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Climate, migration, and the local food security context: Introducing Terra Populus

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Abstract

Studies investigating the connection between environmental factors and migration are difficult to execute because they require the integration of microdata and spatial information. In this article, we introduce the novel, publically available data extraction system Terra Populus (TerraPop), which was designed to facilitate population-environment studies. We showcase the use of TerraPop by exploring variations in the climate-migration association in Burkina Faso and Senegal based on differences in the local food security context. Food security was approximated using anthropometric indicators of child stunting and wasting derived from Demographic and Health Surveys (DHS) and linked to the TerraPop extract of climate and migration information. We find that an increase in heat waves was associated with a decrease in international migration from Burkina Faso, while excessive precipitation increased international moves from Senegal. Significant interactions reveal that the adverse effects of heat waves and droughts are strongly amplified in highly food insecure Senegalese departments.

Keywords

Climate; environment; international migration; Burkina Faso; Senegal; food security; Terra Populus; Demographic and Health Survey (DHS)

Introduction

The study of the relationship between population dynamics and environmental factors requires detailed knowledge of demographic processes and geo-spatial phenomena. Discipline specific training often results in specialized knowledge to work with either household / population data, typically the realm of Sociologists and Economists, or

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geographically explicit data, typically the realm of Geographers and Earth-Systems scientists. A shortage of interdisciplinary training and collaboration has considerably hampered the progress in population and environment research (Hunter and O'Neill 2014).

The novel Terra Populus (TerraPop) data access system (Kugler et al. 2015) was designed specifically to facilitate this type of research through the integration of census-based microdata, area-level data describing geographic units, and raster-based spatial information such as climate and land use/land cover information. Moreover, the availability of geographic unit boundary shapefiles provides researchers with the flexibility to integrate contextual information from sources outside TerraPop, such as data on region-specific food security available through Demographic and Health Surveys (DHS).

The connection between climate change and migration has spurred widespread political and public interest and exemplifies the type of human-environment interaction requiring integrated population and spatial data. In response to fears of massive climate-related migration, especially from poor developing countries to rich industrialized nations (Myers 2002; Stern 2007), an increasing amount of quantitative research on the topic has recently emerged (Hunter et al. 2015; Ward and Shively 2015; Wodon et al. 2014). Despite the burgeoning research efforts, many questions remain unanswered. For example, it is unclear whether the climate- migration association is influenced by the local food security context.

In this research brief, we provide an introduction to the novel TerraPop data extract system and illustrate how TerraPop can be used to answer research questions such as: *Do regions with low levels of food security show a stronger relationship between climate and international migration?*

Climate, migration, and the food security context

Developing countries will suffer most from the adverse effects of climate change due to a lack of capacity and technology to guard against climate impacts (Gutmann and Field 2010). Adverse climate changes such as heat waves, droughts, and floods will have the strongest impacts on rural livelihoods that depend heavily on natural resources and the agricultural sector (Boyd and Ibarraran 2009; Wodon et al. 2014). In the face of livelihood insecurity, households may modify their mobility patterns in contrasting ways.

When climate variability and change leads to agricultural failure, households may choose to send a member elsewhere to access alternative income streams through remittances (Massey et al. 1993; McLeman 2006). An increase in international migration in response to adverse climate impacts has been observed for a number of countries predominantly in Latin America (Feng and Oppenheimer 2012; Gray and Bilsborrow 2013; Nawrotzki et al. 2015b).

In contrast, among extremely poor and marginalized populations adverse climate shocks may inhibit international migration and may “trap” people in place (Black et al. 2011b). An international move is often costly to initiate, and when adverse climate conditions undermine livelihoods, income generation, and employment options, households may lack the financial resources to send a member elsewhere. Confirming this dynamic, a decline in international migration in response to adverse climatic conditions has been observed in a number of African countries (Gray and Wise 2016; Henry et al. 2004).

The relationship between climate factors and migration emerges in a unique socioeconomic and geographic context. For example, the strongest relationships have been observed in rural areas (Feng and Oppenheimer 2012; Nawrotzki et al. 2015a), with historically dry climate conditions (Nawrotzki et al. 2013), in the absence of social networks (Nawrotzki et al. 2015b), and for land-poor households (Gray and Bilsborrow 2013). In combination these findings suggest that the strongest relationships between climate and migration exist among marginalized populations. A measure of marginalization not investigated so far is the local food security context.

Climate impacts such as droughts frequently lead to food insecurity and famines (Barbier et al. 2009; Baro and Deubel 2006), especially on the African continent under conditions of high agricultural dependence and a lack of technological infrastructure (e.g., irrigation). To regain food security, households may first employ in-situ (in place) adaptation strategies such as selling surplus items or drawing on formal and informal assistance (Gray and Mueller 2012a; Haile 2005). Concomitantly or when in-situ adaptation strategies have failed, households may attempt to regain food security by reducing expensive international moves (Henry et al. 2004) and increasing their allocation of labor to food production on the family farm to meet subsistence requirements (Ward and Shively 2015).

The connection between food-security, climate, and migration has been recognized (McGregor 1994; McMichael 2014) but not empirically tested. To begin filling this gap, we investigate whether climate variability is more strongly associated with international migration in highly food insecure regions of two west-African countries: Burkina Faso and Senegal. These two countries provide a useful case for the study of climate-migration and food security due to an established history of migration, widespread poverty and food insecurity, and an observed trend of warming and a reduction in rainfall (see Appendix A: Case).

Data – Introducing TerraPop

We obtained sociodemgraphic data and detailed climate information from the novel TerraPop data access system (Kugler et al. 2015; MPC 2013). TerraPop has developed a user-friendly extract engine that is publically available, free of charge at https://data.terrapop.org. TerraPop combines census microdata from IPUMS International (IPUMS-I) (MPC 2015; Ruggles et al. 2003), with area-level data describing geographic units, and raster data from various sources (e.g., MODIS). The three types of data are blended using location-based integration, allowing population researchers to easily discover and work with geographic data that typically requires specialized software and skills (e.g., analyzing spatial data in a GIS). Even for researchers familiar with multiple data structures, data collection, cleaning, processing, and transformation can consume significant amounts of time – around 40% of the total time spent on a typical modeling project (Munson 2011). By handling these issues, TerraPop allows researchers to spend more time on the substantive analysis that constitutes the core of research activity.

