Climate Change and Migration in West African Coastal Zones

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Working Paper Series: CC-008

Bringing Rigour and Evidence to Economic Policy Making in Africa

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Abstract

Global trends in migration show a predominance of internal over external flows. The African continent is the world's most vulnerable region to climate change due to its higher levels of exposure and its scarcer financial resources for adaptation. Therefore, climate change presents in Africa some peculiar challenges to livelihoods, and security. In this paper, we assess the climate-induced migration in African coastal zones, accounting for many different factors such as conflict, demography, social networks, economic opportunities, and geographical factors such as the terrain. We also provide a critical review of major strands of models of climate-induced migration, namely agent-based models, choice-centred models, gravity model, and household allocation models. The most used data in climate change analyses are also analyzed.

1. Introduction

Global trends in migration show a predominance of internal over external flows. Internal migrants, at global level, reached 740-763 million people (UNDESA, 2013; UNDP, 2009). These numbers suggest that about twice as many people were displaced internally than across borders in 2016 (IDMC, 2017; UNHCR, 2017). It is also expected that these figures are higher in coastal areas, driven by factors such as population growth, urbanization, sea level rise and climate-related hazards (Mbaye, 2020). The global internal migration numbers hide some heterogeneities between regions and countries, with migration being more accentuated in some regions than in others. Internal migration is mostly driven by urbanization (Gemenne et al., 2014). By 2050, two-thirds of the global population is expected to be living in urban agglomerations, with 2.5 billion people to be living in cities by then. Even without climate change, rising internal migration means that effective management strategies are needed (UNDP, 2009; UNDESA, 2013).

According to the World Bank, West Africa is the sub-region of Africa with the most important intra-regional migration flows. These flows make up more than 58.0% of total African migrations compared to only 30.9%, 21%, 1.8% and 24.8%, respectively, in East Africa, Central Africa, North Africa and the southern part of the continent. Long before national colonial borders were established, West Africa had a long history of population mobility and long-distance movements. Migration is a well-entrenched tradition in West Africa, and is mainly shaped by kinship and religious networks operating beyond the boundaries of national borders (Golub and Hayat, 2015). Additional factors such as demography, security and livelihood challenges also come into play in explaining migration flows. In particular, the important demographic bulge in Sub-Saharan Africa (SSA) implies that population will increase about ten-fold between 1950 and 2050. This population increase is likely to settle in desert areas or areas already densely populated to the point of saturation. Recently, internal migration in West Africa has been exacerbated by Jihadist extremist challenges in Nigeria, Niger, Burkina Faso and Mali.

In West Africa, coastal areas are home to approximately 25-80% of the total population. Most of the countries have their national capital along the coast (Amuzu et al., 2018). Certain parts of West African seafront have long been settled by historic marine people (for example the Lebou in Senegal, the Balante in Guinea-Bissau and the Imraguen in Mauritania). The accessible sea has always been an attractive place

for the fishermen. The significance of coastal areas is even bigger for some countries. For example, in Guinea-Bissau, 94.6% of the population are living on 100km of the coastline, and 70.o% of the local population are living in the rural areas with major socio-economic activities as fisheries, forestry, and agriculture (Abuodha, 2009).

The West African coastal ecosystems provide a range of essential services, including a huge fishery resource. These ecosystems also represent an important value to local household livelihoods and economies.

Although it is difficult to establish a direct relationship between the effects of climate change and international migration, indirect relationships can be established, especially for countries highly dependent on agriculture and fishery. The impact of changing climatic conditions on the availability of natural resources, combined with factors such as population growth and weak governance, have led to increased competition for scarce resources and changes in migration corridors in the region, which can also be a source of conflict (UNEP, 2011).

This framework paper discusses the concept around climate induced migrations on Africa's coastal areas, and methodological issues surrounding its analysis, modeling and interpretation. The remainder of the paper is organized as follows. Section 2 presents recent trends in temperature and rainfall change in West Africa. Section 3 reviews the main trends and patterns of climate-induced migration. Section 4 highlights the main vulnerabilities facing Africa's coastlines. Section 5 presents the complex nexus between climate change, conflict, and migration. Section 6 reviews the main drivers of climate change focusing, respectively on demography, conflict, and social networks. Section 7 presents the main models of climate migration, and section 8 the data sources. Finally, there is a short conclusion (section 9).

2. Recent trends in temperature and rainfall in West Africa

Recent figures on temperature and rainfall trends in Africa display very daunting trends. Figure 1 shows the seasonal average temperatures (June to September) in West Africa. Maximum temperatures are witnessed in the northern part of Mali with average values of around 34.5°C while minimum values are around 26°C in Burkina Faso and the Southern Chad. The temporary temperature variation in each country (Figure 3a) shows a more marked increase in temperatures over the period from 1998 to 2017. This increase in temperature is around 0.5°C.

Figure 1: Average seasonal temperatures (June to September) over the period 1978–2017 in West Africa
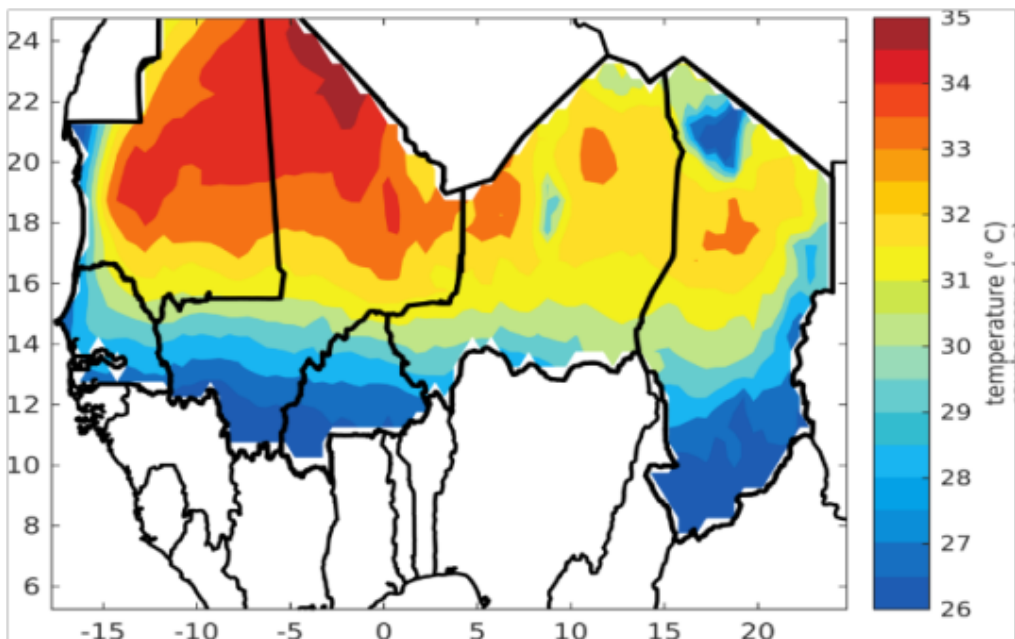
Source: The data used are those of the Climatic Research Unit (CRU)

