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Population dynamics, climate change and variability in Western Africa: the case of Sahel regions

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Abstract

This report is part of the JRC Climate Change Induced Migration (CLICIM) project. CLICIM aims at the provision of evidence on the nexus between climate change and population dynamics in Africa.

In this report, we analyse the relationship between climate change, population and migration in a selected territory within the Sahel – an already documented case of climate related migration. We base the analysis on the recent JRC net migration estimates at high geographical detail, produced in the context of the CLICIM project. Our contribution is twofold. Firstly, the report provides a mapping of the population exposure to climate change in the selected territory over the period 1975–2015. In particular, it identifies the geographical distribution of populations affected by droughts and how their demographic dynamics have changed over time. Second, the report develops a modelling exercise to investigate the climate change–migration nexus. Results from the model confirm a significant association between net migration and drought intensity, which is more accentuated in rural areas. Model findings also document that increasing temperatures and precipitation have contributed to decreasing net migration over the considered period.

Authors and acknowledgments

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1 Introduction

This report is part of JRC Climate Change Induced Migration (CLICIM) project. The objective of CLICIM is to identify the relationship between climate change and migration in Africa, the continent with the fastest projected population growth (Lutz et al., 2019) and one of the most vulnerable to climate change due to its high exposure and low adaptive capacity (Riede et al., 2016). As initial steps, CLICIM has produced estimates of net migration at high geographical detail (Alessandrini et al., 2020) and an extensive review of several indicators of climate change (Petroliagkis & Alessandrini, 2021). The knowledge stemming from CLICIM will feed into the final and complex step of formulating scenarios on how many populations will be exposed and eventually move due to climate change.

The CLICIM project analyses the interconnections between climate change – focusing on slow-onset climatic events such as increasing temperatures (UNFCCC, 2012)- and population long-term mobility at macro-level. It will provide a mapping of populations which are exposed to climate change, particularly in Africa. This mapping exercise, conducted at high territorial resolution, will help to target policy interventions towards areas which are suffering the impacts of climate change both in terms of displacements or trapped populations. From the development perspective, the CLICIM project will take into account how population response to climate change, in terms of migration and mobility, varies with the other factors shaping migration, such as socio-economic development, poverty, and agricultural conditions.

This report examines the complex link between climate change and population dynamics at high geographical detail focusing on a territory within West Africa. Specifically, it addresses the following question: *how population long-term migration and mobility patterns are related to changing climatic conditions?* The report selects a territory between Mali, Senegal and Mauritania, with a long tradition of international migration towards Europe and regional mobility within African continent. The recent policy attention to vulnerable populations in the selected Sahel territories (European Asylum Support Office., 2018) and the growing interest on their migration intentions (Bertoli et al., 2020; Mixed Migration Centre, 2020) justify the focus on this case.

As most of the Western Africa region, the selected territory is characterized by increasing temperatures and highly variable rainfalls since the past decades. Importantly, severe droughts also hit this area in the late 70s and 80s. Scholars have documented how climatic factors have contributed to shape migration and mobility of populations living in this area during the 80s and 90s. In particular, existing qualitative and quantitative studies for the selected territory link out-migration to severe droughts and their negative impacts on food supply. Despite there is no consensus on whether migration from the selected case study area is mostly short or long-term, there is agreement that, in this context, migration and mobility are possible adaptation strategies to cope with the adverse effects of droughts. Yet, a more systematic and long-period overview of demographic and climatic patterns is needed to better understand the role played by climate change on migration dynamics.

The contribution of this report is twofold. First, to provide empirical evidence of climate migration and mobility in the selected territory within Western Africa over the period 1975-2015 using JRC net migration estimates. This constitutes a step to validate the recent net migration at high geographical resolution[1] provided by Alessandrini et al. (2020). Notably, net migration estimates (the difference between in-migration and out-migration) is derived from population estimates of the JRC Global Human Settlement Layer (GHSL)[2] – a combination of satellite and census data. In particular, this report links population and migration data to indicators of slow-onset climatic events, by focusing on areas of about 56 km^2 (or 0.5 degrees). Second, to provide a prototype of the analyses that CLICIM project will carry out for broader areas in Africa.

By overlaying population and climatic data over the period 1975-2015, the report first maps the population that has been exposed to adverse climatic events and describes its dynamics. As a result of the mapping exercise, we document which territories have been hit by extreme and severe droughts in the 80s. As a second step, the report presents a simple modelling exercise to identify the relationship between climate change and migration over the period 1975-2015. Results from the model confirm that drought severity is significantly associated with net migration. If drought severity increases, net migration tends to become lower (in absolute value), with more people out-migrating (or less in-migrating) to the considered territory. Notably, net migration in rural areas is most affected by drought than areas more densely populated. In other words, increasing drought intensity tends to lower net migration more in rural than in densely populated areas. The proposed model also suggests that increasing temperatures tend to decrease net migration. Similarly, the model documents an inverse relationship between precipitation and net migration, with increasing rainfalls associated with net lower net migration (in absolute value).

The report is structured as follows: Section 2 provides an overview of population and climatic patterns in West Africa. Section 3 describes the case study on climate related migration in the selected region, on the basis of existing research. Section 4 describes the main changes of population, net migration, and climatic conditions in the selected case study area. Section 5 maps population exposure to adverse climatic conditions. Section 6 presents the results of a simple modelling exercise to identify the climate change–migration nexus in the selected area. Section 7 concludes.

[1] Visualizations of net migration estimates are accessible here: https://bluehub.jrc.ec.europa.eu/migration/app/index.html#?state=5ee274cf0863ae3229115c38.

[2] https://ghsl.jrc.ec.europa.eu/atlasOverview.php.

2 General context

2.1 Climatic patterns in Western Africa

The Fifth Intergovernmental Panel on Climate Change (IPCC) Assessment Report identifies the main climate trends in Western Africa[3], a heterogeneous region characterized by both arid and tropical zones. In particular, three climatic zones are commonly identified (Parker & Diop-Kane, 2017; Riede et al., 2016) on the basis of geographical differences in precipitation: (a) the Sahelian zone (semi-arid); (b) the Sudanian zone (sub-humid); (c) the tropical humid Guinea Cost zone.

Observed historical data (IPCC, 2014a, 2014b; Riede et al., 2016) suggest that Western Africa since the 1950s is experiencing an increase in annual mean temperatures and extreme climatic conditions, such as the rise in the number of warm days and nights and the decrease in the number of cold days and nights. Western Africa, in particular the Sahel, has been hit by several droughts in the 70s and 80s. Precipitation is subject to greater uncertainty than temperatures due to their higher seasonal and geographical dependence (Riede et al., 2016). Hence, precipitation trends are more difficult to be identified and understood than temperatures trends. This is the case in Western Africa where, after a decrease of rainfalls in the 20th century, a recovery of precipitation has been observed over the last 20 years. The interpretation of the observed recovery in precipitation is controversial and debated among scholars[4].

In this report, we focus on droughts that affected Western Africa in the late 70s and 80s. In particular, we zoom in on a region within Sahel, at the intersection between Mali, Senegal and Mauritania. We select this region since existing research has documented how out-migration from this area is related to the mentioned droughts (Section 3). Despite several difficulties in measuring droughts intensity and the lack of directly observable measures of droughts (Box 1), there is consensus on the fact that West Africa is affected by rising dryness (Riede et al., 2016).

[3] Henceforth, we follow the definition of Western Africa provided by the United Nations Statistic Division (UNSD) classification of Geographic Regions (https://unstats.un.org/unsd/methodology/m49). It should be noted that IPCC refers to the ECOWAS countries to indicate West Africa (Riede et al., 2016). We refer to the United Nations Statistics Division classification since it includes Mauritania, which is a country of interest for our case study.

