Climate change, migration and health: exploring potential scenarios of population vulnerability in Brazil[1]

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Abstract

The main purpose of this paper is to discuss critical linkages between climate change, migration and health, with a particular focus on Brazil. One of the potential impacts of climate change is to induce population displacements, which may in some cases aggravate situations of vulnerability. It is likely, especially in tropical and developing countries, that future population migration induced by climate change may increase population vulnerability given the potential redistribution of endemic infectious diseases. This paper provides a discussion on linkages between climate change, migration and health and analyzes an in-depth case study on Brazil's Northeast Region between 2025 and 2050, in which projected climate changes are analyzed in terms of their potential impacts on population migration and increased vulnerability, particularly in terms of population health. Finally, the paper discusses how the effects of climate change on future scenarios of increased vulnerability of some population groups can be factored-in to Brazilian public policy and planning, helping to promote prompt and strong action in terms of creation or adaptation of institutional settings at different scales.

Introduction

The main purpose of this paper is to discuss critical linkages between climate change, migration and health, with a particular focus on Brazil. One of the potential impacts of predicted climate change is to induce population displacements, which may in some cases aggravate situations of vulnerability. It is likely, especially in tropical and developing countries, that future population migration induced by climate change may increase population vulnerability given the potential redistribution of endemic infectious diseases

We describe a case study on the Brazilian Northeast which shows potential scenarios of migration and health vulnerability due to the predicted climate changes. The reason for choosing this study area is the fact of its being the second most populated (28% of the

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country's population) and the poorest region, with an extensive semi-arid area which will be severely impacted by growing temperatures and reduced rainfall.

The case study in Brazilian Northeast also allows us to better understand how population redistribution through migration may impact population health and thus redefine population vulnerability in future scenarios of climate changes. For example, droughts in the Brazil's Northeast have historically induced rural-urban migration and as a consequence causing epidemic episodes of visceral leishmaniasis in the state capitals; and malaria has been "imported" from the Brazilian Amazon to the Northeast as a consequence of population migration, following a drought year. Great migration processes – particularly to urban areas – also represent pressure over the infrastructure and health systems, especially considering the historically large gap between population demand and supply of infrastructure and health services by the public sector in South America.

The regional persistence of human health problems sensitive to climate variability makes the Brazilian northeastern region structurally vulnerable to the projected impacts of a changing climate. Although the human population of the region is partially "adapted" to the droughts in a semi-arid region, climate scenarios project a progressive worsening of the arid condition, which can make the semi-arid, which currently has about 21 million inhabitants, not appropriate for human settlements, due to the extreme climate. In view of this perspective the northeastern region became a priority for the assessment of the impacts of climate change on the economy, society, health and the health care system.

In this paper, we focus on economic factors impacted by climate change which can trigger migration and consequently impact population health and vulnerability. In this regard we consider not only the sanitary implications of population displacements such as the movement of an endemic focus from the origin area of migrants to their destinations, but also the capacity to control and to absorb the health care demand in the destination. We do not address here the question of health problems caused by climate change as push factors for migration. As a matter of fact, the role of health problems either aggravated by climate change or not as push-factors for migration is, in general, not well established. Economic factors and environmental degradation have historically played a much more important role as triggers of migration in the Brazilian Northeast for example, since these are linked to subsistence strategies.

While in our case study we assume that those at higher risk of migration are those facing income deprivation, this may not be always the case (see, e.g , Martine and Guzmán, 1993). The precise definition of vulnerable populations must consider the identification of all adaptation mechanisms available to a given population, irrespective of their socioeconomic status. The possibility of adopting concurrent adaptation alternatives may be the key mechanism defining migration propensities.

The next section provides a brief literature review on linkages between climate change, migration and health in South America, and is followed by a description of the study area. Then we describe the methodological approach to investigate the linkages between climate changes, migration and health in the Brazilian Northeast until 2050. The last two sections present the results, and the paper conclusions and its policy implications.

Climate Change, Migration and Health

There are scanty evidences in the empirical literature on the impacts of climate change on population redistribution through migration and the related impacts on population health. Regarding the impacts of climate change on migration, some authors have proposed less comprehensive models to investigate the linkages between climate change and migration, usually focusing on specific impacts of climate change (see examples in Döös, 1997; McLeman and Smit, 2006; and Perch-Nielsen et al. 2008)[4]. This is the case of studies which explore how droughts induced by climate changes affect some specific determinants of population movements in less developed countries (e.g., Findley, 1994; Meze-Hausken, 2000; Ezra, 2003; Henry et al. 2004; Kniveton et al. 2008). As examples, Henry et al (2004) findings for Burkina Fasso indicate that population mobility (rural-rural) from drier regions tend to be higher than mobility from wetter regions, and that short-term rainfall deficits tend to increase this trend, particularly in term of long-term migration. Based on empirical evidences from case studies, Kniveton et al (2008) suggest that while droughts can increase the stock of short-term rural-rural-migrants, not necessarily those with more in risk of migration are the poorest, since they can have alternative adaptation options depending on their socioeconomic status.

Perch-Nielsen et al (2008) propose a conceptual model in which sea level rise and floods are major determinants of migration (see also McGranahan et al. 2007 for a study on the impacts on sea level rise on migration from urban areas). The authors conclude that migration as an adaptation mechanism cannot be considered separately, but as a potential response along with several others at multiple spatial scales (households, communities etc). In a similar conclusion, Mcleman and Smit (2006) propose a conceptual model which investigates population migration as a possible adaptive response to risks associated with climate change. These two studies agree with some theoretical perspectives on migration which assumes migration as a concurrent adaptation mechanism in periods of economic depression (Davis, 1963; Bilsborrow, 1987; see also a brief literature review on this subject in Barbieri et al., 2009).

Understanding the determinants of migration and how they may be affected by future climate scenarios is a key requirement for better planning and policies aiming to alleviate the production or reproduction of situations of poverty, particularly that of migrant populations in situations of high socioeconomic vulnerability. In this sense, it is important to define in which degree migration may be a mechanism engendering further vulnerability or else a mechanism of adaptation. The *IPCC Third Assessment Report* (IPCC, 2001) defines vulnerability to climate change as "*the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and*

[4] Adamo (2008) reviews estimates of potential population displacements due to climate change impacts (particularly sea level rise) focusing on less comprehensive methods and found that several estimates usually reflect populations at risk as a surrogate for population displacements. As a result, these studies suggest a great variation in estimates, depending on methods and data used.

extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation and to which a system is exposed, its sensitivity, and its adaptive capacity".