Within the TerraPop system, raster data (structured as a spatial grid of cells, with each cell having a value) are transformed to area-level data by summarizing the values of cells within geographic units. Area-level data are then attached to microdata records based on variables identifying the geographic unit in which the individual resides (Figure 1).[1]

For this study we employ data at the second administrative level - provinces in Burkina Faso and departments in Senegal. The sociodemographic data were extracted for the most recent census rounds available via TerraPop, years 2006 and 2002 for Burkina Faso and Senegal, respectively. We restrict our analysis to rural households (agglomerations of less than 10,000 people), resulting in an analytical sample of n=164,884 (Burkina Faso) and n=57,052 (Senegal) households located in 45 provinces (Burkina Faso) and 31 departments (Senegal).

In addition to the sociodemographic information, the present study required detailed climate information. The climate information available via TerraPop came from the Climate Research Unit (CRU) of the University of East Anglia (Harris et al. 2014). The CRU data constitute a high-resolution (0.5 × 0.5 degrees) gridded data product of temperature (min, max) and precipitation that is available at monthly time steps for the years 1900 to 2013. The climate data and additional raster-based control variables were summarized to provinces/departments and attached to the microdata.

As a final core component for the present analysis we derived indicators of food security from the Demographic and Health Survey (DHS) phase IV for the year 2003 for Burkina Faso (DHS 2004) and the year 2005 for Senegal (DHS 2006).[2] Information of the geographic location of villages (cluster points) available in the DHS data allowed us to link location-specific information on food security to the TerraPop data extract, as done in prior research (Sullivan Robinson et al. 2014). Fig. 2 shows the location of rural cluster points within the second-level administrative units in Burkina Faso and Senegal.[3]

Measures and Methods

Outcome variable

We chose the household as unit of analysis because the decision to migrate in the developing world is mostly reached within the family unit (Stark and Bloom, 1985; Massey et al., 1993). The census question asked respondents to indicate the number of people who left the household and moved to another country in the five years leading up to the census round.

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[1]Geographic unit boundaries are the key to TerraPop's location-based integration, and the system provides several types of boundaries to serve the needs of various users. For use with microdata, geographic units are regionalized to ensure that the population of each unit is greater than 20,000 people to maintain confidentiality. TerraPop also includes both harmonized and year-specific boundaries. In the harmonized boundaries, units that have changed over time are combined to provide consistent footprints facilitating the analysis of change over time (Kugler et al. 2015). For most countries, TerraPop provides first and second administrative level boundaries.

[2]For Burkina Faso the DHS survey year (2003) falls within the 5-year window (2001-2006) prior to the census round in 2006. However, for Senegal the DHS survey was conducted in year 2005, three years after the census round in 2002. Although another full DHS survey was conducted in Senegal in 1997, this earlier wave did not include the relevant anthropometric indicators. We use the Senegal DHS for 2005 based on the common assumption that food security within a population is relatively static (Saha et al. 2009).

[3]For confidentiality purposes, DHS randomly displaces rural cluster centroids between 0-5 km and an additional random selection of 10% of the cluster points between 0-10 km, resulting in a relatively small average displacement distance of 2.45 kilometers (Burgert et al. 2013). The random displacement algorithm ensures that centroids fall within the correct first-level administrative unit (Burgert et al. 2013). Although, we aggregate points to the second-level administrative unit, the introduced uncertainty is likely minimal due to the large size of provinces/departments (most clusters are more than 5 km away from the borders). In addition, the random nature of the displacement ensures that the resulting estimates are not systematically biased.

This variable was dichotomized and coded 1 for households that had at least one migrant and 0 otherwise. In our sample, about 10% of households in Burkina Faso and 11% of households in Senegal had sent a member to an international destination, with percentages varying by province/department (Fig. 3).

Climate change

Agronomical research has shown that temperature and precipitation events above certain thresholds are more problematic for the agricultural sector than changes in average conditions (Lobell et al. 2013; Schlenker and Roberts 2009), and may therefore be more strongly associated with livelihood outcomes. We constructed a set of five climate measures using a threshold of one standard deviation, in line with prior work (Diffenbaugh et al. 2015). The climate measures capture percentage of months for which a threshold was surpassed during a relevant observation window. We use the five years prior to the census year during which migration was observed, plus one year to account for lagged effects, resulting in a six-year (71 months) observation window. A month was counted as surpassing the threshold if the relevant variable was more than one standard deviation above or below the 30-year (1961-1990) long-term average for the particular calendar month for the administrative unit.[4] Thresholds considered were heat waves (maximum temperature), cold snap (minimum temperature), drought, and excessive precipitation. We constructed an additional measure, referred to as the climate impact index, which captures the simultaneous occurrence of drought and heat wave months. Heat waves and droughts exhibit distinct spatial patterning in both countries (Fig. 4).

Food security

We use two anthropometric indices of child nutritional status available through DHS: child stunting and wasting. Physical growth of children under 5 years is an accepted indicator of the nutritional well-being of the population they represent (WFP and CDC 2005). Young children are particularly sensitive to reduced nutrient intake, which directly impacts their skeletal growth rates and overall health conditions (Black et al. 2008). To determine children's (age < 5 years) nutritional status, their weight and height was compared to a reference population of healthy children of the same sex and age (Brown et al. 2014; DHS 2008). The stunting measure was computed as the difference in the height of a child relative to the median height of a child in the reference group reflected in Z-scores (height-for-age; HAZ) (Waterlow et al. 1977; WHO 1983). Stunting indicates a chronic restriction of children's potential growth, resulting from long-term nutrition deficiencies and various health impacts (Black et al. 2008). The wasting measure compares the weight of a child to the median weight of children of the same height in the reference group reflected in Z-scores (weight-for-height; WHZ) (Waterlow et al. 1977; WHO 1983). Wasting measures acute weight loss, resulting from short-term food deficiencies and diseases (Black et al. 2008). We rescaled the stunting and wasting measures (multiplication by -1) so that higher Z-scores reflect more severe undernutrition (e.g., more stunting and wasting) for convenience of interpreting the regression coefficients. Using a geographical information system, we

[4]We use the years 1961-1990 as the standard “climate normal” period recommended by the World Meteorological Organization to be used as reference period for studies of climate change and climate variability (Arguez and Vose 2011).

assigned each geo-referenced cluster point within the DHS sample to the respective province/department ID used in the TerraPop data. In a final step, we computed the population weighted average (mean) value of stunting and wasting for each province/ department and merged the DHS data with our TerraPop data extract. Stunting and wasting result from a combination of inadequate dietary intake and other health impacts (e.g., diseases) and therefore measure food security only partially and indirectly. However, because of strong correlations of stunting and wasting with more direct measures of food security (Baig-Ansari et al. 2006; Saha et al. 2009), we refer to these measures as indicators of food security in the remainder of the text. In Senegal, stunting and wasting are generally more pronounced in eastern regions (Fig. 5). Burkina Faso shows highest stunting levels in southeastern provinces and high wasting levels in central-western regions.