[4] While some studies attribute the recovery of precipitation in West Africa to increase greenhouse gases or reduced aerosol, some others interpret is as natural variability (for a short review, see Riede et al., 2016) .

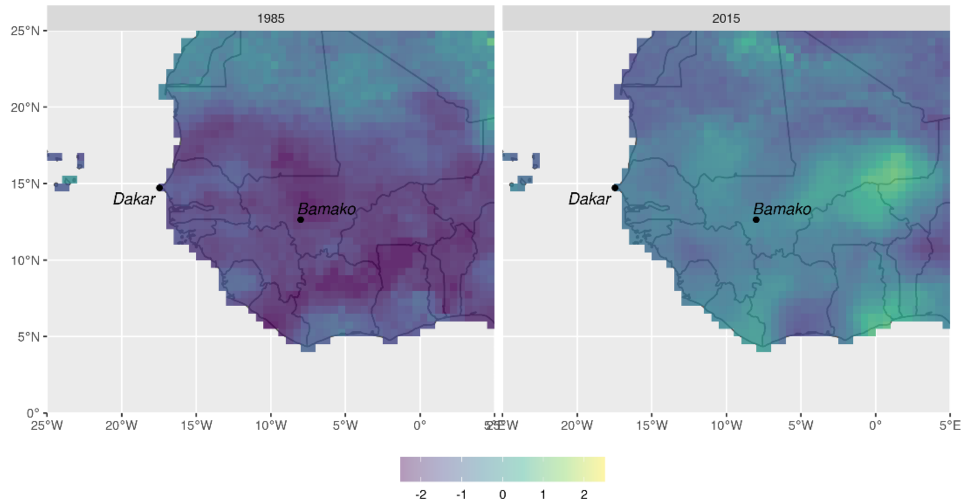
Figure 1 shows the evolution of drought intensity on the basis of the Standardised Precipitation-Evapotranspiration Index (SPEI), one of the most commonly used measure of droughts (for details, see Box 1). The colour purple represents more intense droughts or water deficits (which corresponds to negative values of the SPEI), while yellow indicates water surpluses (corresponding to positive values of the index). When comparing the SPEI over time, it emerges that 1980-1985 was the period when Western Africa was most severely affected by droughts with an average SPEI of -1.57, which corresponds to intense drought (see Box 1). 1990-1995 and 2010-2015 are the less affected periods, recording an average SPEI of -0.68 and -0.35, respectively, i.e. values classified as normal hydrological conditions.

— **Box 1– How is drought measured?**

Climate experts hardly agree on indices to measure drought. Droughts usually become evident after long periods without precipitation although it is difficult to establish their onset, extent, and end (Vicente-Serrano, Beguería, & López-Moreno, 2010). Different indexes have been developed to assess and monitor drought, such as the Palmer drought severity index (PDSI), the Standardised Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI). The PSDI is based on the concepts of water demand and supply and it is calculated by taking into account precipitation, moisture and evaporation (Vicente-Serrano, Beguería, & López-Moreno, 2010). The SPI and SPEI are multi-scalar indexes of drought; while the former takes into account precipitation, the latter takes into account both precipitation and temperatures. Despite being the most commonly used tools to assess and monitor droughts, these indexes have some caveats (for instance, different rankings of the intensity of drought can be obtained depending on the indexes used and their characteristics; for a discussion, see Riede et al., 2016).

In this report, we use the SPEI. This is a multi-scalar index which combines information on temperature variability and precipitation to assess the severity of drought (Vicente-Serrano, Beguería, & López-Moreno, 2010). Specifically, the SPEI is based on climatic water balance, given by the difference between precipitation and evapotranspiration. Negative values of the SPEI indicates water deficits and positive values water surpluses. In this report, we refer to the classification of drought intensity of Li et al. (2015). Specifically, SPEI values less than -2 indicates extreme drought; values between -1.99 and -1.50 severe drought; values from -1.49 to -1 moderate drought; values between -0.99 and 0.99 normal hydrological conditions. Symmetrically, positive values indicate moderate wet conditions (from 1 to 1.49), severe wet conditions (from 1.50 to 1.9) and equal or above 2 extreme wet conditions. The SPEI can be calculated by referring to different time scales over which water deficits or surpluses accumulates – usually from 3 to 48 months (Vicente-Serrano, Beguería, & López-Moreno, 2010). We use the SPEI calculated for 48 months since we are interested in how long-term variations of water balance affects net migration over 5-year periods.

Figure 1 Drought indicator in Western Africa, 1985 and 2015



Notes: SPEI at resolution of 0.5 degrees. The time scale of the SPEI is 48 months. We show the SPEI of June of calculated at the end of each 5-year period. For instance, for 1985, we use the SPEI calculated in June 1985 which refers to water balances or surpluses cumulated in the preceding 48 months. The SPEI for all the other periods included in the analysis is reported in Figure 13 in the Appendix. Data source: S. M. Vicente-Serrano et al., (2010).

2.2 Changes in Western African population

According to UN DESA estimates[5], population in Western Africa has increased by about 214 million over the past 35 years, from about 138 million in 1980 to about 352 million in 2015 (155% as relative change). This implies that region has significantly contributed to the population growth of the African continent as whole[6]: in 2015, 30 out of 100 African people were from a Western African country.

In line with JRC estimates (Alessandrini et al., 2020) based on satellite and census data from JRC GHSL (Pesaresi et al., 2019), population size varies greatly across countries, with that of Nigeria (estimated 176 million) alone being up 54% of the total population. The remaining proportion is constituted by 15 countries (Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Senegal, Sierra Leone and Togo). When comparing the relative weight of the population of each country in Western Africa in 1980 with 2015 (Figure 2), Mauritania and the group indicated as other (which includes Liberia, The Gambia, Guinea-Bissau) remain the least populous countries as they were in 1980. Main changes in the relative weight of population are recorded in Benin, Côte d'Ivoire and Niger – their relative weight increased of one percentage point from 1980 to 2015.

[5] https://population.un.org/wpp/

[6] Africa's share of the world population ranges from 10.8% in 1980 to 15.9% in 2015, and this proportion seems poised to reach 24% in 2050 (European Commission, Joint Research Centre, 2017).

Figure 2 Western African population by country, 1980 and 2015

Notes: Legend: Country population in million and share of Western Africa population reported. BEN Benin, BFA Burkina Faso, CIV Côte d'Ivoire, GHA Ghana, GIN Guinea, MRT Mauritania, MLI Mali, NER Niger, NGA Nigeria, SEN Senegal, SLE Sierra Leone, TGO Togo, Oth (other) includes Cabo Verde, Guinea-Bissau, The Gambia, Liberia. Data source: (Alessandrini et al., 2020).

Over the 1980-2015 period, the population of West Africa as whole grew at an average annual rate of about 4%, with a significant country variation over the region. The country that reported the highest growth rate was Niger (6.2%), followed by Benin (5.7%), while the lowest rate was achieved by Sierra Leone (2.5%).