While assuming the diversity of definitions and conceptualizations of the term "vulnerability" across disciplines, and that there is not necessarily a correct definition (Fussel, 2007), we use this concept to qualify a population degree of exposure and "resilience" to the adverse effects of climate change on their livelihoods –particularly the impacts on the generation of income and employment. This vulnerability is contingent on a diversity of factors, especially socioeconomic, political and institutional, which makes a given population susceptible to an external impact such as increasing temperatures and periods of droughts. The intensity of vulnerability in a population will depend on the adaptive capacity and the adaptation mechanisms available, as discussed above.

In particular, migrants to urban areas in developing countries may be one of the potentially most vulnerable populations in future scenarios of climate change. IIED (2007) suggests that in a context of increasing urbanization driven by migration in most of the developing world, the scale of risk to climate change will be affected by infrastructure and housing quality, by the population ability to cope with changes (proxy of factors such as education, culture, solidarity) and by the quality of institutional responses (e.g., aid and medical care, urban planning).

One of the most dramatic consequences of the relationship between climate change and migration may be on population health. The 2007 IPCC Report (IPCC, 2007) stressed the possibility of global climate change in the coming decades to change the health profile currently observed in different populations, particularly the geographical expansion or intensification of transmission of infectious diseases – especially the vector –borne and water-borne infections – and undernourishment in developing countries and regions.

The social and epidemiological implications of human migration, either at the regional or international level, are well known to public health. "Health Vulnerability" is determined by an aggregate of factors, besides the epidemiological profile of the populations: socio-economic characteristics such as income, education, habitation, sanitation, institutional capacity, public services, such as the increased demand on health care etc. It is also influenced by demographic aspects such as population density, age structure of social groups etc. Other important determinants of vulnerability are geographical in nature such as settlement in drought-prone areas (drylands); flood-prone low lying areas etc. On the other hand, there are several examples of migrations influencing the health profile of people, both of the migrants and of those living in the destination areas. There are reports for Brazil and for other parts of the world (Marques, 1987; Prothero, 1994; Barnett and Walker, 2009). Migration, especially if forced and in large scale affects negatively the well-being of the migrants and often disrupts the patterns of land use, especially in urban areas, facilitating the occupation of risk areas; disrupts local weak economies and overload services in general, creating social unrest. Therefore it contributes significantly to an increased social and health vulnerability

In this regard, the displacement of human population groups can rearrange spatially the foci of endemic infectious diseases, a phenomenon already observed in several parts of Brazil as well as in other countries; the diseases involved were cholera, malaria, leishmaniases, schistosomiases and others. Another important consequence of human migration is the displacement of a burden of chronic diseases to the areas of destination of the migrants, especially urban areas, resulting in an increased demand for the health care systems, especially the public system.

Among the research publications concerned with climate change and social vulnerability in drylands**,** the work by Ribot et al (1996) discusses the fundamental issues and examples of strategies to face the climate change in semi-arid regions; in the Brazilian case it emphasizes the geographical, political, economic and social conditions of the marginalized population. For these authors, the main problem in semi-arid regions is not the harshness of the climate, but the vulnerability of the human population to these processes. Vulnerability is the product of an association of economic, political and social factors (Demo, 1989; Rodrigues et al, 1982) and is a function of a social and economic status, gender, ethnicity, age and other factors (Ribot et al, 1996). In a specific reference to food security, Downing (1992) described vulnerability as an aggregate measure for a given population or region, related to the underlying factors that influence the exposure to the lack of food and predisposes to its consequences.

Perhaps one of the most vulnerable regions to climate change in Latin America is the Brazilian Northeast, a mostly semi-arid area (known as the *caatinga* or dryland ecosystem), with poor soils susceptible to salinization, discontinuous and limited land cover and irregular rain rimes, with low precipitation (Ribot et al, 1996). Projections by CPTEC/INPE suggest changes in temperature and precipitation patterns which will generate an increasing process of “aridization” in the region, with important impacts on the livelihoods of the poorest (particularly those making their living in the agriculture sector). These scenarios will probably increase situations of socioeconomic vulnerability given the persistence of its present status as the poorest region in the country, and the fragility of agricultural systems to climate variations, as well as enhance the desertification process.

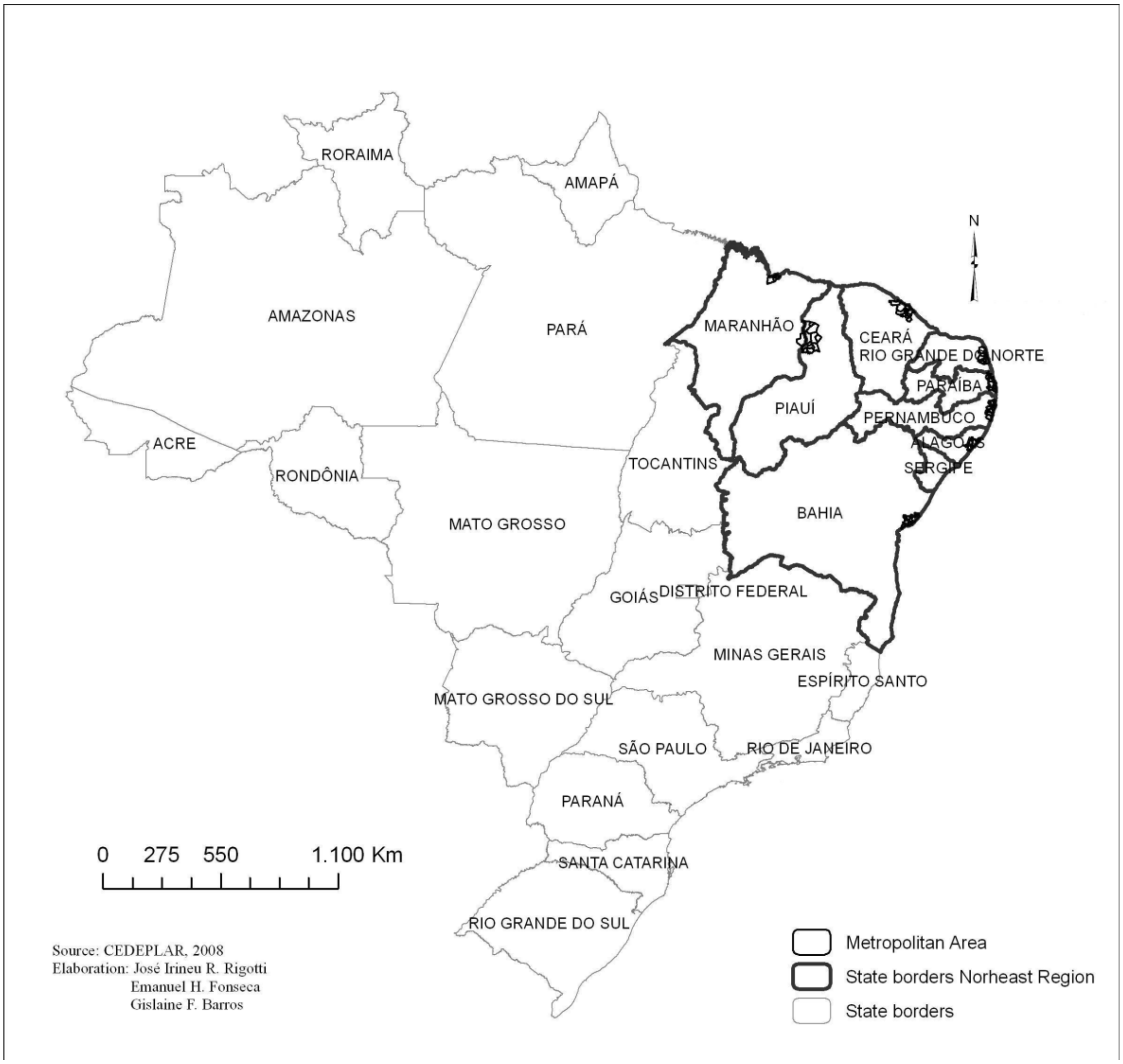
Brazilian Northeast has been historically characterized by the occurrence of periodic droughts associated with annual climate variability (Wang et al., 2004). The agriculture in the semi-arid is mostly based on small subsistence producers, and some studies have shown a loss of until 80% of agricultural production in periods of long droughts (Kahn & Campos, 1992). Historically, these periods of drought have motivated peaks of emigration from the Northeast region, particularly to richer areas in the southeast Brazil. Franke et al (2002) show, for example, that the El Niño oscillations in the beginning of the 1980s and 1990s induced migration from rural areas to São Luís and Teresina (capitals of the states of Maranhão and Piauí, respectively). Confalonieri (2003) links El Niño oscillations in 1982-1983 to migration peaks from the state of Maranhão to the state of Pará (in the Brazilian Amazon) as a cause of the abrupt increase in imported malaria to Maranhão. It is not clear however from these studies if most of these migrants are in fact the most vulnerable among the poorest, or those with some resources (social or financial capital or both) to escape risks and reduce their vulnerability.

