grievances (Goldstone 2001; Collier 2007).

Our study at two spatial scales also highlights that some variables are associated with malnutrition at the sub-national administrative level but not at the village scale. It is in particular the case with environmental change and road density. Famines and violence have political, economic, and ethnic roots (De Waal 1997; Gleditsch 1998; Meier et al. 2007) that, at a fine scale of analysis, may be more important driving factors than ecosystem changes. When disaggregating the analysis spatially from the national to the village scales, one uncovers more complexity related to the mitigation capacities of communities, the motivation and strategies of rebel groups in starting a conflict, landscape heterogeneity, population displacement, etc. This suggests that small range population movements allow responding to localized stresses. However, when a larger geographic entity suffers from repeated droughts and low accessibility, then the population may be affected by malnutrition. Detailed data at the household level on the small-scale, informal socio-economic activity would allow testing this hypothesis.

If ecosystem productivity can be used as a measure of natural resources then our results contradict the neo-Malthusian contention that resource scarcity is an important risk factor of famines and violence. Starvation is not always related to a decline in food availability (Sen 1983). Moreover, the low explanatory power of our conflict models suggests that human security involves much more complexity than represented by our explanatory variables. Other factors have to be taken into account, including feedbacks between resource degradation, institutions and population movements. There might also be threshold effects triggering certain events (Scheffer et al. 2001; Rockström et al. 2009). A decline in natural resource availability may only cause conflicts and famines after a threshold is crossed.

The quality of the available data is one of the main shortcomings of this analysis (Table 1). This is a recurrent problem in regional scale studies of resource-conflict interactions. For example, the gridded global economic data (G-Econ) lacks information on the informal sector that prevails in many conflict prone regions and in countries of the bottom billion (Collier 2007). There are however no official statistics on these informal economic activities. Concerning malnutrition, relief agencies and NGO's tend to conduct their surveys in conflict-affected regions, which could introduce a bias and affect data quality. We controlled for such a bias in our study by using an equal number of surveys presenting high levels of malnutrition and GAM values of over 15, thus ensuring sufficient variability across the key variables. The Armed-Conflict data used here is the best source of information on conflicts currently available, even though it lacks detailed spatial information and does not take into account conflicts with less than 25 deaths. The latter can impact livelihoods and increase food insecurity. However, we believe that the results presented here are sufficiently robust and show a clear relationship between resource availability and variability, and human security.

Clearly the rather short time series of observations, especially for measuring vegetation variability, ecosystem productivity and land degradation, is a limitation. Longitudinal studies of specific conflict areas could test whether there is a cycle of land degradation followed by conflict and by an increase in vegetation after people have left, or whether some other reasons account for the observed correlations.

Finally, we need to be cautious about drawing causal links. The models used in this study highlight associations between variables. Malnutrition and conflicts may be the result of environmental instability and/or degradation, economic activity, and road infrastructure in certain cases. However, wars also induce environmental destruction, famines, displacement, and reduce economic wealth in other circumstances (Gleditsch 1998). To determine the ultimate causes of malnutrition and conflicts defies simple explanation and requires a complementary approach based on local case studies using qualitative methods. For example, the correlation observed between malnutrition and conflict does not imply that one causes the other as they may be both caused by a similar set of socio-economic, political and environmental circumstances. The main purpose of this study was to present the importance of short-term changes in ecosystem attributes induced by climate change in the environmental security field compared to changes in seasonal means as these can be reduced by specific mitigation and adaptation strategies that have to be put in place by local, regional, national, and international institutions.

## 6 Conclusion

Our empirical study suggests that the impact of environmental change on human security is indirect and mediated by several political and economic factors, such that a spatio-temporal association between areas affected by environmental change and conflict areas is weak. In addition to resource availability and socio-economic factors, the interannual variability in ecosystem productivity also impacts human security. Our results also indicate that conflicts are more frequent in regions with more vegetation. This conflicts with a neo-Malthusian view but is consistent with a pattern largely observed for high value natural resource exploitation. It could also result from vegetation recovery after population are displaced out of conflict zones. Finally, at a local scale, the environment plays a less significant role in human security than at a regional scale, suggesting that social coping mechanisms dominate at a fine scale. With climatic conditions predicted to become more variable, there is a need to better understand interactions between environmental conditions, food and human insecurity, and socio-economic changes.

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