Heterogeneity in population growth may be explained by the differences in the country's demographic transition pathways[7]. As argued by Bongaarts & Casterline (2013), before 1980, differences in fertility regime among African regions were relative modest (with an average total fertility rate of seven births per woman). Yet, in 1980s, fertility decline started becoming relevant in several Eastern and Southern regions. By contrast, the majority of Western African

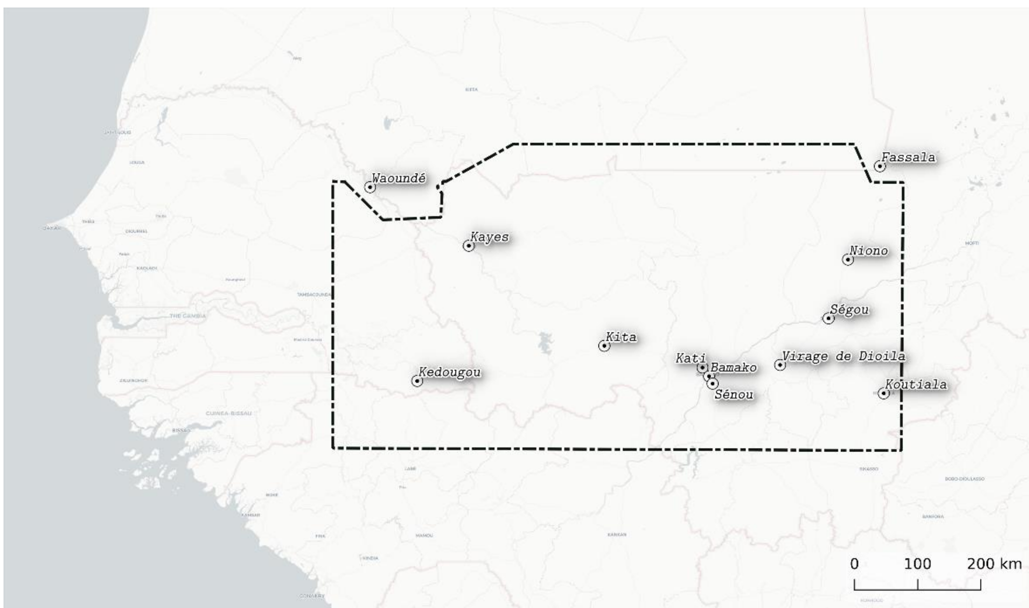
[7] In the initial phase of the process, the number of deaths (mainly due to infant mortality) begins to decline while the number of births stands at high levels. Under this regime, the combined effects of high-birth and low-death rates can result in a rapid increase of population size.

countries continued experiencing pre-demographic transition levels. When looking at the latest decade, from 2005 to 2015, the average annual population growth rate declined also in the Western African region (at about 3.1% for the region as whole), being lower than the average annual growth rate over the period from 1980 to 2000 (about 3.3%). Nevertheless, this acceleration in the demographic transition in the latest decade is limited to some countries, such as the Côte d'Ivoire (2.2%), Liberia (2.4%) and Guinea (2.5%), while in others, such as Niger, population growth rate stalls at 4%.

3 Case study

In this report we focus on a case study documented by previous qualitative and quantitative research in an area between Mali (region of Kayes), Senegal and Mauritania (Figure 3). This is mainly a rural area, except for the towns of Bakel in Senegal, Yélimané, Kayes and the Mali capital of Bamako. The main crops in these areas are cereals, in particular maize, rice, millet, sorghum (FAO/GIEWS, 2020a, 2020b). The area considered has been hit by prolonged and intense droughts between the late 70s and the 80s. Previous studies documented that migration and mobility strategies have been adopted to face the scarcity of food supply during prolonged periods of drought (a review of selected studies for this area is provided in Section 3.1).

Figure 3 Case study selected area



Notes: authors' elaboration.

Two elements are of particular importance for this case study. First, migration out of this area tends to follow established migratory routes and existing migration networks and links with destination regions. Before the droughts in the late 70s and 80s, this area was characterized by out-migration, which originated as seasonal migration of Soninke people in the colonial period. This seasonal migration has then transformed into long-term international out-migration, directed mainly to France (Gonin & Lassailly-Jacob, 2002). Even though there is no consensus among scholars on whether out-migration after the droughts was mainly *long-* or *short-term*, there is a recognised association between drought and out-migration, contributing to enforce traditional migration patterns. In other words, climate change is highly interconnected to other migration drivers. Disentangling socio-economic drivers and climatic factors is a complex task (Migali et al., 2018) and it will be one of the objectives of the CLICIM project.

The second crucial element identified by existing research for this area is that out-migration is one of the possible adaptation strategies to cope with food shortages related to drought and water scarcity. Indeed, in a period of prolonged drought, the traditional household adaptation strategies - such as the use of substitution food – may not be sufficient to satisfy the demand for food. In addition, food shortages, combined with increasing demographic pressure and other migration drivers - such as migration networks previously built up by Soninke group - would push family members to move to other areas, either neighbouring or abroad.

3.1 Drought and migration: evidence from qualitative and quantitative studies

Among the wide literature on the topic, we have here selected a few studies related to the specific area of Sahel; their relevance has been also well documented in (European Asylum Support Office., 2018).

Gonin (1997, 2001), Gonin & Lassailly-Jacob (2002) papers are based on both qualitative and quantitative studies – carried out in the area of the basin of the Senegal river between Senegal, Mali and Mauritania, with a focus on the Malian Kayes region. (Gonin, 2001; Gonin & Lassailly-Jacob, 2002) refer to a survey conducted in 1996-1997 in four villages in the region of Kayes among 32 households (about 1800 individuals), consisting of a non-representative sample of households in the region. Specifically, respondents are asked about the migratory experiences of their family members. (Gonin, 2001) finds that 40% of males aged 15-54 moved abroad, mainly to France. Moreover, survey respondents suggest the presence of migratory networks, composed by people moving to the same destination where their family members have previously migrated. In other words, young people from the villages in the area of Senegal river, between Mali, Senegal and Mauritania, take advantage of the existing migratory channels, especially to France. These migrant networks have transformed Soninke seasonal emigration in the colonial period into long-term out-migration, directed mainly to France. According to (Gonin & Lassailly-Jacob, 2002), since the beginning of the 80s, food shortages that followed the prolonged period of drought, combined with increasing food demand stemming from demographic pressure, further forced young people to out-migrate following the established migration routes. This further contributed to the decline of food supply due to the decrease of labour force in agriculture. Those areas where migration networks were not established (Bafulabe, Bakel, Matam) also faced out-migration of people after the prolonged drought. Even in this case, out-migration tends to follow the established mobility and trade patterns of Sonike people. The complex link between drought and other political events (such as the revolution in Mali in 1990; the regularization of immigrants in France in 1981) that could have fostered out-migration since the 80s is also discussed by the Authors. They conclude that droughts during the 70s and the 80s did not provoke international mass migrations towards the most common migratory destinations. However, out-migration continued from areas with an existing tradition of international migration and started in areas where this tradition was not established. Importantly, migration has become a strategy to cope with water deficit and food shortages.

Findley (1994) analyses migration patterns before and after the 1983-1985 drought in Mali, by focusing on the upper Senegal River Valley, precisely in the region of Kayes. The study is based on a panel household survey conducted before and after the 1983-1985 drought - in 1982 and 1989, respectively. The sample consists of 309 households, about 7000 individuals.

The paper finds that during the drought migration, on average, did not increase. However, this area was already characterized by a tradition of out-migration, with more than 60% of households receiving remittances from family members previously out-migrated. The most important changes after the drought are related to the type of migration – from *long- to short-term* - the destinations as well as the composition of the migratory flows. In particular, 44% of the sample out-migrated during the 1983-1985 drought, a share consistent to that of the previous year. There was a marked increase of short-cycle circulation, defined by Findley as migration with duration from 1 to 6 months, which constituted about 29% of all migration movements before the drought and 63% after the drought. It should be observed that this is in contrast with the previously mentioned studies, which document an increase from seasonal-short term migration to more prolonged migration journeys. While before the drought half of migrants are directed to France and the rest to Mali and other African neighbouring countries, during the drought 42% of destinations are within Mali and migration to France decreases. Finally, during the drought more than half of short-term migrants are female (while about 40% of long-term migrants are female). Short-term migrants are also on average poorer than long term migrants. The predominance of women and children among short-term migrants represents an adaptation strategy of households to cope with food shortages caused by drought and smooth food consumption in the poorest households.