Study Area

Given the discussion in the preceding section about the vulnerability of the Brazilian Northeast to predicted climate changes, we provide an in-depth case study on potential scenarios for this area between 2025 and 2050. Projected climate changes are analyzed in terms of their potential impacts on population migration and increased vulnerability, particularly in terms of population health.

Among the five Brazilian great regions (South, Southeast, Center-West, North and Northeast), the Northeast is the second most populated after the Southeast (where the two Brazilian major metropolitan areas, São Paulo and Rio de Janeiro, are located), with about 49 million individuals in 2000, or 28% of the country's population. The Northeast is within an extensive semi-arid area and a large population share working in the primary sector – mostly agriculture and cattle ranching. Map 1 shows the study area, with its states and metropolitan areas.

Figure 1 – State Borders and Metropolitan Areas: Northeast Region in Brazil



The impacts of climate change on urban areas may also have an important repercussion in the Brazilian Northeast, considering that it is a highly urbanized area. The urbanization rate in the region jumped from 46% in 1960 to 71% in 2000 and 75% in 2005 (IBGE). In addition, it has been observed in recent years an increasing concentration of the population in the major cities of the region. This phenomenon has also contributed to increase economic inequality and poverty concentration in major urban areas. The Northeast is characterized by high income inequality compared to other regions (Theil-L of 0.78 compared to 0.60 in the South[5]) and concentration of poor families throughout the region (over 40% of families considered to be poor); the UN Human Development Index for the region is 0.57 compared to 0.78 for the South. Furthermore, urban areas in the Northeast are characterized by poor infrastructure: sewage and treated water covers less than 50% of the population, the region has the lowest ratio of doctor per 100.000 inhabitants and the worst educational performance indicators in the country. *Ceteris paribus*, or given small improvements in mechanisms which can assure a greater adaptive capacity (e.g., investment in human capital and in infrastructure), these characteristics of urban areas in the Northeast can imply an increasing scenario of population vulnerability given the potential increases in temperature over the next decades

Historically, poor socioeconomic indicators associated with periods of drought and demographic pressures have historically motivated peaks of out-migration – with these migrants being known as *retirantes* - from the Northeast region to richer areas in southeast Brazil. During the 1960s and 1970s, a period of increasing industrialization and urbanization in the Southeast, the Northeast's Net Migration (given by the difference between total number of immigrants and total number of emigrants in the Northeast) was -2,166,258 and -3,049,459 individuals (Carvalho and Garcia, 2002). These figures correspond to Net Migration Rates – NMR (ratio of the NM to the total population in a given year) of approximately -7,6% and -8,7%, respectively.

The intensity of migration flows from the Northeast has shown a dramatic decrease since the late 1980s and 1990s due especially to slower rates of economic growth in the Southeast. In fact, an analysis of the 1991 and 2000 Brazilian censuses, and the National Household Surveys (PNADs) between 2001 and 2005 showed a Net Migration of -138,659 in the period 2000-2005, which corresponds to a NMR of approximately - 0.3% (CEDEPLAR, 2007). Furthermore, the largest cities in the Northeast (particularly the state capitals) have increasingly attracted migrants from rural or smaller urban areas in the region.

Methodology

[5] The Theil-L is one of the most used index of income concentration. It is equal to the logarithm of the ratio between the arithmetic and geometric mean of income. In a society with perfect income distribution (everybody has the same income), the index is zero; otherwise, the index is one.

We describe in this section the methodology to create migration and population health scenarios for the Brazilian Northeast between 2025 and 2050[6]. We first describe the regional climate projections for Brazil, followed by the projected impact of these climate changes on the performance of the agricultural sector and on the economy in the Northeast. Then we discuss the methodology to estimate migration given climate change and economic scenarios, and finally we integrate migration and other factors in an indicator of health and population vulnerability impacted by climate changes.

Climate change scenarios

We used climate scenarios provided by the Brazilian National Institute of Space Research (INPE) through the regional model HadRM3P, further disaggregated by municipality. The model generates the IPCC's A2 and B2 scenarios[7]. The A2 scenario implies high carbon emissions, with temperature increases for the Brazilian Northeast Region up to 4ºC until 2070; and the B2 scenario implies low carbon emissions, and with temperature increases for the Brazilian Northeast Region up to 1.8ºC until 2070[8].

INPE's scenarios for the Brazilian Northeast (Marengo, 2009; Marengo et al, 2007) suggest an average temperature increase of between 2 and 4 degrees Celsius and 15-20% drier in the A2 scenario until 2070. The figures for the B2 scenarios are between 1 and 3 degrees Celsius and 10-15% drier. The major impacts of these scenarios are a) loss of biodiversity in the caatinga ecosystem, b) "aridization", c) desertification, d) great impacts on agriculture (especially subsistence), and e) impacts on population health.