Regarding precipitation, Figure 2 shows that they are higher in the southern part. They vary between 60 and 180 mm/month. The temporal evolution of seasonal average precipitation (Figure 3b) shows an increase, from 1998, in all countries. This increase is around 20 mm for Mali, Niger and Chad while for Burkina Faso and Senegal

the increase is larger and is around 30 mm. This increase agrees with the results of Descroix et al. (2015) and of Bodian (2014). These trends are confirmed by data shown in Figure 3, which consider individual countries.

Figure 2: Average seasonal precipitation (June to September) over the period 1978–2017 in West Africa
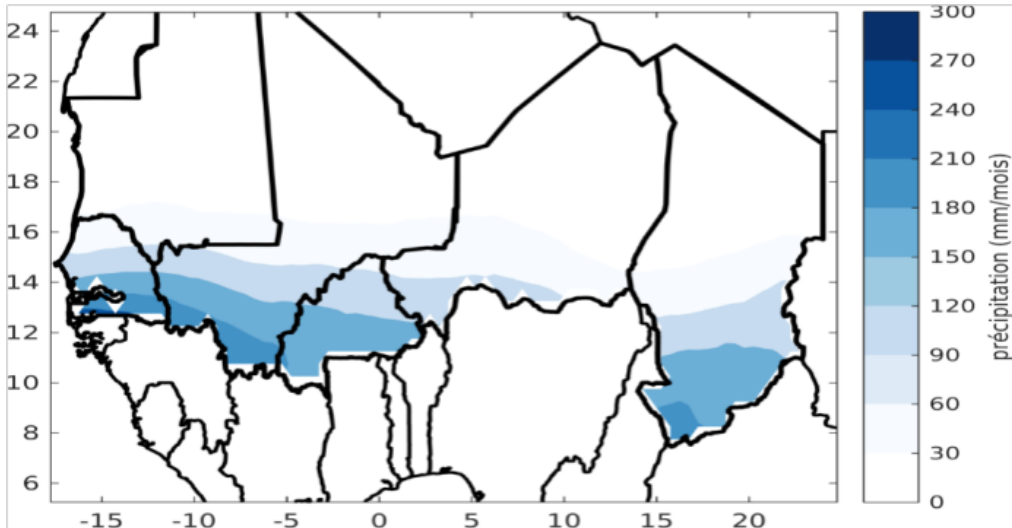
Source: The data used are those of the Climatic Research Unit (CRU)

Figure 3: Evolution of seasonal average temperatures (a) and precipitation (b) (June to September)

(a)   **(b)**
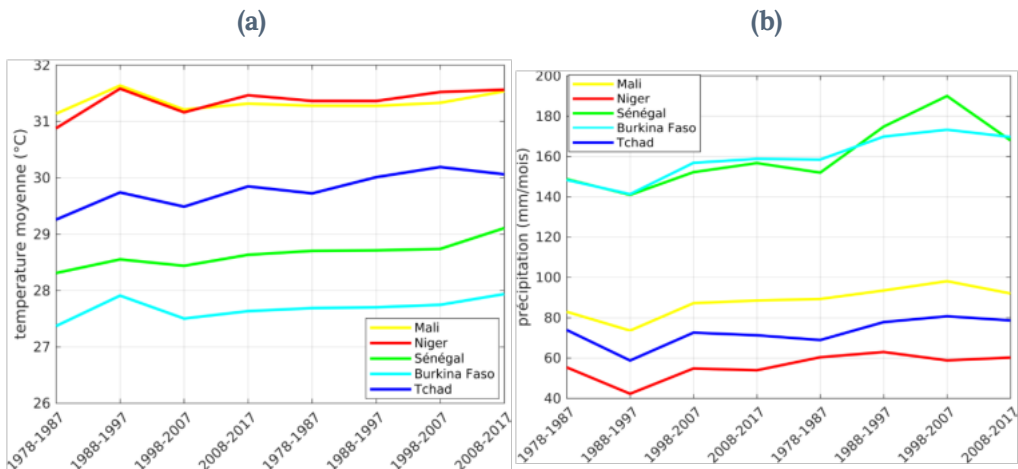
Source: The data used are those of the Climatic Research Unit (CRU)
NB: The averages are calculated by five-year period to better highlight the main trends.

Rising temperatures could impact agricultural yields and water resources. Indeed, Faye et al. (2019) show that the yield of millet and short-cycle sorghum could decrease by 30% by 2050 at Niakar in the Fatick region (Senegal). This drop in yields is mainly due to rise in temperatures, which leads to a decrease in the cereal development cycle. The increase in temperatures will also impact water resources via evapotranspiration. Bah et al. (2019) also show that by 2050, a 9% decrease in precipitation and a 1.2°C/year increase in temperature would bring renewable water supplies to decrease to 60 mm^3/ year and 65 mm^3/year for RCP4.5 and RCP8.5 at Fatick, respectively. These impacts of temperature and precipitation could increase migration.

3. Patterns and magnitude of migration flows in West Africa

Coastal areas in the West African region are experiencing different kinds of environmental changes resulting from sudden shocks and slow processes. These changes considerably influence migration patterns of population within and outside West Africa (Gemenne et al., 2017).