A recent study (Defrance et al., 2020) analyses climate induced migration in Mali over the period 1987-2009, by focusing on drought events that hit the country since the 80s. By combining census and climatic data at high geographical detail (0.5 degrees), the study finds that drought has increased out-migration from rural to urban areas in Mali. The effect of drought on net migration differs across Malian regions and depends on the different capacity of households to adapt to climatic conditions. The study also estimates an increase of international migration from Mali over the period 2004-2009 that can be related to the dryness that affected Mali in the 2000s.

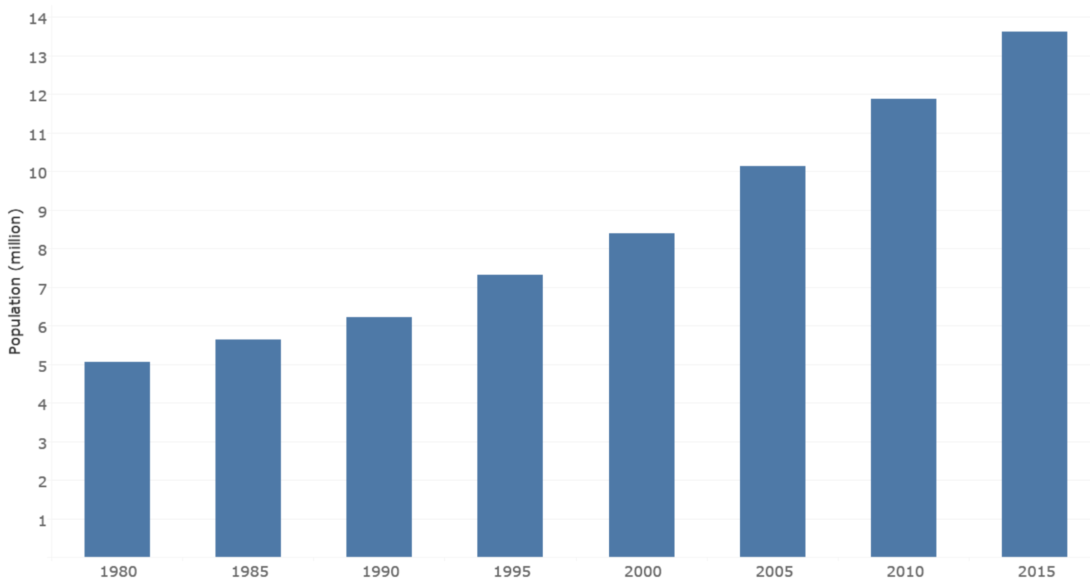
4 Population, net migration and climate in the case study area

The aim of this section is to briefly describe the main changes of population and net migration, as well as the main patterns of climatic conditions in the selected case study area. The data presented here will be then used for the mapping of population exposed to adverse climatic conditions (Section 5) and for the modelling exercise of the relation between climate change and migration (Section 6).

4.1 Population

This report uses population estimates at geographical detail provided by Alessandrini et al.(2020) on the basis of JRC GHSL data (Pesaresi et al., 2019). Specifically, for each territory of about 56 km^2 (or grid cell), we provide annual population estimates every 5 years. The case study selected area consists of 144 territories distributed by country as follows: 14 in Guinea, 101 in Mali, 10 in Mauritania, 18 in Senegal and 1 in Burkina Faso. As overall, population residing in this area ranged from 5 million in 1980 to 13.6 million in 2015. Population growth was about 2%[8] when comparing population size in 1980 with population size in 1985, as well as in 1985 with 1990. It increased thereafter (3.9%) – i.e. when comparing 2000 and 2005.

Figure 4 Population in the case study selected area, 1980-2015



Notes: Data source: Alessandrini et al. (2020).

The accelerated change in population size is mirrored by the average population density (inhabitants per km^2), varying from an average, at the grid cell level, of 12 inhabitants per km^2 in 1980 to 31 in 2015. The area of Bamako records a population of about 3.7 million in 2015 and an average population density of 310 inhabitants per km^2 in the same year. Population has mostly increased in urban areas. For instance, the population of Bamako recorded a relative change of 54% from 2005 to 2015. Similarly, its density has grown from

[8] Henceforth, the compound rate is computed as r=[(Pop_t+5/Pop_t)^(1/5)]-1 as in Alessandrini et al.(2020) – in line with (United Nations. Department of Economic Affairs, 1974).

about 200 inhabitants per km^2 in 2005 to about 310 inhabitants per km^2 in 2015. Urban population increase is expected to continue in the near future with several implications also for climate development policy, as pointed out in the 5th African Union – European Union Summit with the Addis Ababa Action Agenda on Financing for Development (Agenda, 2015).

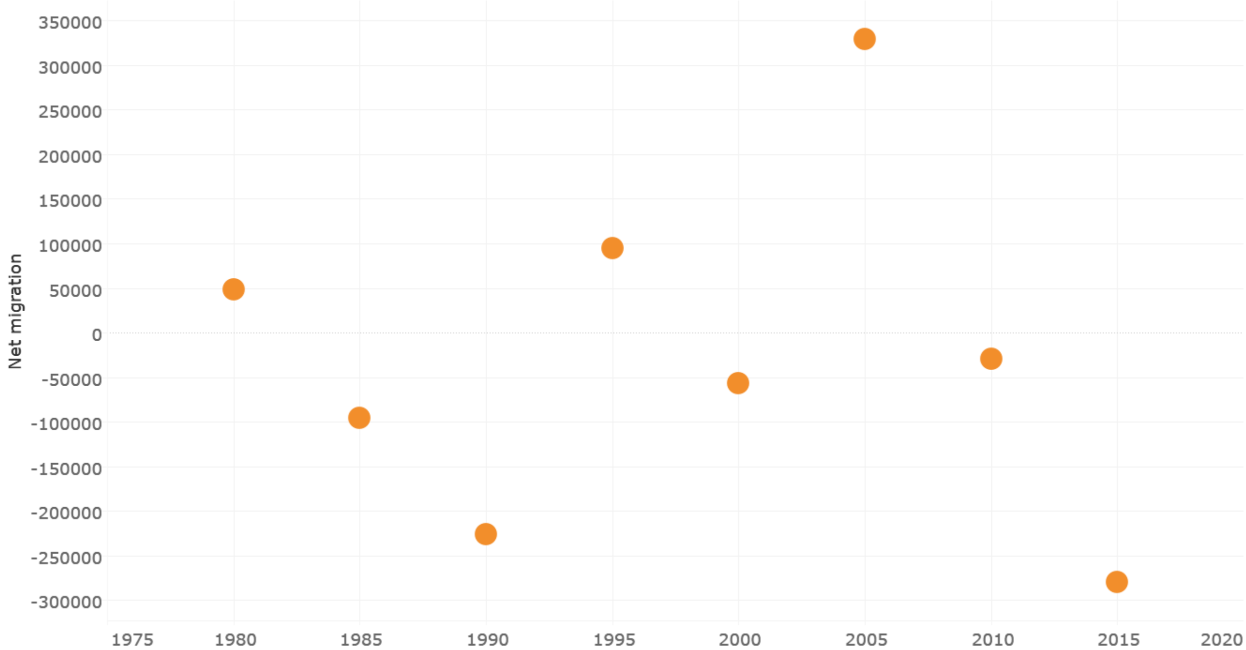
4.2 Net migration

This report uses 5-year net migration estimates referring to territories of about 56 km^2 recently developed by the JRC (Alessandrini et al., 2020). Net migration is defined as the difference between the number of immigrants and emigrants[9] in a given territory. Positive net migration indicates an excess of people in-migrating (or entering the territory) over people out-migrating (or leaving the territory). Hence, it could be interpreted as a population gain. On the contrary, negative net migration, an excess of out-migration over in-migration, can be interpreted as population loss. It should be mentioned that the net migration estimates that we use in this report refers to 5-year intervals. For example, 5-year net migration in 1980 refers to the difference of in-migration and out-migration over the period 1975-1980. This implies that short-term movements happening within the 5-year interval are not captured.