Economic scenarios: impacts of climate change on the agriculture sector

We then estimated the economic impacts of the A2 and B2 scenarios on the performance of the agricultural sector in the Brazilian Northeast. These impacts are particularly relevant given the weight of agriculture on the regional economy and its strong articulations with the other economic sectors. We used scenarios built by the Brazilian Agriculture Research Agency – EMBRAPA (Pinto and Assad, 2008) on climate impacts on land supply (land suitable or not for cultivation) for the eight most important agricultural products in the region – rice, beans, corn, cotton, manioc, soybeans, sugar cane and sunflower.[9] Based on these data, the amount of land suitable or not for cultivation for other less important agricultural products and pasture was estimated. At the end, the impacts of the A2 and B2

[6] This methodology is described in full details in Cedeplar (2008). To the extent of our knowledge there are no previous studies using this approach of linking climate change, economic and migration dynamics and health.

[7] The A2 and B2 regional scenarios were the two available by INPE at the time of this study.

[8] The A2 and B2 scenarios discussed in this paper refer to climate scenarios, and not necessarily the socioeconomic scenarios implicit in the A2 and B2 scenarios. This distinction is important because not necessarily the economic behavior in Brazil may reflect the same trajectory of the global economy (reflected in the assumptions of the A2 and B2 scenarios). In any case, we assume that the A2 and B2 scenarios provided by INPE are consistent with national and global trajectories.

[9] For a detailed discussion of agricultural scenarios by EMBRAPA, see Pinto and Assad (2008).

scenarios on the agricultural sector represents a proxy of land availability for cultivation in the Northeast up to 2050.

Regarding economic scenarios, we used a computable general equilibrium model - IMAGEM-B (Integrated Multi-Regional Applied General Equilibrium Model for Brazil), developed at Cedeplar (Cedeplar, 2008). Given technological and preference changes, the macroeconomic scenarios and population projections, the model generates economic scenarios (income, employment, gross product, level of consumption of families) for Brazilian states until 2050. The next step was to incorporate the climate impacts in the agriculture on future economic scenarios in the Northeast. In other words, while in a first moment we estimated economic scenarios without climate changes in the IMAGEM-B model, now we measured economic scenarios with climate impacts on the agriculture. These impacts are both *direct* (reduction in the economic performance of the agriculture) and *indirect* (how this reduction in the economic performance of the agriculture impacts services and industries).

Population and migration scenarios

As we mentioned in the previous subsection, one of the inputs of the IMAGEN-B model was population projections for Brazilian states until 2050. This baseline population scenario includes the predicted behavior of fertility, mortality and migration until 2050 without climate change impacts (Cedeplar, 2008b).

The migration scenarios impacted by climate change (alternative scenario) are estimated using economic parameters of the IMAGEM-B model. As discussed above, we assume that as a region face the impacts of climate change on land supply (EMBRAPA scenarios), it suffers variations in income and employment levels (IMAGEM-B model) and consequently population migration. This relationship between employment variation and migration follows our focus on the role of economical factors on population displacements.

Thus, the IMAGEM-B generates a parameter,δ, which measures the effects of variations in employment affected by climate change in relation to the baseline demographic model for each five-year period between 2010 and 2050. This parameter indicates changes in the use of labor as a productive factor impacted by climate changes, and refers only to individuals 15-64 years old (working-age population). Given the interest in estimating migration for the whole population, including those below 15 and over 64 (considering, for example, that migrants under 15 are children following their parent's migration), we developed in another work (Cedeplar, 2008) a model which estimates Total Net Migration (for all age groups) from economic and demographic parameters. The model relates the working-age population (15-64) to the dependent population (below 15 and over 64), and how the first is affected by employment variation and, consequently, migration. The sum of the three estimated NM (for age groups below 15, 15-64 and over 64) gives net migration estimation for the total population.

Besides the two steps above – estimation of employment variation for the population aged 15-64, and estimation of migration for the total population - we included a third refinement in the estimation of migration. We assume that a positive variation in employment levels may be followed by the absorption of local unemployed population (and not necessary in-migrants), and that non-economic factors such as human capital endowments and household structure may favor the mobility or immobility of the population. For these reasons, we adjusted the NM to include a tolerance,υ, to the positive or negative variation in the employment level. The tolerance was estimated through a microeconomic model for Brazilian micro-regions (an area which encompasses a set of municipalities), with the Net Migration as a dependent variable, and sex, age, education and fixed-effects as control variables. Thus, an income-elasticity of migration of 0.259 was obtained, meaning that a 1% increase in the wage of a given micro-region may increase in 0.26% the in-migration flow into this region[10].

The NM thus obtained is a 5-year residual measure of the balance between in-migrants and out-migrants in a given location between t and t+5, corresponding to the period 2010-2050. It represents the net impact of climate change on migration. Therefore, the lack of net impacts of climate change on the employment level generates null net migration in the alternative scenario.

Population vulnerability: linking migration and health

Barros (2006) stressed the importance of indices as metrics of vulnerability. He mentions the work done by Confalonieri et al (2006; 2009) in Brazil that created an aggregate Index of General Vulnerability by combining epidemiological indicators, socioeconomic indicators and epidemiological indicators. This was the first work in Brazil to produce policy-relevant indices to support adaptation strategies in the health sector related to climate change. [11]

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[10] This result is robust and significant, and consistent with other studies for Brazil using different data and methodologies (see, e.g., Lima, 1995).

[11] The general formula for the vulnerability index (IVG) is:

$$IVG\_A2 = \frac{(IVS_p + IVD_p + IVED_{p\_A2} + IVC_{p\_A2})}{4}$$

$$IVG\_B2 = \frac{(IVS_p + IVD_p + IVED_{p\_B2} + IVC_{p\_B2})}{4}$$

where,
IVSp= Standardized health vulnerability index
IVDp = Standardized desertification index
IVEDp = Standardized economic – demographic index
IVCp = Standardized health care cost index.
General vulnerability indices were developed for IPCC’s A2 and B2 scenarios since the IVEDp and the IVCp were produced for both scenarios.

As already stressed by different authors, there is a need to develop quantitative indicators of vulnerability to guide public policies for human health protection. In this paper we used empirical information as well as model projections to assess the possible regional social and health impacts of human migration triggered by long term climate changes.

Aiming to summarize in one metric the major social-environmental components of vulnerability to the impacts of climate change, we developed an aggregate index of vulnerability for each State in the Brazilian Northeast. It includes trends in endemic infectious diseases sensitive to climate factors; trends in desertification; demographic projections as well as potential impacts of climate-induced migration on health care costs for major cities.