In Africa, migration is mainly about internal displacements (Fox et al., 2018). The large exodus of important numbers of rural residents into African cities has indeed several explanations, including higher poverty incidence in African villages, low productivity levels in rural activities (Harris and Todaro, 1969; MacMillan and Rodrik, 2011), compared to the ones happening in urban dwellings, a lower access to quality education and healthcare (IOM, 2015), etc. Natural disasters, ostracism, and lack of educational opportunities, social amenities and recreational activities in the rural areas also push people to move to cities.

Environmental migration

Environmental migration is becoming one of the greatest policy challenges of this century. Currently, there are about 50 million environmental refugees around the world, many of whom have been forced out of their homes due to food insecurity and or lack of employment opportunities, often as a direct consequence of degradation of natural resources. West Africa is one of the regions most affected by this type of migration. Desertification, land degradation and drought undermine the well-being and resilience of local communities, playing a major role as a cause of migratory flows within and outside Africa.

The channels through which climate change and environmental degradation can impact migration in West Africa are varied.

Droughts and desertification in agro-pastoral areas have accentuated internal migrations of pastoralists and nomadic farmers in West Africa. With these adverse climatic conditions, populations are more attracted by areas where the weather is more friendly to their agricultural and pastoral activities (RGPH, 2013; ONS, 2013).

Sea level rise and floods: Sea level rise threatens the dune cordon, which serves as protection of African coastal cities. An increasing number of cities in West Africa are

therefore exposed to floods (Alex and Gemenne, 2016). Rising sea levels and floods in coastal urban areas are likely to accentuate internal migration. Migration of populations from continental to coastal areas has significantly contributed to increase in the exposure of coastal communities to sea level rise in West Africa (Barrat, 2012).

Other migration drivers

Apart from climate change, the following factors are affecting migration in West Africa:

Development of means of transport and networks: The development of maritime and road transport infrastructure has made it possible to diversify means, routes and cross-border migration networks. For example, the construction of the Nouakchott-Nouadhibou (two main Mauritania cities) road linking Sub-Saharan Africa and the Maghreb has strengthened the role of Mauritania as the transit point for migrants from other West African countries to Europe. The cities of Nouadhibou and Nouakchott are, therefore, important regional hubs for African migrations to Europe (Mohamed-Saleh, 2009).

Demographic and socio-cultural factors: Socio-demographic factors under consideration here include age, education level and socio-professional activity status. In Africa, an important demographic bulge, contrasting with few economic opportunities and failing social services, is an important driver for migration on coastal areas. Young people make up the majority of lifelong migrants[3]. In 2000, for example, in Mauritania, the age group between 0 and 15 years old represents 36% and 31% for the age between 15 and 30 years (RGPH, 1998). Therefore, 66% of migrants are under 30 years old. In 2007, according to EMOE[4], these age groups account for 35% and 33%, respectively. When considering the level of education, illiterate individuals represent 54% in 2000 against 46% in 2007 (Ould, 2010).

Geo-politics and security: In recent years, due to the spread of Islamist threat in the whole region of the Sahara and the Sahel, various flows of any kinds of traffic including weapons, counterfeit drugs, human, and of course migrations exist across the Sahara region.

4. Climate change and vulnerabilities in African coastal areas

With climate change, African coastlines are increasingly under considerable threat. Coastal areas are generally seen as the most densely populated (Neumann et al., 2015) areas in the world, with an estimated 50% of world population living within 100 kilometres of a coastline. This trend is expected to significantly deepen in the future. Population in coastal zones is growing faster due to their relatively higher economic growth, attracting more migrants from the hinterland. Average population density in coastal areas in 2000 was 241 people per km2, contrasting with a world average of only 47 people per km2. In Sub-Saharan Africa, the population in LECZ[5] (Dasgupta et al., 2011) is projected to grow at an annual rate of 3.3% in 2000-2030 and 3.2% in 2030-2060, contrasting with only 1.4% in 2000-2030 and 1.2% in 2030-2060 in Asia, for example. Rising sea level is the most daunting threat to livelihoods and human settlements and safety coastal areas are confronted with, especially in Africa. With climate change, increase in the sea surface temperature is found to affect all oceans (Dasgupta et al., 2011). Recent estimates show that see level rise can achieve 100 cm by 2100 (Nicholls et al., 2014), further compounding the array of hazards coastal areas have to deal with and their severity. Throughout the 20th century, average temperature has increased by 0.76°C, and global warming accelerated starting from 1976 to achieve 0.18°C per decade. For tropical waters, the increase has achieved 1.2°C. African coastal areas are considered among the most exposed to sea level rise in the world (IPCC, 2014). Climate change affects coastal ecosystems in several ways. It entails rise in sea level, water acidification, coastal surges and storms.

Impact on food production

Food production is an important activity in coastal zones, where marine resources constitute the main source of animal protein for a great number of population. In Africa, artisanal fishing, which is characterized by its high labour intensity, is by far the most important economic activity on coastlines with an estimated share of about 91% of total jobs in those areas. In addition, a diversity of ecosystems appears as one moves from the ocean to the hinterland, each of which having a particular set of resources and providing a large spectrum of livelihoods. Coastal areas are therefore home to intense agricultural and pastoral activities, but also manufacturing and services. In the fishing sector, it is expected that important migrations of species will occur,

leading to a total extension of some, in some places. Rise in sea surface temperature and level of acidification also affects species physiologic functions.

Increased flooding

By substantially increasing sea surface temperature, climate change brings about more violent cyclone activity and storm surges on coastlines. It is expected that continued sea surface warming will provoke more tropical cyclones, higher wind speeds, and heavier precipitations. For example, an increase in tropical sea surface by 1°C will increase wind speed by 3-5% (Brecht et al., 2012). This is likely to make disaster forecasting, evacuation, and emergency shelter provision more challenging. A study of 84 developing countries (including African countries) shows that 7.82% of their combined coastal territories is exposed to inundation. A 100 cm sea level rise accompanied by a 10% intensification of storm surges increases the potential inundation area to 13.3% and would affect 31 million more people from baseline scenario and increase GDP loss to 12.92% from 6.95% in baseline scenario. In Côte d'Ivoire, for example, exposed coastal areas will increase by 285.2%.