Household controls

The decision to migrate internationally is influenced by a plethora of sociodemographic and contextual factors (Brown and Bean 2006) and we account for these influences through various control variables (Table 1). We include the marital status (1=married, 0=other) and the religious affiliation (1=Muslim, 0=other) of the household head to capture differences in *social capital* based on access to extended family networks (Abu et al. 2014) and religious norms, expectations and sanctions (Smidt 2003) that may influence migration behavior. To capture *human capital*, we included a measure of the age of the household head (Booysen 2006), the percentage of household members with at least primary education (Taylor and Martin 2001), the percentage of household members employed (Nawrotzki et al. 2013), and the total number of persons in the household (Abu et al. 2014). Following the UN Population Division (UNPD 2012), we constructed the child (age < 15 years) and retiree (age > 64 years) dependency ratio as the proportion of household members in the particular age group relative to the total household size. Home ownership (1=owner) was included as measure of *physical capital* because migration is frequently used as means to access capital to fund the purchase of property or the construction of a home (Taylor et al. 1996). In addition, an additive wealth index, based on nine items (Chronbach's alpha: 0.74) was used as a measure of overall household wealth (Mberu 2006; Nawrotzki et al. 2013).[5]

Province/department controls

We approximated access to migrant networks as important predictor of future migration (Fussell and Massey 2004) by computing the percentage of households with international migration experience during the prior census round (Burkina Faso: 1996; Senegal: 1988). To capture access to urban infrastructure we used a measure of the percentage of urban land, based on MODIS urban extents (Schneider et al. 2009). To account for different levels of agricultural dependence we employed a measure of the area harvested (sqm/100ha) for cotton (Burkina Faso) and groundnuts (Senegal) as the crop types of primary economic importance (CIA 2014), constructed by the Global Landscape Initiative (GLI) (Monfreda et al. 2008). Finally, to account for the historical climatic context (Nawrotzki et al. 2013) we

[5]The wealth index combined three measures of the quality of the housing unit (material of floor, wall, roof), three measures of the type and quality of services available at the residence (type of cooking fuel, toilet type, access to electricity), and three measures to capture the possession of appliances (car, refrigerator, TV).

included a measure indicating whether the temperature in a given province/department was above or below the country average during the 30-year (1961-1990) baseline period.

Estimation strategy

We employed multilevel logit models to estimate the odds of a move to an international destination from a household i located within a province/department j (Equation 1).

$$\text{logit}(y_{ij}) = b_0 + b_1(FS_j) + b_2(\text{CLIM}_j) + b_3(FS_j * \text{CLIM}_j) + \sum_{n=4}^{k} b_n(x_z) + u_j$$

Parameter b_0 constitutes the conventional intercept term. Parameters b_1 and b_2 reflect the effect of food security (FS_j) and climate ($CLIM_j$) on the migration response. Due to high correlation among variables, only one climate and one food security measure at a time could be included in the model. Most important for the present study, the parameter b_3 reflects the effect of the interaction between a given food security and climate measure ($FS_j * CLIM_j$). The summation term reflects the effects ($b_4, b_5, \ldots, b_k$) of various control variables ($x_{4z}, x_{5z}, \ldots, x_{kz}$), operating at the household and the province/department level, as indicated by the generic subscript z. Finally, the parameter u_j constitutes the province/department random effects term, which accounts for the clustering of households within geographic regions.[6]

Results and Discussion

Controlling for various socioeconomic and contextual factors (for details see Appendix B: Base model), we observe no significant associations between the local food security context and migration probabilities (Table 2). For example, households residing in areas characterized by high versus low levels of stunting are similarly likely to send a member to an international destination.

We also observe few significant climate effects in line with assumptions that influence of climate on migration is largely indirect in nature and therefore difficult to detect (Black et al. 2011a). Similar to a study using data from the African Migration and Remittances Surveys (Gray and Wise 2016), we observe that an increase in heat wave occurrence is associated with a decrease in international outmigration from Burkina Faso. When heat waves adversely impact agricultural production and livelihoods, the resource base of households may degrade, making it difficult to finance an expensive international move (Henry et al. 2004). In contrast, for Senegal we observe that an increase in precipitation is associated with an increase in international outmigration. In the arid climate of Senegal, above average precipitation is likely beneficial for the agriculture sector. An increase in agriculture-based income may enable households to finance an international move. Together, these findings suggest that international migration from Burkina Faso and Senegal increases under

[6]The models were fit using the package *lme4* (Bates 2010; Bates et al. 2014) within the R statistical environment (RCoreTeam 2015). For improved speed and more robust convergence properties, we adjusted the model settings (integer scalar setting nAGQ=0) so that the random and fixed effects were optimized (optimizer=”bobyqa”) in the penalized iteratively reweighted least squares step (Bates et al. 2014).

beneficial climatic conditions and decreases when conditions become less favorable (Nawrotzki and Bakhtsiyarava 2016). A similar directionality has been observed for rural South Africa where improved access to natural resources enabled outmigration (Hunter et al. 2014).

However, rather than focusing on main effects, the primary goal of this study was to investigate whether climate effects on international migration differ by the local food-security context. To test for conditional effects, we interacted the anthropometric measures of stunting and wasting with the climate measures (Table 3).

Significant interactions predominantly emerged for Senegal for climate and the food security indicators of child wasting. This suggests that the climate-migration relationship differs by the acute (short-term) rather than the chronic (long-term) nutritional status of the population. The interactions are significant for heat waves, droughts and the climate impact index and show generally a negative directionality.

We observe a similar shape of the interactions for heat waves, droughts, and the climate impact index (Fig. 6). In general, heat wave and drought occurrence is strongly associated with a decrease in migration probability in marginalized Senegalese departments characterized by high levels of child wasting (90^{th} percentile, solid black line). However, the depressing effect of adverse climatic conditions on the probability to migrate weakens considerably in departments with average food security conditions (50^{th} percentile, dashed line), and becomes even slightly positive in areas with very good food security conditions (10^{th} percentile, dotted line). In short, the interactions suggest that adverse climate impacts are associated with a decline in international migration predominantly in highly food insecure regions. This finding is supported by earlier work, demonstrating that poverty may constrain migration in response to adverse environmental conditions (Gray and Mueller 2012b).

Conclusion

In this article we have introduced the novel TerraPop data access system and showcased its use with an example exploring the importance of the local food-security context for the climate-migration association. For this study we extracted microdata for Burkina Faso and Senegal linked to high-resolution climate information. In addition, TerraPop provides geographic unit boundary shapefiles that allow users to easily add external information, such as data from the Demographic and Health Survey (DHS), describing the health or nutritional status of the local population.