Figure 5 plots 5-year net migration for the selected case study area. After a positive net migration in the first period (1975-1980), net migration becomes negative in the subsequent two periods (1980-1985 and 1985-1990). A downtrend can be observed from 1995-2000 to 2000-2005 (-160%), and a peak is recorded in 2005-2010 when net migration reached the highest level (around 329 000) over all-periods, falling to the lowest one (-279 900) later in 2010-15. Negative net migration in the first periods indicates that, overall, the selected area experiences an excess of out-migration over in-migration (contributing to population loss). This confirms that the area considered is characterized by out-migration even since the 70s, as documented by previous studies. Sustained levels of out-migration during and after the droughts in the 70s and 80s can explain the fact that net migration becomes more negative and reaches the lowest level of about -226 000 over the period 1985-1990.

[9] https://ec.europa.eu/eurostat/statistics-explained/pdfscache/2124.pdf

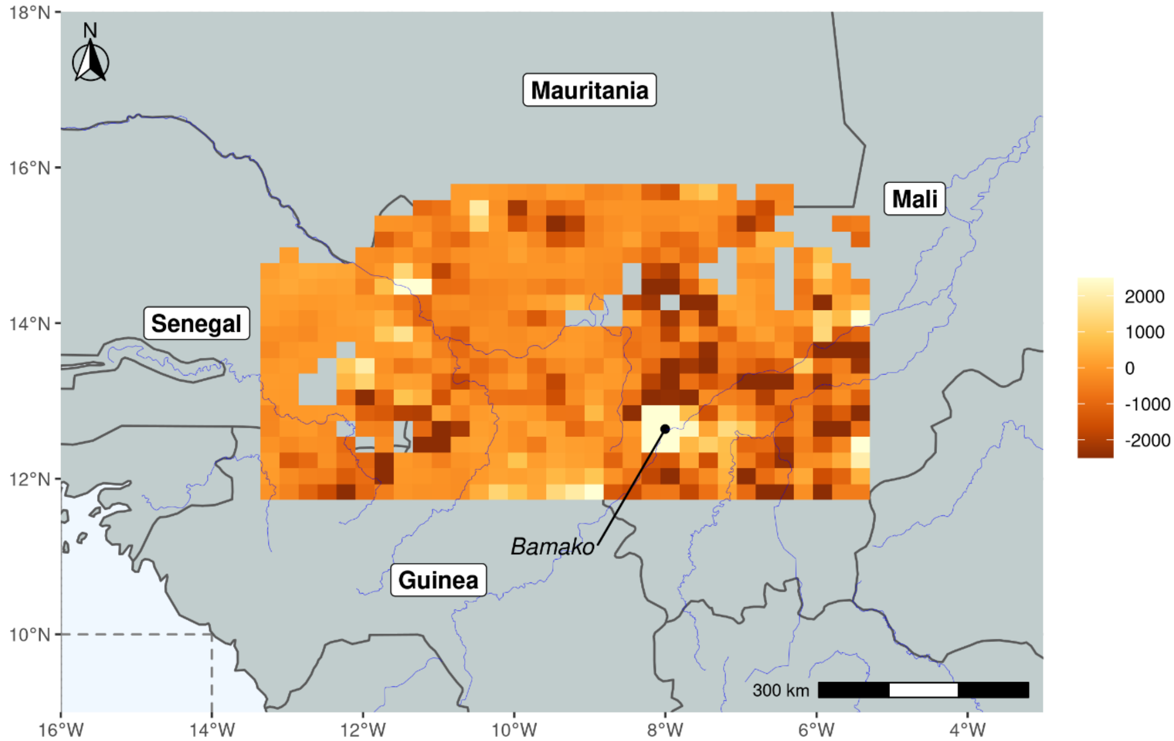
Figure 5 Net migration in the case study selected area, 1980-2015



Notes: data source: Alessandrini et al. (2020).

Positive net migration observed in the subsequent periods could be explained by urbanization processes. Specifically, in 1990-1995 and 2000-2005 net migration reaches values of about 94 000 and 329 000, respectively. The two positive peaks could be related to the development and urbanization process of the area of Bamako. In other words, positive and increasing values of net migration can be interpreted as the attractiveness of the area, characterized by an excess of in-migration over out-migration. The urbanization process can be better visualized in Figure 6, where the cells with positive net migration (light yellow) correspond to the area of Bamako. When the area of Bamako is excluded from the analysis, net migration in the area considered is negative in all periods (Figure 17 in the Appendix). A part from the area of Bamako, Figure 6 confirms that most of the cells in the area considered experience population losses (orange).

Figure 6 Net migration in selected region, 2000-2005.



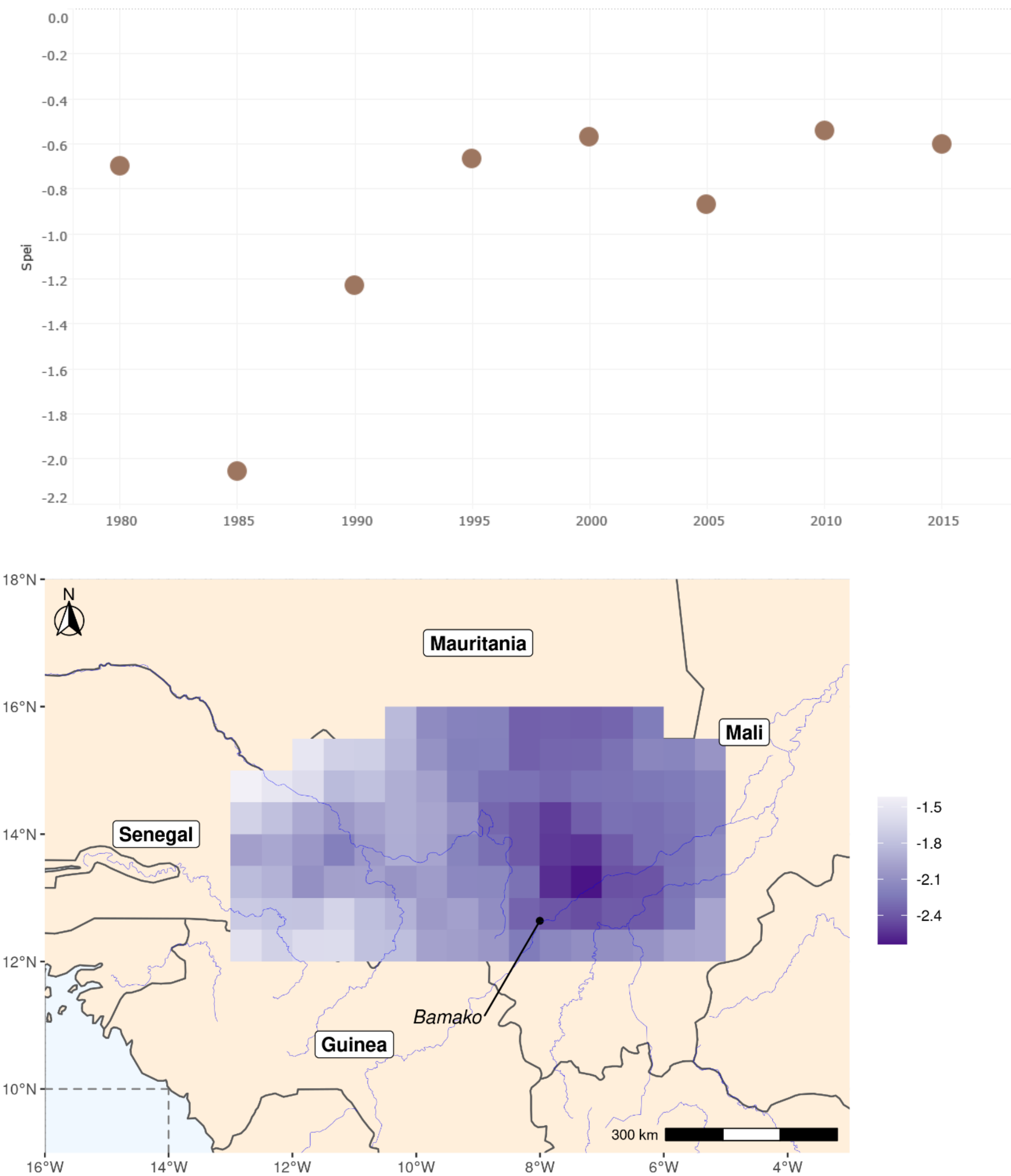
Notes: data source: Alessandrini et al.(2020).