Natural defenses weaknesses and acidification

Mangroves are known for the role of the effective buffer they play in reducing coastal vulnerability to storm surges. Mangroves can play the same role as infrastructure designed to protect coastal areas in tropical regions from such extreme events as storm surges, cyclones, and inland water salinization. For relatively low levels of waves, mangroves rehabilitation projects are found to be 2 to 6 times cheaper that other forms of construction infrastructure. Yet, increase in ocean surface temperature, which leads to higher salinity of inland water, increasingly puts mangroves in jeopardy, thereby further weakening the already fragile adaptive capacity of coastlines. According to some estimates, the vulnerable population exposed to the risk of mangrove destruction is likely to increase by 103% and losses in GDP by 233% (Dasgupta et al., 2016).

Beyond its effects on mangroves, saltwater intrusion into inland coastal areas negatively impacts river salinity, hence available drinking and irrigation water, making both dry-season agriculture and freshwater fishing more challenging. Therefore, crops that heavily depend on river irrigation, such as rice, are tremendously affected. In some areas, salinity has provoked a significant decrease in yield, followed by an output decrease by 15.6%. Saline water intrusion into inland water has also important health effects. It increases risk of high blood pressure on pregnant women and higher mortality rates for their babies (Dasgupta et al., 2016). Lastly, salinity stemming from sea-level rise also affects road infrastructure and construction through land subsidence, progressive blistering, cracking, and pulverization. In some instances, the costs of maintenance stemming from salinity are found to increase by 252%.

5. Understanding the complex nexus between climate change, conflict, and migration

In the mid-1990s, Thomas Homer-Dixon made very famous assertions about climate change being associated with different types of violent conflicts, and these have triggered an increasing body of findings on the relationship between climate change, violent conflict and migration. According to several estimates (UNU, 2005; Stern, 2006) climate migration flows may reach a magnitude of 50 million to 200 million in the coming decades. Some studies have established a direct link between climate variables and migration. For example, Feng and Oppenheimer (2012), and Hunter et al. (2014) found a link between precipitation and Mexico-US migration. However, most of this literature has remained highly inconclusive about the existence of a causal link between climate change and violence, or migration (IOM, 2009).

Definition matters

Understanding migration drivers and dynamics in general is difficult for several reasons. First and foremost, projections on future climate trends are rarely convergent, and their hypothesized impact on migration are even more so. Indeed, there is a lot of uncertainty about how levels of gas emissions can change in the future depending on their hypothesized factors; how climate systems might evolve over time, and how robust are models of climate systems.

Moreover, the very notion of migration is very large, encompassing many different phenomena with varying characteristics such as forced migration (conflict-related displacements, refugees), internal migration, international migration, and what is increasingly termed as environmental migration, of which climate change migration is only a component. Furthermore, migration can be short-termed or permanent, seasonal or circular, voluntary or forced. All these notions of migration relate to varying drivers and display a diversity of patterns. When studying environmental migration, scholars refer to one or a combination of these notions of migration, and no standard definitions emerge as commonly accepted. There is a growing consensus that migration is best described as a continuum of different situations spanning the two extremes of forced and voluntary displacements.

The International Organization of Migration (IOM, 2007) defines environmental migrants as: "persons or groups of persons who, for compelling reasons of sudden or progressive change in the environment that adversely affects their lives or living

conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad."

While displacements triggered by disasters tend to be temporary and of shorter distance, longer-term changes to the environment, as in the case of climate change, can provoke more permanent movements to remoter places (Hatton, 2016).

Considering the many different layers of migration drivers, often intertwined, it is not easy to isolate climate change as one single determinant. Demography, conflict, social networks, all contribute in shaping migration patterns. Other factors such as individuals' socio-demographic characteristics are also at play. Age, marriage and child-bearing might push people to stay. Previous migration also matters, insofar as when migrants send back remittances that might discourage subsequent migrations.

The climate-migration nexus

Climate change is usually a part of a very complex and dynamic system where ecological variables interact with social, political, and economic factors in a way that makes it difficult to isolate its individual effect on migration by merely relying on observational data. In many instances, inconsistent findings have been underscored in the literature with respect to the correlation between climate change and migration. For example, Halliday (2006) has documented an increase in migration flow following a loss of harvest and livestock but decrease in flow following a severe earthquake in El Salvador. Likewise, a decrease in migration flows during drought years is documented in Mali by Findley (1994) and in Burkina Faso by Henry et al. (2004). Similarly, migration was found to alternatively decrease and increase with decreasing rainfall in Mexico by Munshi (2003), and Kniveton et al. (2008).

Entwisle et al. (2016) use the same datasets to simulate the impact of climate change using alternatively standard regression and Agent-Based Model (ABM) analyses. While their regression model has generated a strong relationship between the two, their ABM results show a much weaker correlation. Their explanation is that in rural areas most affected by climate change, migration is a well-entrenched practice in people's daily lives, and climate change only marginally affects this pattern. Most people who would be pushed to migrate by climate change would have already been migrating under previous existing conditions. Moreover, while migration is recognized as an adaptive strategy, there are alternative adaptive strategies that people rely on, such as crop diversification, and change in land use response, which can dampen migration.

There are several channels through which climate change may affect migration:

1. Natural disasters, such as hurricanes and cyclones, are likely to be more frequent with climate change. By jeopardizing housing and livelihoods, they are acting as a "push" factor

2. Increase in temperature and rainfall variations affects agricultural yield and livestock

3. Rise in sea level adversely affects coastal areas through flooding, increased salinity, and other challenges to people's livelihoods and security

4. Conflict over increasingly scarce natural resources can also trigger displacement.

Importance of geography and adaptive capacity

Estimates suggest that up to 1 billion people could be displaced due to climate change by 2050. But these figures mostly refer to the number of people who might be exposed to some climate risks, and relatedly migrate. They usually fail to account for adaptation to climate change and how they might dampen its impact on migration. Adaptation can be related to institutional improvement, innovation, and training.