We find that an increase in heat waves was associated with a decrease in international outmigration from Burkina Faso, while an increase in precipitation increased in international outmigration from Senegal (Nawrotzki and Bakhtsiyarava 2016). These results suggest that international migration may increase under favorable climatic conditions but decrease under climate stress, possibly related to changes in resources available to finance an expensive international move (Henry et al. 2004). Moreover, interaction models revealed important conditional effects for Senegal: Heat waves and droughts were associated with a decrease in the probability of international migration predominantly in regions characterized by high levels of acute undernutrition (wasting).

However, a number of caveats should be considered. First, our anthropometric indicators of stunting and wasting measure food security only indirectly. Although stunting and wasting are strongly correlated with more direct measures of food security (Baig-Ansari et al. 2006; Saha et al. 2009), future research may validate our findings using dietary schedules and child feeding indices. Second, our food security measures operate at the regional level. Stronger interactions between climate and food security can be expected when household-specific indicators of food security are used. Third, we deliberately chose to investigate international migration based on data availability and the political and policy relevance of this migration stream. Exploring the interaction between climate variability and food security on domestic moves remains a topic for future research.

Our findings have important policy implications. Migration can be viewed as an important strategy of income diversification to adapt to climate change (Black et al. 2011b). Our results show that households in food insecure regions of Senegal are particularly vulnerable to become “trapped” in place and climate change adaptation programs should be targeted towards these communities. For example, programs to fund the installation of small-scale irrigation systems (Burney et al. 2013), distribution of heat and drought-resistant crop varieties, and improve access to seasonal weather forecasting tools (Cooper et al. 2008) may serve the dual benefit of reducing food insecurity and may improve household's resource base, enabling them to employ migration as an important strategy of livelihood diversification (Ward and Shively 2015) and climate adaptation (Black et al. 2011b). The Matam department of Senegal displays the highest levels of acute undernutrition (see dark blue center polygon of Fig. 5d) and may be a good candidate for the implementation of livelihood based climate adaptation programs.

The present study provides only one example of the type of population-environment research that can be performed with TerraPop data. Many other topics can be addressed, spanning the whole spectrum of household/individual population responses including fertility, mortality, family composition, socio-economic status, and gender differences, to mention just a few. Similarly, at the community-level a wealth of variables is available, capturing ecosystem services, land cover/land use, road networks, species distribution, vegetation indices and many other aspects of the natural and built environment. In addition, harmonized shapefiles enable longitudinal studies at the community level and allow the linking of spatial data sets that are not part of TerraPop. Because TerraPop is available to the public free-of-charge, it has the potential to become a primary source of population-environment data for demographers and other researchers, and will facilitate the growth of knowledge in this important field of study.

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Appendix A: Case

Burkina Faso and Senegal are among the poorest countries of the world, ranking 181 (Burkina Faso), and 163 (Senegal) out of 187 on the human development index (UNDP 2014). In rural areas, households depend heavily on agricultural production for sustenance and income generation (Davis et al. 2007). In Burkina Faso about 90% and in Senegal about 78% of the labor force is employed in the agricultural sector (CIA 2014). The low development level and associated constraints in financial resources hinder the use of technology to guard against adverse climatic impacts (Gutmann and Field 2010). For example, only 0.2% and 1.3% of cropland is irrigated in Burkina Faso and Senegal, respectively (CIA 2014). The confluence of high agricultural dependence and low technological development renders households vulnerable to climate impacts.

Burkina Faso and Senegal are located in the semi-arid Sahelian region of Western Africa. Both countries are characterized by a distinct North-South gradient of temperature and precipitation (Grouzis et al. 1998; Hampshire and Randall 1999). While the northern Sahelian areas are generally hot and arid, the southern regions are relatively cooler and more humid, making farm production more lucrative (Henry et al. 2003; Henry et al. 2004). Since the 1960s, West Africa has experienced a long-term reduction in rainfall and a warming in temperatures (Funk et al. 2012; Nicholson 2001). These historical trends are projected to continue in future decades as a result of global climate change (Niang et al. 2014), making this region an important geographical location for the study of climate impacts on rural livelihoods.

Burkina Faso and Senegal have a rich history of diverse migration patterns within and across national boundaries. International outmigration is generally employment-related and most migration is directed to neighboring countries on the African continent. For Burkina Faso, the primary destinations include Nigeria, Ghana, and Ivory Coast (Arthur 1991), while Senegalese labor migrants often seek employment in Mauritania and Gabon but also in Italy and Spain (Plaza and Ratha 2011; Sinatti 2011). Due to employment in the manual construction and agricultural sectors, these labor migrant streams are characterized by a distinct demographic profile, largely comprised of young males (Henry et al. 2003; Plaza and Ratha 2011; Sinatti 2014). Labor migration is often temporary and circular in nature and migrants usually return to their village of origin after a saving target has been reached (Sinatti 2009).

Appendix B: Base model

Because international migration is a process influenced by various sociodemographic determinants (Brown and Bean 2006), our multivariate base model accounts for these factors (Table 4).

Table 4

Multilevel base model predicting the odds of international migration from rural households in Burkina Faso and Senegal

	Burkina Faso		Senegal	
	b	sig.	b	sig.
Variables				
Intercept	0.02	***	0.01	***
Head married	0.88	***	1.10	
Muslim	0.76	***	0.96	
Age of head [a]	0.96	***	1.05	***
Primary education [a]	0.94	***	0.97	*
Child dep. ratio [a]	1.03	***	0.97	***
Retiree dep. ratio [a]	1.02	*	1.08	***
Employed in HH [a]	1.02	***	0.93	***
Persons in HH [a]	1.09	***	1.54	***
Home owner	2.07	***	1.64	***
Wealth index	1.03	***	1.39	***
Network density [a]	2.01	***	2.41	**
Urban land	0.96		0.71	*
Cotton/groundnuts	0.93		0.97	**
Baseline climate hot	1.29		1.32	
Model statistics				
Random intercept	1.469		1.600	
BIC	98406		33802	
N (households)	164884		57052	
N (provinces/departments)	45		31	

Note: Coefficients reported in odds ratios;

[a]Coefficients refer to an incremental change of 10 units; HH = household; Low values on the Variance Inflation Factor (VIF < 3.1) suggested that multi-collinearity did not bias the estimates;

* $p<0.05$;

** $p<0.01$;

*** $p<0.001$

The factors influencing international migration from Burkina Faso and Senegal show considerable similarity. In line with prior research from Ghana, South Africa, and Mexico, we find that the typical migrant household is relatively large (Abu et al. 2014), is relatively wealthy in terms of home ownership and physical assets (Hunter et al. 2014), and has good access to established migrant networks (Fussell and Massey 2004). In addition, an increase in the proportion of retirees was associated with higher odds of international migration, probably related to the added income from old-age pensions that may help finance an international move as demonstrated for rural South Africa (Schatz et al. 2012). Marital status and religious affiliation influence the odds of international migration from Burkina Faso but not from Senegal, with a lower probability of international migration from Muslim households in which the head was married, comparable to findings from rural Ethiopia and Mexico (Ezra and Kiros 2001; Riosmena 2009). In contrast, international migrants from Senegal are more likely to originate from regions with limited access to urban infrastructure and limited production of the primary crops. Finally, the directionality of the effect of age of the household head, child dependency ratio, and proportion of household members employed varied between countries as a result of the country-specific socio-political context.