4.3 Climate

As mentioned in Section 2, three main climatic patterns can be identified for Western Africa on the basis of past observations. The period of drought in the 70s – 80s; the gradual increase of temperatures since 1950; the irregular pattern of precipitation, with decreasing rainfall in the 20th century followed by a recovery. In the modelling exercise, we include three indicators to measure the mentioned patterns: the SPEI for drought, minimum temperatures, and precipitation (for details see Table 1 in Appendix and Petroliagkis & Alessandrini, 2021). The focus on minimum temperature is motivated by the existing evidence on the relationship between temperature minimum values and crops (see, for instance, Peng et al., 2004; Sultan et al., 2019). As a next step, the CLICIM project will include a broader set of different climatic indicators – as those provided by Petroliagkis & Alessandrini (2021).

The following figures zoom in on the selected area and plots the evolution of the mentioned climatic indicators. Figure 7 shows the evolution of the SPEI. An increasing trend of the SPEI can be observed, indicating improving water balances from 1975 to 2015. The early 80s are hit by the most severe dryness and water deficits, with the SPEI ranging from the extreme values of -2.6 and -1.4.

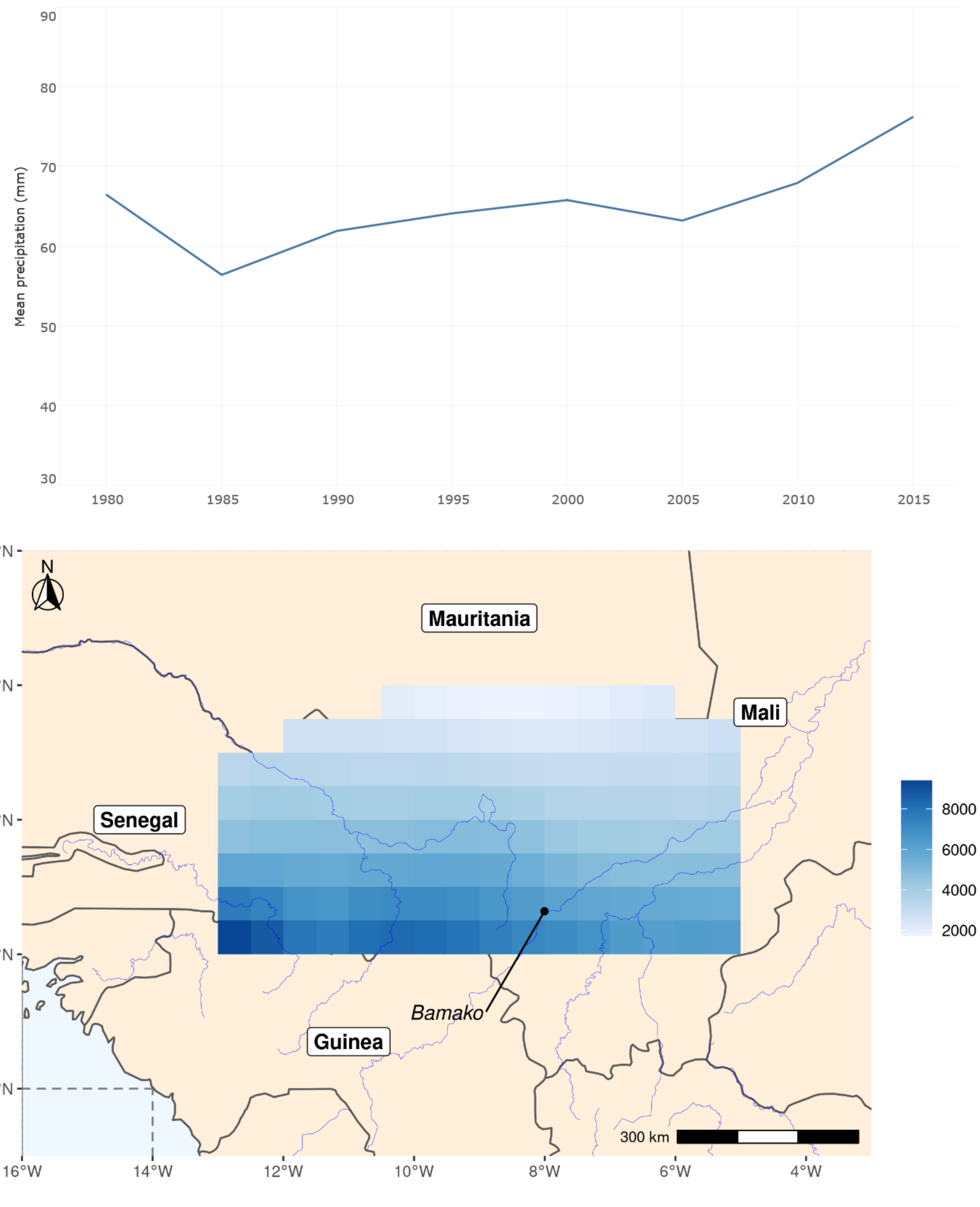
Figure 7 SPEI in the case study selected area



Notes: the upper panel plots the 48 months SPEI averaged for the selected area, 1980-2015. As in Figure 1, we show the SPEI of June calculated at the end of each 5-year period (for details on the indicator, see Appendix, Table1). The bottom panel shows the SPEI in 1980-1985 (resolution 0.5 degrees). Data source: authors' elaboration based on S. M. Vicente-Serrano et al. (2010).