Results

Migration scenarios

Table 1 shows the results of the projected migration for the A2 and B2 scenarios and for the baseline scenario. The net effects of climate change on migration in the Northeast during 2025-2030 are virtually null: 0,03% in the A2 scenario (representing a volume of 17.752 individuals in-migrating to the Northeast) and -0,01% in the B2 scenario (6.026 individuals out-migrating from the Northeast). The B2 scenario is also associated with only marginal impacts on migration for 2035-2040 and 2045-2050, with MRs of -0,02% and -0,03%, respectively, showing that this scenario of climate impacts on the agriculture is not associated with significant population migration.

Table 1 – Net Migration (NM), Migration Rate (MR) and Total Population by Scenario (Baseline, A2 and B2) – Brazilian Northeast Region, 2025-2030, 2035-2040 and 2045-2050.

Scenario	Net Migration			Net Migration Rate (%)			Total Population / Projected		
	2025-2030	2035-2040	2045-2050	2025-2030	2035-2040	2045-2050	2025-2030	2035-2040	2045-2050
Baseline	-192513	-203925	-208781	-0,29	-0,29	-0,29	65339961	68559267	70349764
A2	17752	-246777	-236065	0,03	-0,36	-0,34	65357713	68312491	70113699
B2	-6026	-13565	-20603	-0,01	-0,02	-0,03	65333935	68545703	70329161

The A2 scenario shows stronger impacts on the agricultural sector when compared to the B2 scenario. According to the results for 2025-2030, by affecting more intensely the agricultural sector in the South and Southeast regions (these results are not presented here), the A2 scenario might reduce out-migration from the Northeast. For example, the B2 scenario is less severe in Minas Gerais and Espírito Santo (two states in the Southeast which border the southernmost states of the Northeast region) than in the A2 scenario. The impacts on migration become more significant in 2035-2040 and 2045-2050, and are even higher than the one projected by the baseline demographic model. The model suggests a MR of -0.36% in the period 2035-2040, which represents the migration of 246.777 individuals, and -0.34% and 236.065 individuals in 2045-2050, respectively, only as a consequence of climate change. Once the expected climate changes are taken into account, the negative net migration would be higher than the baseline scenario between 2035 and 2040, and between 2045 and 2050.

Table 2 shows the projected A2 and B2 scenarios of NM and MR for 2025-2030, 2035-2040 and 2045-2050 for Metropolitan Areas (MAs) and clusters of municipalities according to size. Following the trend shown in table 1, the results are marginal in both scenarios in 2025-2030 except for significant and negative MRs for the MAs of São Luís, João Pessoa (A2 and B2), Teresina and Salvador (B2). In the following years for the B2 scenario, the MRs are also marginal except for the MAs of São Luís, João Pessoa, Salvador, and Teresina.

The A2 scenario shows consistently negative and significant NMs and MRs in 2035-2040 and 2045-205 (except for the MA of Aracaju). The higher NM occurs in the MAs of Recife and João Pessoa. The MA of São Luís, probably due to its proximity to the Amazon (which may gain population in the future A2 scenario) also shows high negative MR, both in the A2 and in the B2 scenarios as discussed above. The MA of Salvador and Teresina will also have significant loss of population.

The municipalities over 150,000 inhabitants will probably experience significant NMs and MRs in the A2 scenario in the three periods of analysis, with higher intensity in 2035-2040 and 2045-2050 (with MRs above the Northeast average in the period of analysis). On the other hand, municipalities between 70,000 and 150,000 inhabitants in the A2 scenario, and municipalities between 25,000 and 70,000 inhabitants in the A2 and B2 scenarios, will have small positive MRs in 2025-2030. However, the trend is the same as in the larger municipalities, with negative MRs in the last two periods of analysis. Finally, the municipalities with less than 25,000 inhabitants also show a trend of negative MRs in the last two periods, scenario A2.

Overall, the results show that climate impacts mediated by the performance of the agricultural sector may generate loss of income and employment which by their turn may act as a relevant push factor on population migration. These impacts may be reflected through most of the region, from rural areas to smaller or larger urban areas. While these results reflect a classic migration response, it represents also a new source of population vulnerability assuming that those moving can potentially pressure the public health and infrastructure systems in the place of destination and act as potential agents in the redistribution of endemic infectious diseases.

Table 2 – Net Migration (NM) and Migration Rate (MR) for Metropolitan Areas (MAs) and Municipalities According to Size in the Brazilian Northeast Region – Scenarios A2 and B2, Years 2025-2030, 2035-2040 and 2045-2050

Metropolitam Areas (Mas) and Municipalities	**2025-2030**				**2035-2040**				**2045-2050**			
	A2		**B2**		**A2**		**B2**		**A2**		**B2**	
	NM	**NMR (%)**	**NM**	**NMR (%)**	**NM**	**NMR (%)**	**NM**	**NMR (%)**	**NM**	**NMR (%)**	**NM**	**NMR (%)**
MA of São Luís	-1167	-0,06	-5169	-0,26	-9529	-0,42	-5958	-0,27	-5492	-0,23	-6849	-0,28
MA of Fortaleza	547	0,01	-131	0,00	-9462	-0,21	-343	-0,01	-7576	-0,16	-697	-0,01
MA of Natal	541	0,02	366	0,02	-5782	-0,22	526	0,02	-7262	-0,24	715	0,02
MA of João Pessoa	-1387	-0,08	-1445	-0,08	-13728	-0,68	-1780	-0,09	-16948	-0,75	-2223	-0,10
MA of Recife	123	0,00	8	0,00	-47518	-0,99	61	0,00	-53005	-1,10	131	0,00
MA of Maceió	436	0,02	74	0,00	-2236	-0,11	77	0,00	-2388	-0,11	81	0,00
MA of Aracajú	495	0,04	237	0,02	-406	-0,03	447	0,03	54	0,00	732	0,04
MA of Salvador	-1286	-0,03	-4021	-0,08	-12321	-0,24	-4877	-0,10	-10561	-0,21	-5869	-0,12
Teresina	-422	-0,04	-1246	-0,12	-5824	-0,59	-1236	-0,13	-4731	-0,58	-1120	-0,14
More than 250.000 inhab.*	-101	-0,01	-838	-0,04	-8355	-0,44	-869	-0,05	-7448	-0,40	-894	-0,05
Between 150.000 and 250.000 inhab.**	320	0,01	-883	-0,04	-17061	-0,67	-826	-0,03	-19862	-0,77	-788	-0,03
Between 70,000 and 150,000 inhab.***	3038	0,07	-647	-0,01	-10987	-0,22	-21	0,00	-7239	-0,13	-1435	-0,03
Between 25.000 and 70.000 inhab.***	7490	0,05	7490	0,05	-49907	-0,34	1124	0,01	-45612	-0,32	-2364	-0,02
Less than 25.000 inhab.***	9124	0,05	178	0,00	-53661	-0,29	110	0,00	-47995	-0,25	-22	0,00
Total - Norteast Region	*17752*	*0,03*	*-6026*	*-0,01*	*-246777*	*-0,36*	*-13565*	*-0,02*	*-236065*	*-0,34*	*-20603*	*-0,03*