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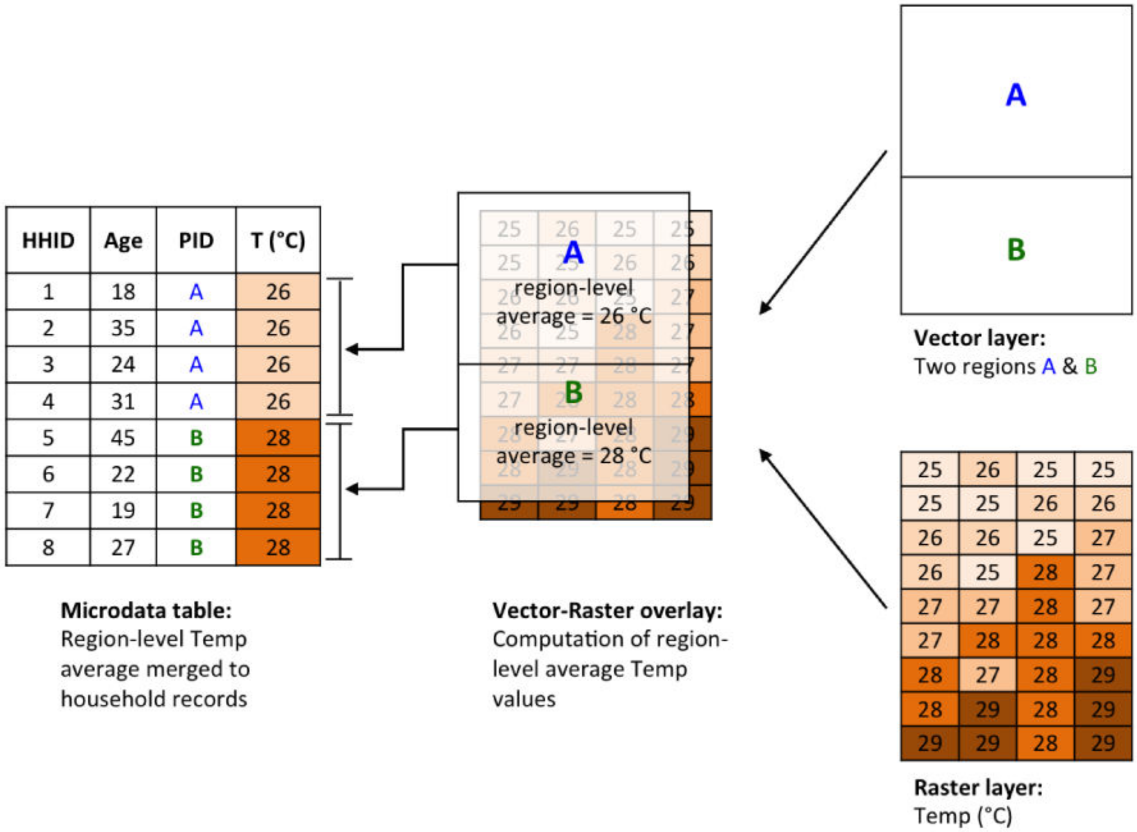

Fig. 1. Attaching raster information to microdata through vector-raster overlay performed by TerraPop

Notes: HHID = unique Household ID; PID = province ID; vector layers of regions at the 2nd administrative level are regionalized and harmonized prior to the vector-raster overlay operation (for details see Kugler et al., 2015); microdata records are available via IPUMS International (MPC, 2015; Ruggles et al. 2003) and contain province ID information that allow linking area-level aggregates to person and household records.

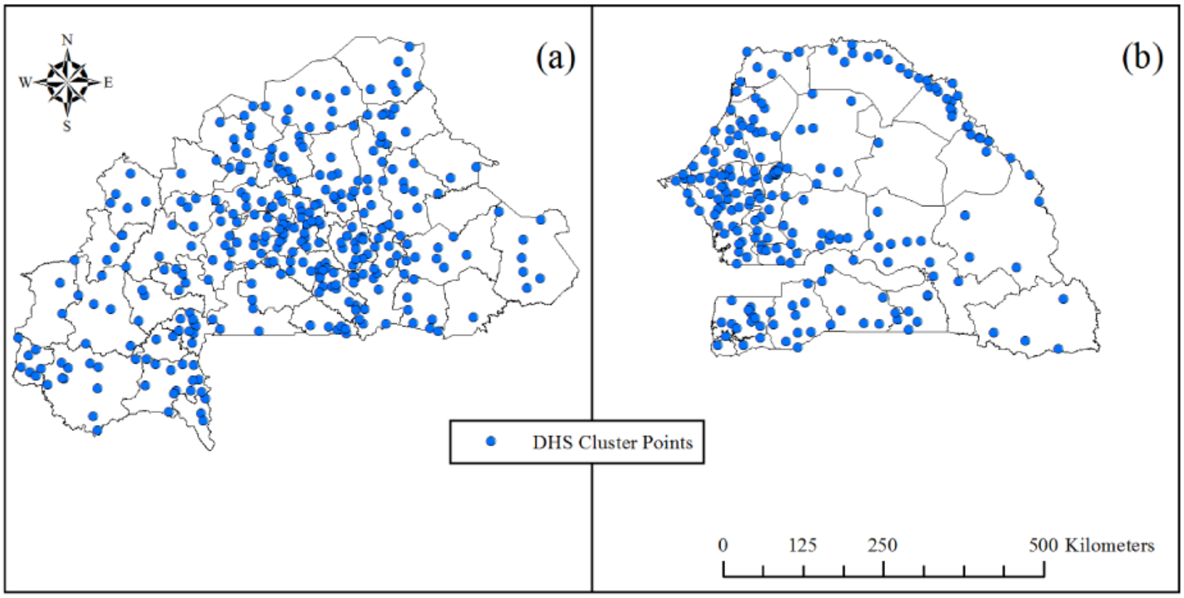

Fig. 2. Location of rural DHS cluster points within second-level administrative units for Burkina Faso (a) and Senegal (b)

Notes: For the present analysis we aggregated DHS data from n=308 (Burkina Faso) and n=208 (Senegal) rural cluster points (villages) to n=45 provinces (Burkina Faso) and n=31 departments (Senegal).