According to Stern (2006), developing countries are at a disadvantage in the face of climate change because they lack adaptation capacities. In Sub-Saharan Africa, migration is cited by 23% of households as a coping strategy against climate change (Wiederkehr et al., 2018). In the face of climate shock, while coping strategies are about keeping basic functions running in the short to medium term, adaptation is more about managing the system to allow it mitigate moderate harm stemming from slower onsets of the said shock. While coping refers to spontaneous and temporary adjustments, adaptation deals with anticipatory and longer-term adjustments (IPCC, 2012).

In addition, developing countries are geographically disadvantaged, being located in lower latitudes found to experience more temperature increases, longer dry seasons, and higher water scarcity, all of which endanger livelihoods. Africa is considered one of the most exposed regions to climate change. In particular, dry lands (desert and semi-desert settings) are hardest hit by climate change due to their exposure to scarce and more variable rainfall and high potential evapotranspiration. With climate change, dry lands are expected to increase their share of global land surface to 50% by 2100. In addition, an estimated 90 million hectares of dry lands in Africa could experience drought in the next several decades, and this could trigger migration.

6. Some alternative drivers: Demography, conflict, and social networks

One most recognized determinant of migration is conflict. By drying out sources of livelihoods in Africa, climate change will likely affect migration directly by pushing people to leave, and indirectly through conflict over increasingly scarce resources (Mbaye, 2020). But alternative drivers such as demography, social networks, and level of economic development also come into play.

Conflict

The implication of violence on the decision of migrating internally or overseas depends on people's perceived probability of victimization (being victim of persecution) (Moore and Shelmann, 2006). In case of a civil war, opposing the state and dissidents, the latter might tend to protect civilians to gain their support, in which case people are likely to look for spots of heaven in their own home countries instead of attempting to leave the country. Available information on neighbouring countries will mainly determine out-migration. In particular, political institutions, existence of wage-jobs, cultural proximities, and level of violence in the neighbouring country will all contribute to determine the distribution of migrants between refugees and internally-displaced people. Geographical distance and difficult terrain on the borders are seen as transaction costs to migration, and therefore also play a role in shaping the decision to migrate.

Violence can take the form of human rights abuse, genocide, politicide or ethnic cleansing. Cleansing is found to be more likely in conventional wars where forces are balanced in which belligerents' primary objective is to conquer and control territory, while forced relocation is more likely in irregular wars where one side overwhelms the other when identification is trickier. While cleansing and depopulation tend to move people to remote areas, forced relocation is more about moving them closer to their place of origin.

Patterns of violence significantly differ between conventional conflict (Balcells and Steele, 2016) and irregular civil wars. When belligerents inflict damages to each other, civilians are affected either as collateral victims or well-targeted groups and can decide to flee. Displaced civilians are often involved in warfare, either by their identities or loyalties to one of the fighting parties. Armed groups tend to target civilians associated with rivals in terms of ethnicity of affiliation by sect, tribe, profession, or politics.

Ethnic conflicts are the most prevalent form of civil war, with an estimated 57% of all civil wars identified between 1945 and 2008 being ethnic in nature (Fearon and Latin, 2011). Some conflicts involve indigenous 'sons of the soil" against recent migrants from other parts of the country. In this case, which often corresponds to rural-rural displacement, migrants are usually from the dominant ethnic groups in search for land or government jobs, and are supported by the State.

Scholars also classify violence into two main components (Schon, 2016); home violence which is violence in residential areas and road violence, which is violence along migration routes. While home violence increases displacement, road violence decreases it. Both actual level and expectation of home and road violence affects migration decisions. In situations of conflict, civilians who can afford to leave either because they are wealthier or have better connections are the ones who leave the earliest (Schon, 2018).

Demography

Demography is an important determinant of conflict and migration. Population size and growth are associated with misery and, therefore, can lead to violence (Goldstone, 2002). Some evidence suggests that countries with larger population are more exposed to conflict. Countries with larger youth cohorts tend to experience conflicts with more casualties. Population growth can exacerbate conflict over scarce resources if elites are fighting to control resources and governments are overwhelmed. In addition, some demographic factors are found to play a more determinant role of conflict: a labour force growing faster than existing jobs, an educated youth population growing fast and aspiring to elite positions while these positions are scarce, an unequal growth rates between ethnic groups, a level of urbanization exceeding employments, and a model of in-migrations that changes the ethnic balance of the region.

Social networks

Social networks operate like migration facilitators between origin and destination countries (Nawrotzki et al., 2015). Colonial experience, casual contact with the developed world through tourism, trade, and aid all contribute in shaping them. Social networks facilitate migrants' entry into, settlement in destination locations, and assistance in finding relevant documentation and jobs. Growing evidence shows that past migration, which is a proxy for social networks, is highly associated with displacements (Davenport et al., 2003; Edwards, 2009; Moore and Shelman, 2006; Schmeidl, 1997). Network members share information about the journey to the place of destination with their families and friends in origin places. This information is then used to feed into their migration decision functions. Therefore, networks can reduce the costs and risks associated with migration in areas of origin.

Economic drivers

The level of economic development is an important "push" factor from origin, and "pull" factor into destination locations. This means that poor economic conditions in origin location will tend to drive out-migration while favourable conditions in destination location are likely to attract in-migrants. Therefore, the level of economic development in origin countries is found to be an important determinant of displacement. Richer countries and locations tend to produce much fewer out-migration than poorer ones. Also, people would only go to areas where economic conditions are better than home. The same logic also holds at individual level. Deteriorating economic conditions play an important role in individuals' migration decisions. Economic insecurity, mainly poverty therefore provokes migration (Davenport et al., 2003).

An important contribution to the economic literature on migration is The Harris and Todaro's two-sector model (Harris and Todaro, 1970). Their starting point is the observation that rural-urban migration in Africa is accelerating despite high unemployment level in urban areas, and a positive marginal product in agriculture in rural areas. They develop a two-sector model (rural and urban), with the former producing agriculture and the other a manufacturing good, part of which is exported to the rural areas in exchange for agricultural goods. The model predicts that migration to urban areas will continue as long as the expected marginal urban income exceeds real agricultural product. From this standpoint, migration is the rational response to urban rural differences in expected earnings. Due to politically determined minimum wage, migration is proceeding despite high levels of unemployment in urban dwellings.