* Except the state capitals and the municipalities in the MAs. Include the municipalities of Campina Grande, Caruarú, Feira de Santana and Vitória da Conquista.
** Except the state capitals and the municipalities in the MAs. Include the municipalities of Imperatriz, Juazeiro, Sobral, Petrolina,
Arapiraca, Ilhéus, Itabuna and Juazeiro.
*** Except the state capitals and the municipalities in the MAs

Demographic dynamics, health and population vulnerability

Figures 2 to 5 show the results for the Standardized Economic – demographic Index (IVED) and for the General Vulnerability Index (IVG), in the A2 and B2 scenarios. The IVED and IVG indices represent the cumulative percent difference between the values observed in the A2 and B2 scenarios and the baseline scenario in the period 2005-2030. Regarding the last index, in the worst case scenario (A2) we observe that the higher values (0.75 or over, in a range from 0.0 to 1.0) correspond to the States of Ceará (1.0), Pernambuco (0.89) and Bahia (0.75). In the case of Ceará, all four partial indices – IVS (Health), IVD (Desertification), IVED (Economy-demography) and IVC (Health care costs) – influence the high values of the IVG since they have values equal or higher than 0.66. Pernambuco (0.89) was basically influenced by the high values of IVED (1.0) and the IVD (0.88) while the IVG for Bahia is influenced by the IVS (0.73), IVD (0.88) and the IVC (1.0).

High values of the Economic-demographic Index (IVED) are observed for the States of Pernambuco (1.0), Ceará (0.92) and Paraíba (0.75). The results for the two first states are influenced by extreme values in all three components of the IVED (GDP, Employment and population migration), whereas in the case of Paraíba only GDP decrease and employment loss played an important role.

Figure 2 - Standardized values for the Economic-demographic Index, for each state in the Brazilian Northeast, and for climate scenario A2, 2005-2030

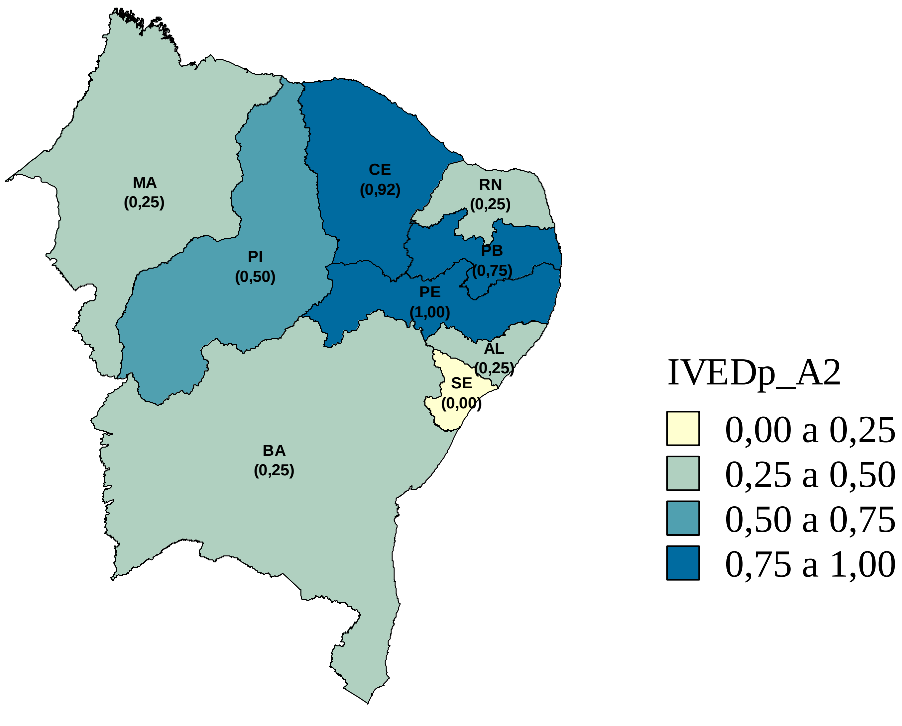


Figure 3 - Standardized values for the Economic-demographic Index, for each State in the Brazilian Northeast, and for climate scenario B2, 2005-2030

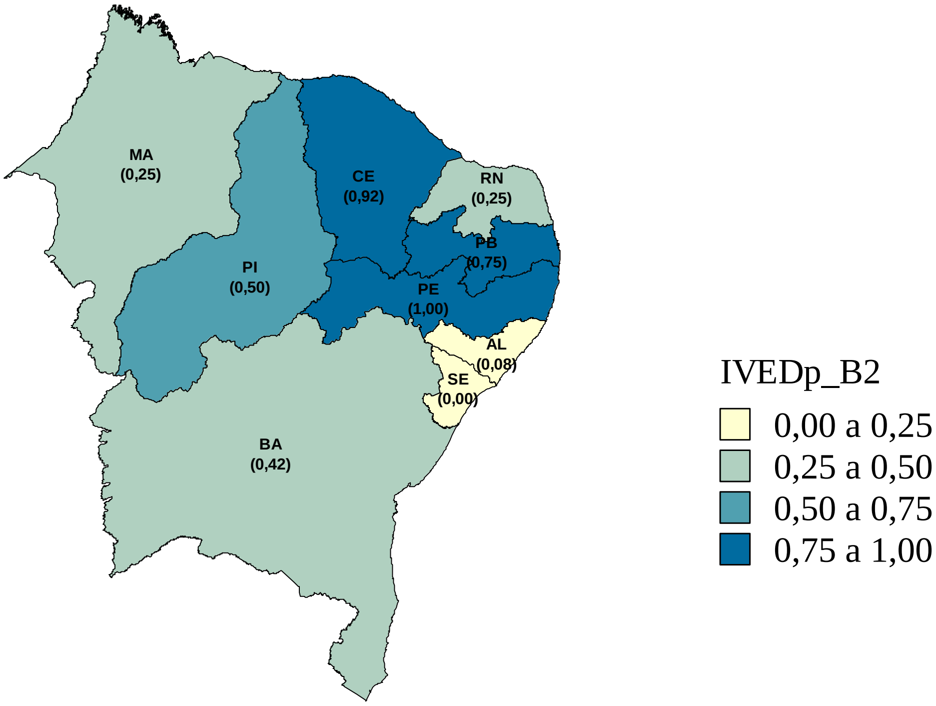


Figure 4 - Standardized values for the General Vulnerability Index for each state in the Brazilian Northeast, and for climate scenario A2, 2005-2030