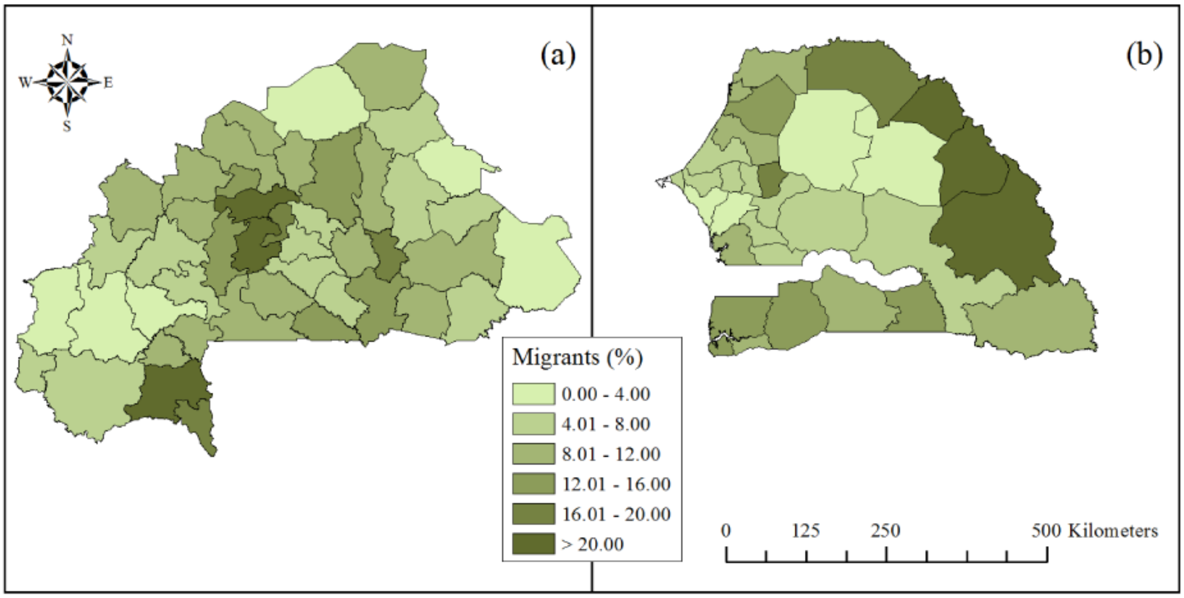

Fig. 3. Spatial distribution of migration prevalence across second-level administrative units in Burkina Faso (a) and Senegal (b)

Note: Migrant prevalence is reflected as the percentage of households who have sent a migrant to an international destination within the five years leading up to the census.

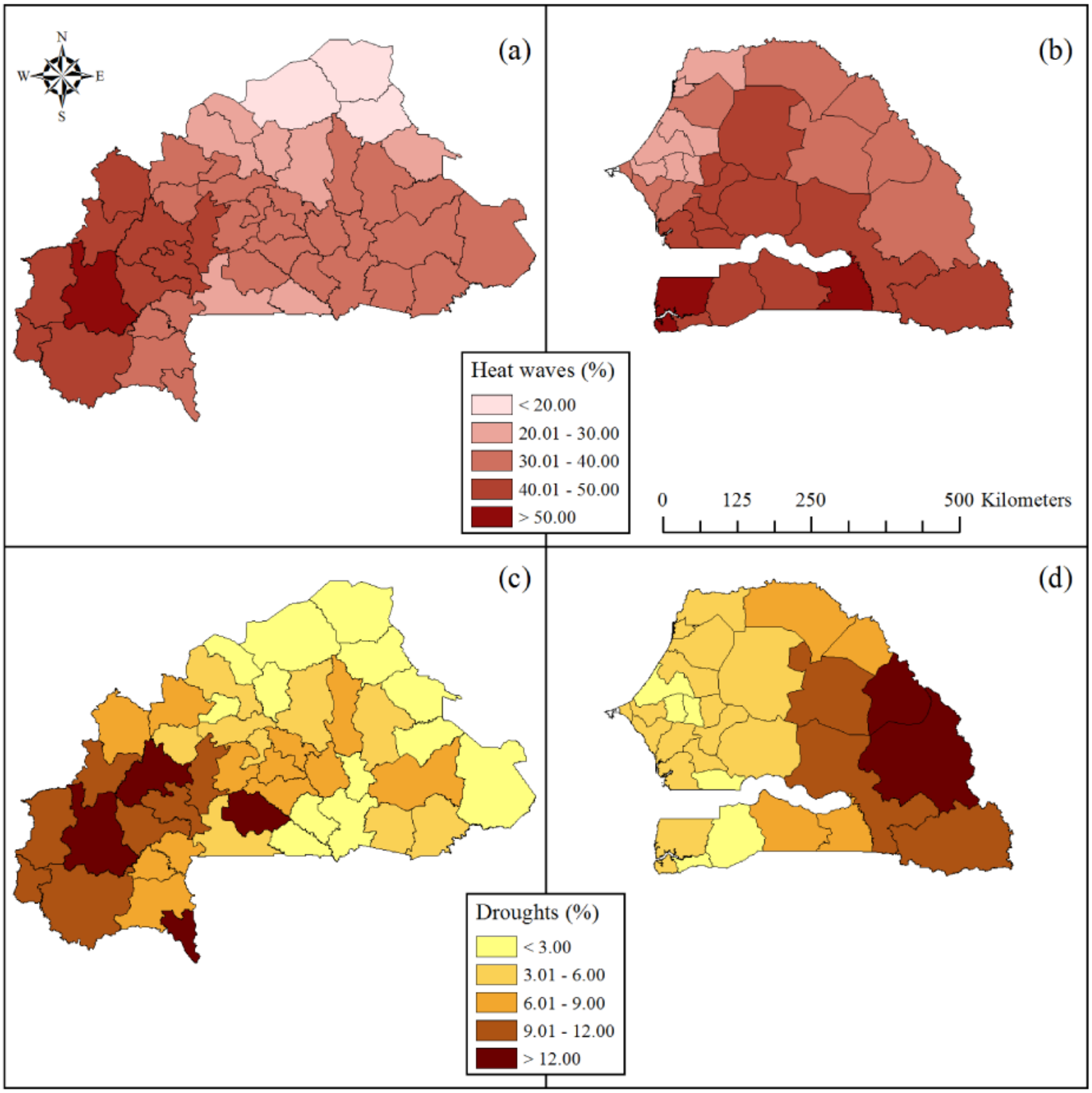

Fig. 4. Spatial distribution of heat wave (top panels) and drought (bottom panels) occurrence during the 6-year period prior to the census for Burkina Faso (a, c) and Senegal (b, d)

Note: Percentage of heat waves and droughts refers to the number of months during the 6-year (71 months) period, leading up to the census, during which temperature and precipitation were above/below a 1 SD threshold relative to the 30-year (1961-1990) long-term average.