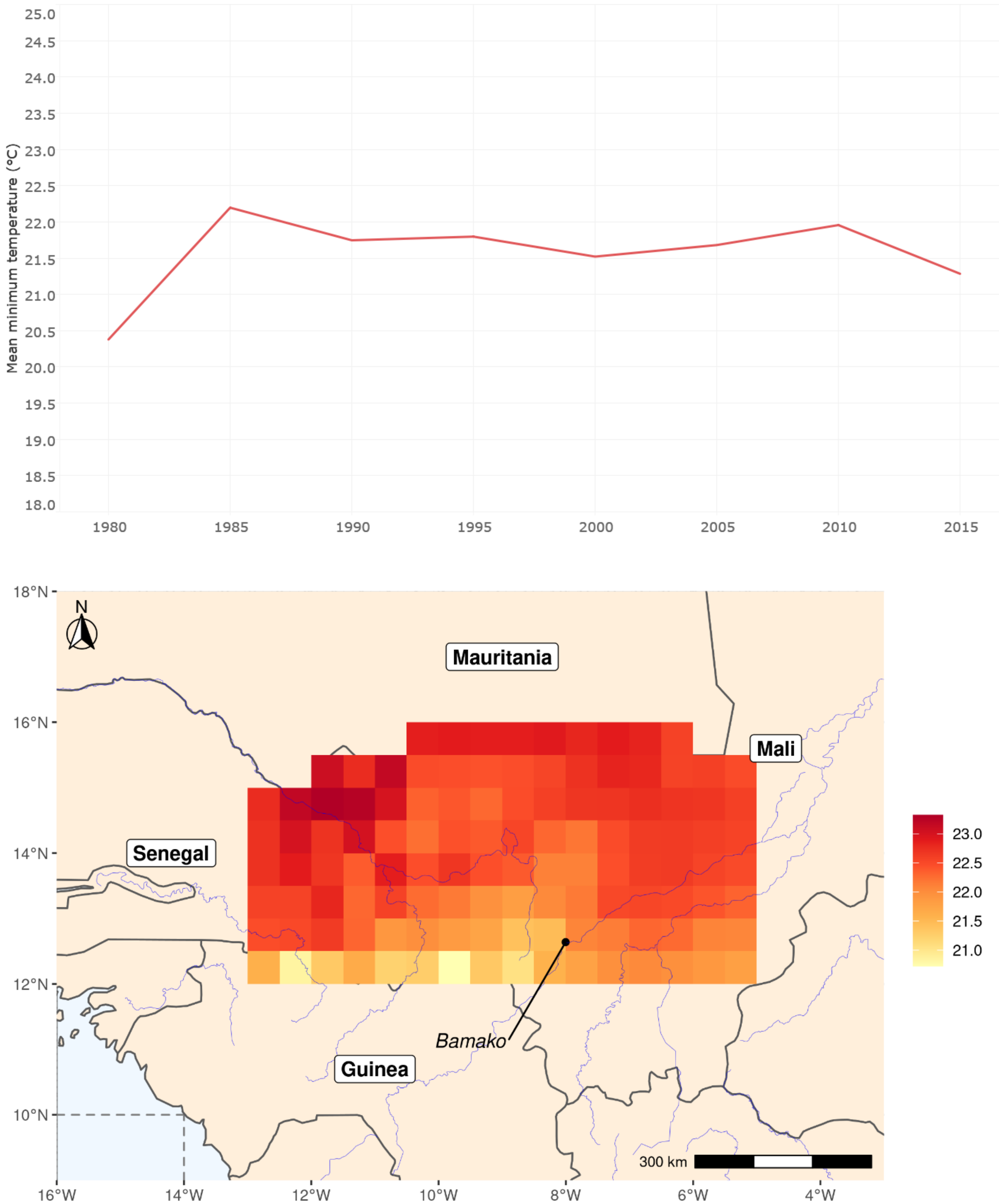
Figure 8 plots total monthly precipitation, averaged over 5-years. The lowest values of precipitation can be also observed in the period 1980-1985. The map in Figure 8 focus on the period 1980-1985 that records, on average, the lowest level of precipitation (of 56.4 mm). The same period – 1980-1985 – records also the highest values of minimum temperatures, with an average of 22.20 C° (Figure 9).

Figure 8 Precipitation (in mm) in the case study selected area



Notes: the upper panel shows the estimated 5-year average of total monthly precipitation (in mm) averaged for the selected area, 1980-2015 (for details on the indicator, see Appendix, Table 1). The bottom panel shows the estimated 5-year average of total monthly precipitation (resolution 0.5 degrees) in 1980-1985. Data source: authors' elaboration based on Willmott & Matsuura (2001).

Figure 9 Minimum temperature (in °C) in the case study selected area

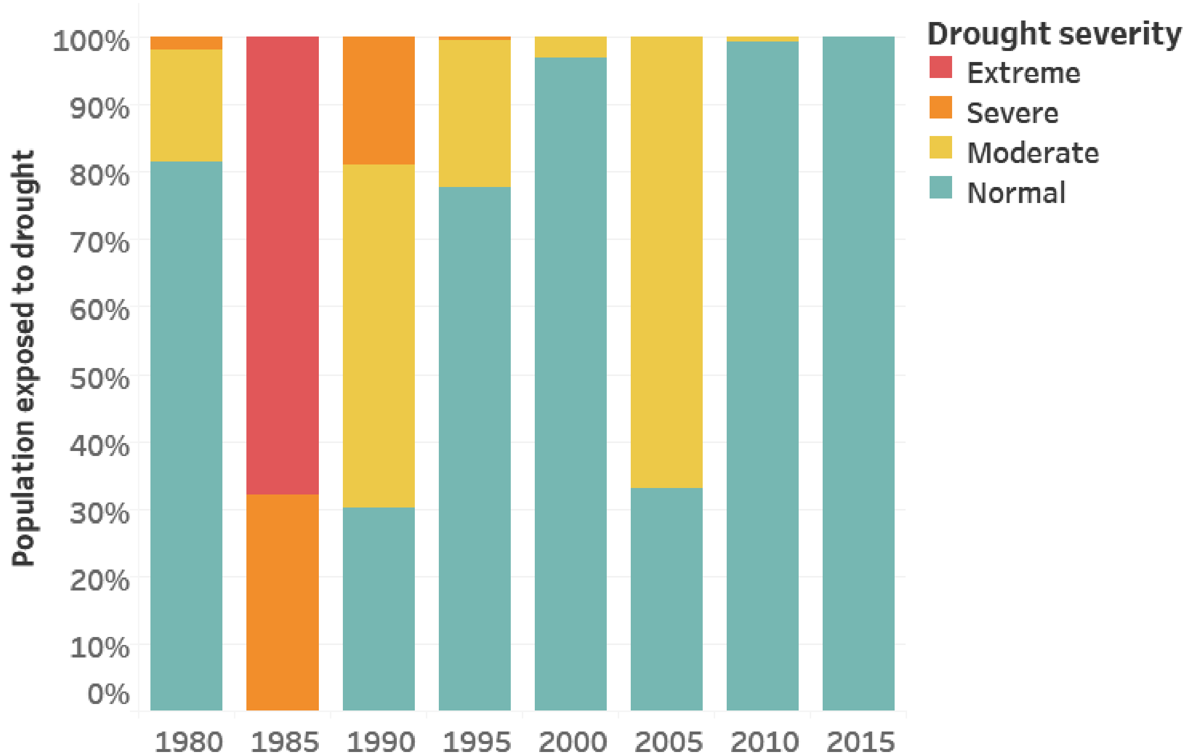


Notes: the upper panel shows the estimated 5-year average of mean minimum temperatures (in °C) – averaged for the the selected area, 1980-2015 (for details on the indicator, see Appendix, Table 1). The bottom panel shows the estimated 5-year average of mean minimum temperature in 1980-1985 (resolution 0.5 degrees). Data source: authors' elaboration based on Mistry, Malcolm Noshir (2019).

5 Mapping population exposure to climate change

The aim of this section is to map the population that has been exposed to climate change over the period 1975-2015 in the selected case study area. The population exposure to drought can be defined as the number of people exposed to moderate, severe and extreme drought (Chen & Sun, 2019). Figure 10 plots the percentage of population exposed to droughts of different severity in the case study area. Drought severity is defined according to the thresholds values of SPEI reported in Box 1. The period from 1980 to 1985 is the most affected by droughts, with almost all territories in the case study area experiencing extreme or severed severe droughts[10]. Indeed, in this period all population has been exposed to drought. Specifically, about 32% of population (about 1.7 million) is exposed to severe drought and 68% (about 3.6 million) to extreme drought.