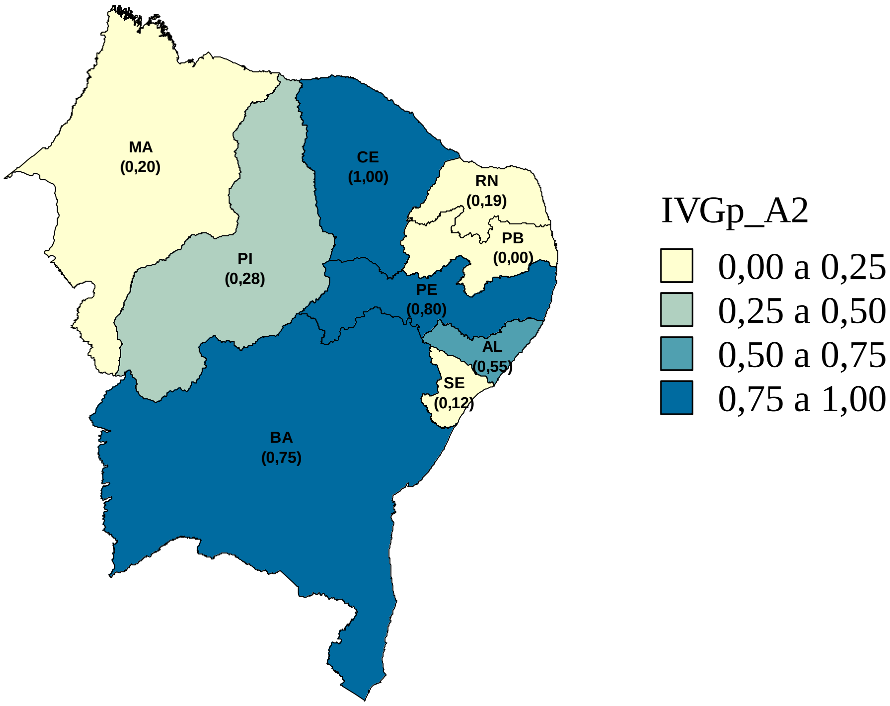
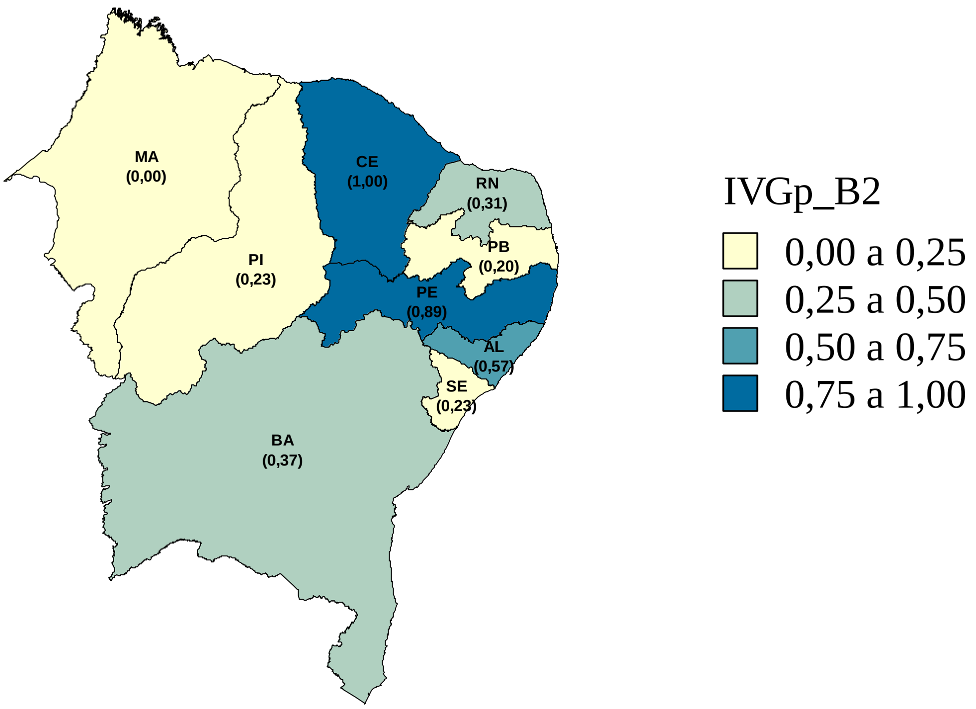


Figure 5 - Standardized values for the General Vulnerability Index for each state in the Brazilian Northeast, and for climate scenario B2, 2005-2030



Conclusions and Policy Implications

This paper discusses the long-term relationship between climate change, population migration and population health, with a case study on the Brazilian Northeast. If high migration rates in the past were mostly result of a combination of severe drought periods and better labor opportunities in the Brazilian southeast, we project a key role of these two factors as important drivers of migration from the Northeast (albeit at a much lower level than observed in the past). These scenarios may also create new foci of endemic diseases due to the mobility of infected people, as well as to increase pressure on urban infrastructure and the public health system.

Understanding climate change impacts on migration is important because population adaptation may depend upon their ability to move across space. In the case of the Brazilian Northeast we assume that this response is associated with those most vulnerable economically. On the other hand, we recognize that the “migration response” is not only a mechanism of adaptation of the poorest or less favored in any social or economic dimension, but may also in some circumstances be a mechanism available only for those with sufficient resources or capital (social, financial).

Our case study in the Brazilian Northeast shows that while the B2 scenario does not indicate a significant impact on population migration, the A2 scenario indicates significant population migration from the Northeast after 2030. While still modest compared to historical out-migration from the Northeast (particularly in the 1960’s and

1970's), these figures are higher than what we project in the baseline (trend) scenario, and show potential impacts due to a poorer performance of the agricultural sector.

While modest (compared to the baseline scenario), our migration results impacted by climate changes are probably underestimated. It is important to notice that our model captures the impacts of climate changes only on the agricultural sector. While this is an important sector in the Northeast compared to other regions in Brazil, services and industries are still more important in economic terms (particularly in terms of income generation). Thus the results capture only one dimension of economic impacts, and we believe that they could be bigger depending, of course, of the efficacy of adaptation measures. Regarding this last point, many other factors in the construction of migration scenarios which affect adaptive capacity and population vulnerability may be taken into account. For example, water supply issues are particularly important, especially because the Northeast can face important water shortages in the future due to temperature increases, what can decisively impact livelihoods and public health.

We then relate climate impacts on population dynamics to potential repercussions on public health, hoping to suggest prompt adaptation measures of the public health system. One such adaptation strategy would be to increase the capacity of health care systems, especially in those areas projected to have climate change of higher magnitude. However, health adaptation strategies should be developed in conjunction with other adaptation measures relevant for public health such as the improvement of food security and the management of water resources. The comprehensive Vulnerability Indices provide a reference to prioritize areas for intervention in the context of regional general adaptation policies to climate change.