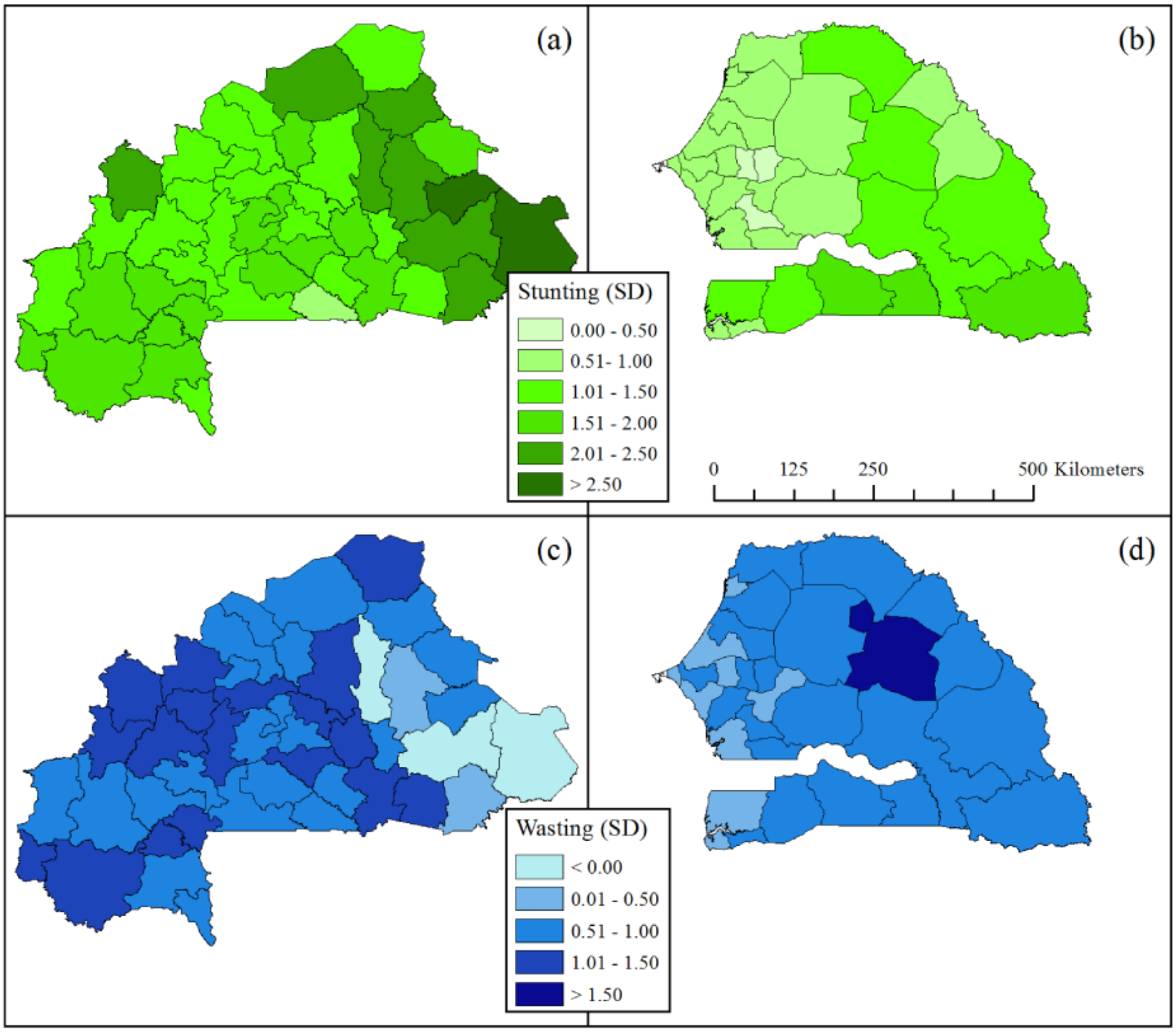

Fig. 5. Spatial distribution of DHS-based anthropometric indicators of child stunting (top panels) and wasting (bottom panels) for Burkina Faso (a, c) and Senegal (b, d)