Migration results from a utility maximization process whereby the costs of staying are weighed against the costs of leaving. Differentials in wages, and in returns on human capital are important factors. The new economics of labour migration (Taylor, 1999) (NELM) builds on Harris and Todaro and contends that migration through remittances can set in motion a developmental dynamic by loosening production and investment constraints households face in imperfect markets and create income growth linkages in origin countries. It is argued that migration decision is part of a family strategy to raise income, and increase funds to mitigate risks and finance investments. According to NELM, migration is a household strategy to overcome market failures that limit production, especially credit and insurance markets. Remittances will therefore provide households with liquidity they need to finance innovation, inputs and activities.

7.   Modeling climate-induced migration

To shed light on the complex drivers of migration, several models have been developed from different disciplines: economics, geography, politics, etc. While an important body of modelling refers to the household as the principal unit in the decision-making process regarding migration, another set of models referred to as "the choice-centred models" consider the individual. Gravity model, agent-based models, household allocation models, and more ad hoc models are all used to predict migration decisions taken either by households, individuals, or through dynamic interaction of various actors in origin locations. The relationship between climate change is assumed to be strong in rural areas due to the higher dependence of rural subsistence on the weather.

The process of migration includes two parts: the decision to migrate and the destination of migration.

Choice-centred models

Many scholars rely on "choice-centred models" to investigate drivers of migration. While these models primarily focus on forced migration, climate variables are also considered. Choice centred models assume that individuals are making migration decisions based on a set of "push" and "pull" variables. Push variables such as political oppression, violent conflict, human rights violation, state failure, climate change, economic hardship and economic discrimination against some ethnic groups are likely to increase flows of out-migrants (Neumayer, 2005). Pull factors usually include economic conditions, employment opportunities, the rule of law, democracy, availability of social services (education, health care), etc in destination locations. Cultural and religious similarities lower the cost of adjustment to the destination country, while generous welfare provisions to asylum seekers reduces the costs of migration in destination countries/locations. Beyond these two sets of factors, they consider a third group of factors facilitating or deterring migration, which includes social networks, road violence and the terrain.

This type of model is extensively used to predict refugee flows and other types of forced migration.

According to the International Refugee Convention, refugees are defined as those who have been displaced outside their origin country owing to a "well-founded fear of persecution". To investigate this type of migration, it is very common to use data

from destination countries, which are mainly OECD countries. A diversity of datasets pertaining to various aspects of forced displacement have been developed. Such models use, as dependent variable, a measure of the number or share of refugees in destination country. For example, Hatton (2016) uses as dependent variable the log of applications for asylum per head in origin country.

"Choice-centred" models of refugees produce significant results. Refugee flows are found to be larger in the face of State-sponsored genocide/politicide than for other types of violence (Moore and Shellman, 2006). Countries surrounded by poor and authoritarian regimes tend to generate fewer refugees than those surrounded by wealthier and more democratic regimes. As it is well documented, migration is usually not the only option people are left with when faced with violence. People who flee violence could have taken up weapons or do otherwise. Political affiliation plays a central role because people who are somewhat affiliated with the rebel party might not migrate. The decision to stay or flee depends on the expectations of victimization, which is the likelihood of becoming a victim of persecution, and of socio-politico-economic opportunities in destination locations. The decision to relocate depends both on victimization and economic opportunities in both origin and destination places. Results by Hatton (2016) indicate that an increase in terror by 1 point on a scale of 1 to 5 increases asylum applications by 20% while tightening of migration policies in destination countries yields insignificant effects on refugee inflows.

In the model developed by Neumayer (2005), the dependent variable is the number of asylum seekers per annum in western European countries. The equation, which is tested, takes the following form.

$$y_{ijt} = \alpha + \beta_1 \sum_{k=2}^{5} y_{i(t-k)} + \beta_2 x_{it} + \sum_{j=1}^{T-1} \gamma_j D_j + \varepsilon_{it}, where\ \varepsilon_{it} = u_i + v_{it} \qquad (1)$$

The subscript *i* refers to country of origin in year *t*, and *y* is the number of people filing for asylum. The first term on the right-hand side represents the cumulative number of asylum seekers from the same origin and is supposed to capture the social network effect. The variable *x* is a vector of all remaining explanatory variables: economic discrimination, the labour force rate, indicators of autocracy, dissident's violence, state failure, genocide and politicide, food availability, natural disasters, colonial background, contacts with western countries through aid, trade or tourism, etc. *D* represents a set of specific dummy variables capturing lower transportation costs, tighter communication links, facilitating the search for asylum for individuals in all countries of origin, etc.

In other model specifications, such as Ruegger and Bohnet (2018), the dependent variable is the number of co-ethnic refugees from the same origin.

Agent-based models of migration

Agent-based Models (ABM) are supposed to have superior performances compared to alternative models (Suleimenova et al., 2017). ABM are about simulating migration dynamics, therefore circumventing the limitations associated with observational assessments of climate-induced migration (Entwisle et al., 2016). Napoletano (2017) presents the multi-agent model as a framework for analyzing a dynamic economy made up of heterogeneous agents that interact with each other. One of the specificities of the ABM model is that it does not rely on the assumption of perfect rationality of the economic agent. The model considers that agents act with limited rationality in an environment that is too complex to control (Howitt, 2011; Tesfatsion, 2006). In this model, we observe a heterogeneity of the agents and their interactions, which are at the origin of non-linearities in the dynamic system describing the economy.