Even the partial picture in this paper may provide an understanding of critical linkages between climate change, population mobility and population health. Simulations of scenarios of increased vulnerability of some groups - particularly migrants - can help to promote prompt and strong action in terms of creation or adaptation of institutional settings at different scales.

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References

Adamo, S. (2008). Addressing environmentally induced population displacements: a delicate task. Background paper for the Population-environment Research Network Cyberseminar on “Environmentally Induced Population Displacements”. www.populationenvironmentresearch.org.

Barbieri, A. F., Carr, D. and Bilsborrow, R. (2009). Migration within the frontier: the second generation colonization in the Ecuadorian Amazon. Population Research and Policy Review 28(3): 291-320.

Barnett, Elizabeth D. and Walker, Patricia F. (2009). Role of Immigrants and Migrants in Emerging Infectious Diseases. Medical Clinics of North America 92(6): 1447-1458.

Barros, M. (2006). Clima e endemias tropicais. Estudos Avançados, 20(58): 297-306.

Bilsborrow, R. (1987). Population Pressures and Agricultural Development in Development Countries: A Conceptual Framework and Recent Evidence. World Development, 15(2), 183-203.

Carvalho, J. A. and Garcia, R.A. (2002). Estimativas decenais e quinquenais de saldos migratorios e taxas líquidas de migração do Brasil. Belo Horizonte, Cedeplar/UFMG.

CEDEPLAR (2008). Mudanças climáticas, migrações e saúde: cenários para o Nordeste brasileiro, 2000-2050. Relatório de Pesquisa (Research Report): Belo Horizonte, CEDEPLAR.

CEDEPLAR (2008b). Cenário Tendencial do Modelo Econômico de Projeções Territoriais – Período 2007/2027. Research Report: *PPA 2008-2011*. Belo Horizonte: Cedeplar/UFMG.

CEDEPLAR (2007). Projeção Populacional para o Brasil e Unidades de Federação por Idade, 200-2020, Cenário Básico. Relatório de Pesquisa (Research Report): Belo Horizonte, CEDEPLAR.

Confalonieri, U.E.C. (2003). Variabilidade climática, vulnerabilidade social e saúde no. Brasil. *Terra Livre*, S. Paulo, 19-I (20):193-204.

Confalonieri, U.E.C et al. (2005). Analise da Vulnerabilidade da Populacao Brasileira aos Impactos Sanitarios das Mudancas Climaticas. MCT-PPA, Programa de Mudancas Climaticas, 201 pp (http//www.mct.gov.br/upd_blob/0014/14534.pdf).

Confalonieri, U E C, Marinho, D.P. and Rodriguez, R.E. (2009). Public Health Vulnerability to Climate Change in Brazil. Climate Research, 40:175-186.

Davis, K. (1963). The Theory of Change and Response in Modern Demographic History. Population Index, 29(4), 345-366.

Döös, B. R. (1997). Can large-scale environmental migrations be predicted? Global Environmental Change, **7**(1), 41-61.

Downing, T.E. (1992). Climate Change and Vulnerable Places: Global food Security and Country Studies in Zimbabwe, Kenya, Senegal and Chile. Research report No. 1., Environmental Change Unit, Oxford.

Ezra, M. (2003). Environmental Vulnerability, Rural Poverty, and Migration in Ethiopia: a Contextual Analysis. Genus, 59(2), 63-91.

Findley, S. E. (1994). Does Drought Increase Migration? A Study of Migration from Rural Mali during the 1983-1985 Drought. International Migration Review, 28(3), 539-553.

Franke, C.R., Ziller, M., Staubach, C., and Latif, M. (2002). Impact of the El Niño: Southern oscillation on visceral leishmaniasis, Brazil. Emerging Infectious Diseases, 8(9), 914-7.

Füssel, H.-M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. Global Environmental Change, 17(2), 155-167.

Henry, S., Schoumaker, B., Beauchemin, C. (2004). The Impact of Rainfall on the First Out-Migration: A Multi-level Event-History Analysis in Burkina Faso. Population and Environment, 25(5), 423-460.

IIED (2007). Reducing risks to cities from climate change; an environmental or a development agenda? London: IIED.

IPCC (2001). Third Assessment Report: Climate Change 2001 (TAR). (http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm).

IPCC (2007). Fourth Assessment Report: Climate Change 2007 (AR4). (http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm).

Kniveton, D., Schmidt-Verkerk, K, Smith, C., Black, R. (2008). Climate change and migration: improving methodologies to estimate flows. Brighton, UK, International Organization for Migration.

Lima, R. (1995). Um Exame dos Determinantes da Migração Rural-Urbana no Brasil. Cadernos de Ciência & Tecnologia, 12(1/3): 55-67.

Marengo, J.A; Nobre, C.A.; Salati, E. and Ambrizzi, T. (2007). Caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do século XXI. Min. do Meio Ambiente, SBF/DCBio, Brasília, 54 pp

Marengo, J.A. (2009).Vulnerability, Impacts and Adaptation (VIA) to climate change in the semi-arid region of Brazil, pp 137-164. In: MK Poppe (org). Brazil and Climate Change: Vulnerability, Impacts and Adaptation. CGEE, Brasília

Martine, G, Guzmán, J. (2002). Population, Poverty, and Vulnerability: Mitigating the Effects of Natural Disasters. Environment Change & Security Project Report, 8, 45-68.

McGranahan , G., Balk, D., Anderson. B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment & Urbanization, 19(1), 17-37.

McLeman, R., Smit, B. (2006). Migration as an adaptation to climate change. Climatic Change, 76, 31-53.

Meze-Hausken, E. (2000). Migration caused by climate change: how vulnerable are people in dryland areas? A case study in Northern Ethiopia. Mitigation and Adaptation Strategies for Global Change, 5, 379-406.

Perch-Nielsen, S. L., Bättig, M.B., Imboden, D. (2008). Exploring the link between climate change and migration. Climatic change, 91(3-4), 375-393.

Pinto, H.S., Assad, E. (2008). Aquecimento Global e Cenários Futuros da Agricultura Brasileira (Research Report). Project FCO-GOF: PGL GCC 0214, Campinas, Brazil.

Ribot J. C., Najam, A and Watson, G., (1996). Climate Variation, Vulnerability and Sustainable development in the Semi-arid Tropics. In: : J.C. Ribot, A.R. Magalhães and S.S. Panagides (Eds.). Climate Variability, Climate change and Social Vulnerability in the Semi-arid Tropics. Cambridge: Cambridge University Press, chapter 1.

Wang, X., Auler, A.S. Edwards, L., Cheng,H., Cristalli, P.S., Smart, P.L., Richards, D.A., and Shen, C. (2004). Wet periods in northeastern Brazil over the past 210 kyr linked to distant climate anomalies. Nature, 432, 740-743.