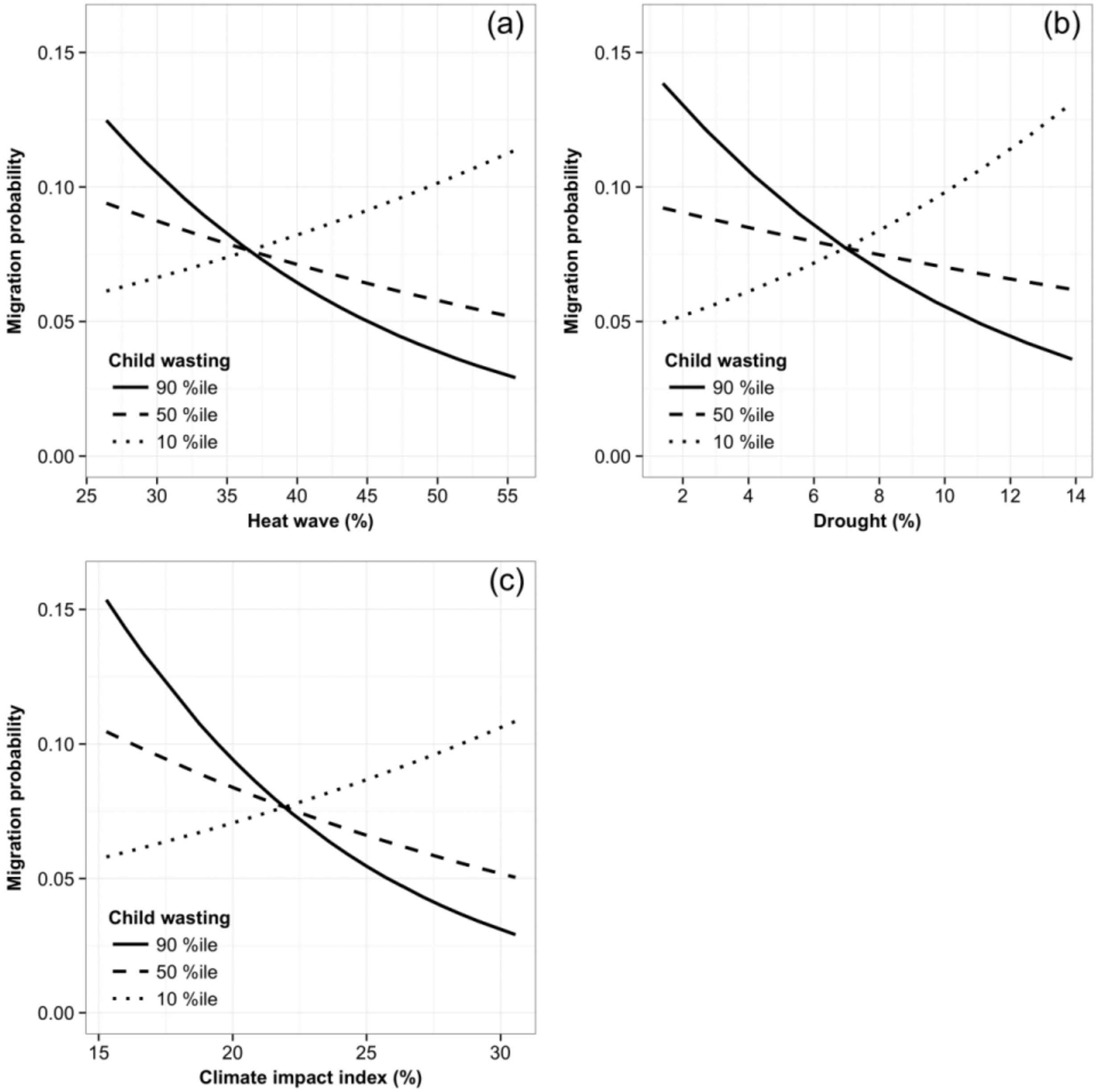

Fig. 6. Graphical representation of interaction between child wasting and heat wave (a), drought (b), and climate impact index (c) in predicting international migration from Senegal

Notes: Graphs reflect predicted probabilities, using mean values on all control variables and only varying the measures involved in the interaction.

Table 1

Descriptive statistics of variables employed in the analysis of the relationship between climate, migration, and the local food security context in Burkina Faso and Senegal

	Unit	Min	Max	SD	Sample mean	
					BF	SN
Outcome variable						
Migrant HH	1|0	0	1	0.30	0.10	0.11
Household controls						
Head married	1|0	0	1	0.26	0.91	0.99
Muslim	1|0	0	1	0.46	0.60	0.96
Age of head	years	15	98	15.76	42.41	49.56
Primary education	%	0	100	13.55	4.01	5.98
Child dep. ratio	%	0	90	21.18	41.55	43.56
Retiree dep. ratio	%	0	100	12.55	4.41	4.60
Employed in HH	%	0	100	26.73	54.16	35.31
Persons in HH	count	1	99	5.06	6.35	10.32
Home owner	1|0	0	1	0.27	0.93	0.91
Wealth index	count	0	9	1.60	0.86	2.36
Province/department controls						
Network density	%	0.37	27.95	6.89	12.05	4.38
Urban land	%	0	4.68	0.67	0.16	0.48
Cotton/groundnuts	sqm/100ha	0	42.71	6.40	0.72	6.70
Baseline climate hot	1|0	0	1	0.50	0.49	0.55
Food security measures						
Child stunting	z-score	0.17	3.2	0.55	1.62	0.89
Child wasting	z-score	-0.34	1.88	0.38	0.88	0.63
Climate measures						
Heat wave	%	19.44	55.56	8.39	34.20	39.11
Cold snap	%	0	18.06	3.60	2.07	3.32
Drought	%	0	13.89	3.50	6.20	5.60
Excess precip	%	5.56	16.67	2.28	10.19	9.36

	Unit	Min	Max	SD	Sample mean	
					BF	SN
Climate impact index	%	9.72	34.03	5.14	20.20	22.36
Sample size						
Households	count				164884	57052
Provinces/departments	count				45	31

Note: BF=Burkina Faso, SN=Senegal; Values for Min, Max, and SD refer to the complete sample.

Table 2

Impact of the local food security context and climate on the odds of international migration from rural households in Burkina Faso and Senegal

	Burkina Faso		Senegal	
	b	**sig.**	**b**	**sig.**
Food security measures				
Child stunting	0.80		0.67	
Child wasting	1.20		0.84	
Climate measures				
Heat wave	0.79	*	0.96	
Cold snap	0.96		0.97	
Drought	1.01		0.70	
Excess precip	1.02		3.37	**
Climate impact index	0.77		0.85	

Notes: Coefficients reported in odds ratios; Coefficients of climate measures refer to an incremental change of 10%; Each estimate is derived from a separate model using all control variables (Appendix Table 4) and adding one food security or one climate measure at a time. Separate models were necessary due to high correlation among the climate and food security measures. A jack-knife type procedure was performed, removing one province/department at a time from the sample and re-estimating the models (Nawrotzki 2012; Ruiter and De Graaf 2006). This test demonstrated that the results were highly robust.

* $p<0.05$;

** $p<0.01$;

*** $p<0.001$

Table 3

Interaction between climate and food security in predicting the odds of international migration from rural households in Burkina Faso and Senegal

	Burkina Faso						Senegal					
	Clim		FS		Clim × FS		Clim		FS		Clim × FS	
	b	sig.	b	sig.	b	sig.	b	sig.	b	sig.	b	sig.
Child stunting x climate												
Heat wave	0.80	*	0.87		1.24		0.98		0.77		0.81	
Cold snap	1.00		0.80		1.10		0.93		0.66		0.75	
Drought	1.12		0.93		2.30	*	0.82		0.74		0.34	
Excess precip	1.14		0.78		1.95		3.25	*	0.89		0.39	
Climate impact index	0.80		0.87		1.55		0.87		0.94		0.43	
Child wasting x climate												
Heat wave	0.80	*	1.10		1.50		0.83		0.65		0.25	**
Cold snap	1.01		1.14		0.52		1.03		0.87		8.40	
Drought	1.03		1.12		0.34		0.77		1.86		0.03	**
Excess precip	0.92		1.21		4.77		2.34		0.95		0.12	
Climate impact index	0.78		1.16		1.29		0.64		0.85		0.05	***

Notes: Coefficients reported in odds ratios; Coefficients of climate measures refer to an incremental change of 10%; Clim = climate effects, FS = food security, Clim × FS = interaction between climate and food security; each row represents a fully adjusted multi-level model (Appendix Table 4) of which only the coefficients involved in the interaction are shown; variables were centered;

* p<0.05;

** p<0.01;

*** p<0.001