ABM models describe the dynamic pathway through which the climate-migration relation might operate. ABM considers many types of agents and their dynamic interactions: individuals, land parcels, villages, households, and social networks. Contrary to regression approach, ABM is dynamic, and accounts for interactivity between individuals, demographic changes and adaptation over time. Households are the main points of integration in the model as they are constituted by individuals, and are embedded in villages and social networks, and also manage land parcels. Households can own or rent land and pass it on to other people when they pass away or for whatever reason. Their composition can change when members get married and form a separate household. Households also own land and other assets, and are also central in developing and maintaining networks and connections with the wealthy, within the community. Each individual in the household manifests some important characteristics such as gender, age, and marital status. Individuals are subject to demographic, social, and economic changes such as death, marriage, procreation, or migration. Land parcels also have attributes such as being exposed to flooding, their distance from the village, their size, and the suitability of their soil to different agricultural uses. Villages' attributes include: being an aggregate of individuals, households, and land parcels, the size of their population, their migration patterns, and social network (connectivity). In ABM, the relationship between climate change and migration follows a clear sequencing: rainfall affects crops, crops affect income, income affects assets, and assets affect migration.

Due to the number of agents and their characteristics, the ABM model requires several variables. To deal with all these variables, some authors introduce the Decision Support System for Agro-technology Transfer (DSSAT) by Jones et al. (1998), which provides the logical framework for controlling a variety of inputs such as climate and soil. Doing a simulation from the DSSAT model requires a lot of data. The database used in the article by Walsh et al. (2013) has 405 columns (5 soil types x 9 climate x 3 speculations x 3 fertilization levels). In addition, the DSSAT is a productivity model that uses data on the type of speculation, the type and quality of the soil, the rainfall

and the period of seeds, and the level of fertilization necessary to produce a number of kilogrammes for one crop given per hectare for each piece of land.

Entswisle et al. (2016) in their ABM modelling of climate-induced migration consider four scenarios based on weather dryness. Their crops production function uses the so-called DSSAT (Decision Support System for Agro-technology Transfer) model. In this setting, yield influences income and then assets. Individuals have specific probabilities of migrating or returning, which is estimated through a regression model. In this setting, household assets, marital status and ties to migrants are considered among the explanatory factors of migration. While climate change is found to be strongly influencing yields and assets, it elicits a very limited migration response to climate variables. An already high rate of 40% of the population was migrating in the reference period. Therefore, almost all people who were able and could benefit from migration could already do so.

Gravity modeling of migration

Gravity models are a useful tool to understand migration patterns. They are based on the Newton's law, predicting that interaction between two places depends on "bodies" and "masses" The World Bank (2018) is one of the most up to date application of gravity model in the assessment of migration flows in African coastal areas (Sherbinin, 2021). It assumes that movements between two locations are determined by distance, geography and political barriers. One of the main limitations of this approach is that it does not address individual motivations for migration.

Backhaus et al. (2015) assess the impact of climate change (change in temperature and rainfall) on permanent migration from 142 countries into 19 Organization for Economic Cooperation and Development (OECD) countries using a gravity model, augmented with climate variables. Naudé (2009) investigates the determinants of migration from 43 African countries, considering as environmental variables the sum of seismic and weather disasters in origin countries.

Backhaus et al. (2015) test the following model:

$$lnM_{ijt} = \alpha_0 + \alpha_1 wtemp_{it} + \alpha_2 wpre_{it} + \alpha_3 GDP_{it} + \alpha_4 GDP_{jt} + \alpha_5 DemPres_{it} \quad (2)$$
$$+ \alpha_6 lnPopulation_{it} + \alpha_7 U_{jt} + \alpha_8 Trade_{it} + \gamma_t + \omega_{ij} + \varepsilon_{ijt}$$

Ln M_{ijt} denotes the logarithm of the migration inflows from country i to country j in year t.

The population-weighted average annual temperature in degrees Celsius is denoted by $wtemp_{it}$;

$wtemp_{it}$ denotes average annual precipitation in millimeters;

GDP_{it} (GDP_{jt}) denotes PPP-adjusted GDP per capita divided by a factor 1000 in the origin (destination) country in year t. A squared term of GDP_{it} is also included in all specifications to account for non-linear effects of income in the origin country;

$DemPres_{it}$ denotes the share of young people in the country of origin working age population;

U_{jt} denotes the unemployment rate in the country of destination at time t; and

$Trade_{it}$ denotes the openness ratio (Exports + Imports)/GDP, in the country of origin at time t.

The term ω_{ij} captures country-pair characteristics, while a set of year dummies γ_t captures global shocks. Finally, ε_{ijt} is the error term.

They find climate change in sending countries to be highly associated with emigration. A one degree C increase in temperature is associated with a 1.9 increase in emigration and an additional 1 mm of rainfall provokes an increase in migration by 0.5%.

Household allocation models of migration

In household allocation models, migration results from household labour portfolio diversification strategy under uncertain circumstances, instead of being determined from individuals' own decision. Households optimize the allocation of their members between urban and rural areas based on their objective to maximize current income and mitigate climate risk. It is assumed that the considered household resides in a rural area situated beyond the commuting distance from the neighbouring urban area. Below, we present the Dasgupta et al. (2011) model, which includes varying sequences.

Model 1: household income maximization without insurance

In this model, a household allocates labour to maximize current income:

$$Max\ Y = W_U L_U + A(L_R, S)$$

$$\textbf{s.t}$$

$$\bar{L}_T = L_U + L_R$$

$\bar{L}_T$: Total working-age household members;
L_U: Household working-age members located in the urban area;
L_R: Household working-age members located in the rural area;
W_U: Fixed urban wage;
A: Agricultural output; and
S: Soil salinity

Model 2: Household income maximization with inundation risk

The previous model is augmented with inundation risk and household disaster insurance

$$Y = \mu[A(L_R,S)]^\gamma L_U + W_U L_U + A(L_R,S)V(P)$$

P: Probability that an inundation will occur; $V'(p) < 0$; and

γ: Income elasticity of household demand for disaster insurance.

The final specification of the model is:

$$\eta_{ij} = \beta_0 + \beta_1 T_j + \beta_2 S_j + \beta_3 C_j + \beta_4 C_j \times log E_j + \varepsilon_{ij}$$

Expected signs: $\beta_1, \beta_3 < 0$; $\beta_2, \beta_4 > 0$, where for household i in cluster j

η_{ij}:   Household percent of resident working-age individuals (male or female);

T_j: Travel time to nearest urban center from cluster centroid (hundreds of minutes);

S_j: Average cluster soil salinity in 2011 (dS/m);

C_j: Coastal proximity dummy variable (1 if cluster is within 4 km; 0 otherwise);

E_j: Elevation of the cluster centroid (m); and

ε_{ij}:   Random error term

Model 3: Household income maximization with drought risk

The previous model is augmented with drought risk

$$Max\ Y = W_U L_U + A(L_R,P,TS)V(EW)$$

Urban income   **rural income**

P: Probability that drought will occur; $V'(p) < 0$;

Or EW: probability that extreme weather event happens (drought, floods, water stress, extreme temperature);

s.t

$$\bar{L}_T = L_U + L_R$$

Where:

Y: income

$\bar{L}_T$:   Total working-age household members;

L_U: Household working-age members located in the urban area;

L_R: Household working-age members located in the rural area;

W_U: Fixed urban wage;

A: Agricultural output;

D: Drought; and

E: Erosion

8. Data sources

When analyzing environmental-induced migration in West Africa, the lack of accurate and detailed data on environmental migration flows is a big challenge. The main sources of information on migration are censuses, population surveys and administrative data.

The study reports are mainly produced by international organizations (IOM, World Bank, UNHCR) and the various governmental bodies working on migration in West Africa. These are specifically the Ministry of Employment and the Interior Ministry in charge of migrations, the Ministry of Foreign Affairs (dealing mainly with the diaspora) and the Ministry of National Education.

Countries have individually undertaken various censuses and surveys we can draw upon. Usually, a General Census of Population and Housing (RGPH[6]) has been implemented by many national statistics offices and provides useful information about migrations. Most studies refer to these censuses. Sometimes these data sources are complemented by a survey of a sample of the population in a given area. These specific surveys provide additional information on causes, consequences of migration and others. For example, there are four such censuses carried out in Mauritania, respectively, in 1977, 1988, 2000[7] and 2013. These data are usually supplemented by those of the National Surveys on Migrations conducted within the framework of the Migration and Urbanization Network for West Africa (REMUAO), and the Labour Force Surveys (encompassing a foreign labour force component). We also have administrative sources of data provided by the relevant administration in charge of collecting data related to migration (for example, data collected at the borders by police, and from consular information). This type of information is highly problematic in West Africa, though. Despite the importance of border crossings, there is little data recorded from the borders. It is only the crossing points that are subject to police surveillance where migrants are regularly registered. Again, only travelers with travel documents are registered. The others, which constitute a much larger number, cross the border without any control. Moreover, the data collected are classified using only two different categories: foreigners and nationals for entry and for exit. No additional information, as for example related to gender, age, country of origin, type of mobility (daily, seasonal, long-term, etc) is provided (IOM, 2015; 2016).

Reliable migration statistics are generally hard to locate. From disparate sources using different approaches and methods of data collection and analysis, these data

are indeed difficult to exploit and compare (IOM, 2016). Data gaps are also due to lack of regularly updated censuses and population registers or the non-use of airport data on entry and exit from the national territory.

Another critical issue about data on migration in West Africa beyond being scarce is that the few existing data sometimes diverge in terms of approaches and concepts, which makes comparison and exploitation rather challenging.

Migration models often use different indicators to measure genocide, terror and other forms of persecution. Also, indicators of the level of institutional democracy and functioning are available, so are those related to the size of the diaspora. They also use data on ethnicity and conflict from the Ethnic Power Relations project. Several datasets compile these kinds of data. Below we list a few of them.

The Uppsala conflict data programme index provides data on social networks and economic opportunity that are used in many regression models on migration. Indexes of toughness of asylum policy in destination country are also available. It is accessible here: https://ucdp.uu.se/

Data on political regimes characteristics and transitions can be found here: https://www.systemicpeace.org/polity/polity4.htm

Data on mass atrocities and genocides can be found here: https://link.springer.com/chapter/10.1007/978-3-319-54463-2_12

Data on ethnic power relations can be found here: https://icr.ethz.ch/data/epr/

9. Conclusion

In this framework paper, we investigate the concept of climate-induced migration in West Africa and the many issues regarding data gathering, methodology, and controversies surrounding it. Trends in temperature and rainfall show that West Africa is one of the most exposed regions to the effects of climate change. Climate change, therefore, presents some important challenges to livelihoods, and people's security. While climate change is an important driver of migration, there are many other factors such as conflict, demography, social networks, economic opportunities, and geographical factors such as the terrain, which all come into play in explaining migration trends and dynamics. Failing to account for them might result in spurious assessments of the individual impact of climate change. We have also reviewed major strands of models of climate-induced migration, namely: agent-based models, choice-centred models, gravity model, and household allocation models. The most used data in climate change analyses are also reviewed.

Notes

1. This framework paper was prepared by the LAPD (Laboratoire d'Analyse des Politiques de Développement) affiliated with the University Cheikh Anta Diop of Dakar (UCAD). The authors would like to thank participants in two AERC-sponsored workshops in 2019 and 2020 for useful comments. We have also received important insights from the CCEDA coordinating unit within the AERC, namely John Asafu-Adjaye, Théophile Azomahou, and Abebe Shimeless. We are also grateful to participants at the conference convened by the Centre for International Earth Science Information Network (CIESIN), affiliated with Columbia University for significant inputs on an earlier version of this paper. One anonymous referee also made important comments that highly contributed to enrich the paper. Of course, the usual disclaimer applies.

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3. Moreover, the distribution of the population by age reflects the profile of a young population with 43.5% under the age of 15 and 5.5% over the age of 60.

4. For the RGPH 2000, the structures presented concern all the foreigners in the country, whereas for the EMOE 2007 is limited to the three cities (Nouakchott, Nouadhibou and Rosso).

5. Proportion of Population in Coastal Zones (LECZ)

6. Recensement Général de la Population et de l'Habitat – RGPH

7. Specialized surveys on migration have never been undertaken at national level. The issues dealt with in the RGPH in 2000 are old and limited to the number of migrants and do not allow to deepen the socio-economic characteristics of the migrants identified (see Mohamed-Saleh, 2009). The 2013 RGPH is realized for a more global purpose.

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