Figure 10 Population exposed to drought (percentage) in the case study area



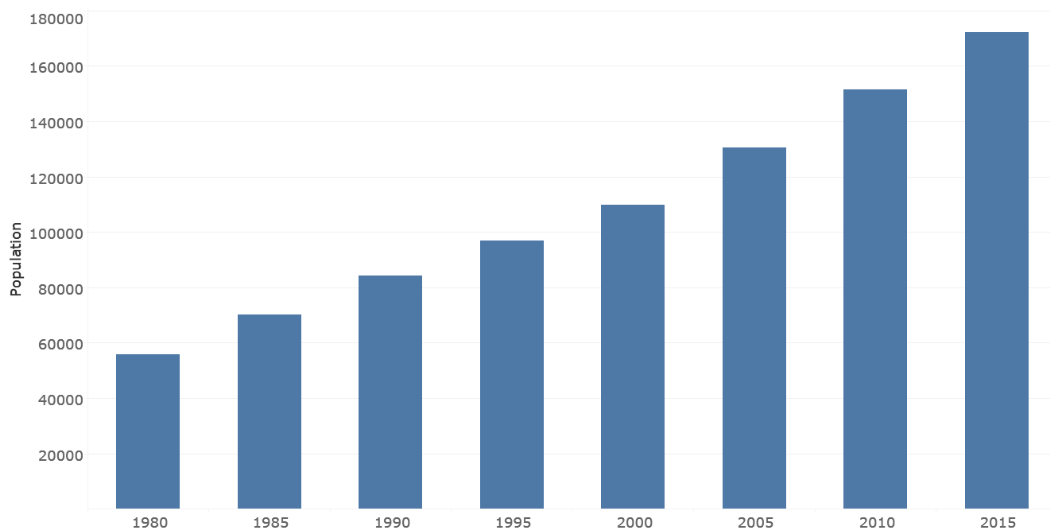
Notes: population refers to the average 5-year population.

In the period from 1990 to 1995 the SPEI does not take values lower than -2, which corresponds to extreme drought. In this period, half of the population is exposed to moderate drought (about 3 million) and 19% to severe drought (1.1 million). The conditions improve in the subsequent 5-year interval, when less than 1% of the population is exposed to severe drought and 21% to moderate drought. In the most recent periods, SPEI indicates normal hydrological conditions, with the exception of 2000-2005, when 67% of the population (corresponding to about 6.2 million) is exposed to moderate drought.

[10] In 1980-1985, only two territories (or cells) – corresponding to about 1% of the selected case study area - have a SPEI of -1.4, which is classified as moderate drought.

We identify populations exposed to severe and extreme drought in 1980-1985. One example is constituted by populations in the territory of Bakel. Changes in population size are plotted in Figure 11 for the territory of Bakel. Historically, this area was populated by Soninke, which belongs to the pre-colonial indigenous Muslin merchants who used to travel across the Sahel region, from Eastern Mali to the Atlantic coast (Bathily, 1989); from the 1950s, Soninke emigration started reaching the European continent, in particular France, where they became one of the largest immigrant communities (Section 3). Some authors have argued that migration was a rite of passage by Soninke male youths achieving adulthood (Jónsson, 2007). As visualised by Figure 12 in the Appendix, the territory of Bakel is one of the areas that has suffered from climatic constraints over the last decades. Precisely, the population in the territory of Bakel is exposed to severe droughts in 1975-1980 and 1980-1985 and moderate droughts in the two subsequent periods.

Figure 11 Bakel territory: population (1980-2015)



6 Estimating climate induced migration

This section provides empirical evidence of climate induced migration in the selected case study area using the new JRC estimates of net migration (Alessandrini et al., 2020). The aim of this section is twofold. First, to validate net migration estimates through the examination of the case study described in Section 3. Second, to provide an example of the analytical potential of CLICIM project through a simple modelling exercise of the climate change migration nexus.

To identify the relation between climate change indicators and net migration in the case study area, we present the results from a regression model using 5-year net migration over the period 1975-2015 as the dependent variable and climatic indicators - temperatures, precipitation, or drought – as the main independent variables. Details on the regression models are provided in Box 2 below.

— **Box 2 – Modelling the climate change-migration nexus**

In this report, we estimate the relationship between climate change and net migration by using panel data models with fixed effects. Indeed, we have a panel dataset consisting of 144 territories of about 56 km^2 from 1975 to 2015, every 5-years (in other words, we have 8 time intervals). In the panel data model, the dependent variable is net migration; the independent variables of interest are climatic conditions (temperatures or precipitation averaged over 5-years; drought referring to 48 months). As control variable, we include the population density of the cells, averaged over 5-years[11].

It should be mentioned that there are characteristics of the territories that do not change over the period considered. Some of the time invariant characteristics are observable – such as geographical factors, distances of a territory from a specific location, context or territory specific cultural and institutional aspects that have not changed over time. Some other characteristics of the territories that do not change over time may be unobservable. One example of an unobservable time invariant characteristics could be the propensity of a territory to attract population or to be resilient to climate change. A problem arises if the unobservable characteristics of the territories are correlated with the control variables, such as climatic conditions and population density. This may well be the case. For instance, the resilience of a territory may be related to the density of the population or the type of climatic slow-onset events the territory is exposed to. These interconnections could make difficult to isolate the effect of climatic conditions on net migration and disentangle it from the unobservable factors. To address this problem, in this report we model the climate change migration nexus through panel data models with fixed effects. These models, that exploit the variability over time of climatic conditions within cells, provide a way to get rid of the factors that do not change over time. Hence, they allow to disentangle the effect of climate change from those factors. This advantage comes at the expense of not being able to evaluate the effect of observable time invariant characteristics on net migration - such as distances.

[11] As a caveat, it should be noted that using 5-year averages of the climatic indicators reduces their variability. However, we are interested in capturing the long-term association between climate change and net migration.

In other words, the results of the fixed effects models reported in the Appendix should be interpreted as the long-term association between climatic conditions and 5-year net migration, after taking into account population density and all the other characteristics of the territories that have not changed over the period considered. These characteristics can be interpreted broadly – such as all geographic, context, cultural, institutional aspects of the territories that have not evolved through time.

Results from the models (Table 3 and Table 4 in the Appendix) suggest that in the case study area temperatures are negatively associated with net migration. In other words, when mean minimum temperature increases, the territory affected experiences a decrease of the 5-year net migration (positive net migration decreases or negative net migration becomes more negative in absolute value). This result is in line with existing evidence for Western Africa documenting an adverse effect of minimum values on crops and cereals (Peng et al., 2004; Sultan et al., 2019). Similarly, increasing average precipitation tend to decrease net migration. In line with the existing literature on this area, we also document a relation between drought intensity and net migration. In particular, an increase of the SPEI - which corresponds to less severe drought or improving water balance - is associated with an increase in net migration or in the attractiveness of the territories.

As a further step, we analyse whether the effect of climatic conditions on net migration depends on population density. Interestingly, when including an interaction term between 5-year population density and the SPEI, we find that the effect of intense drought on net migration is less pronounced for high levels of population density. In other words, drought tends to decrease net migration more in rural than urban areas. When we exclude the territories of Bamako from the analysis – where the peaks in net migration may be attributed to the urbanization process - the sign of the relationship between climatic conditions and net migration remains the same. This again confirms that drought has tended to decrease net migration – hence the attractiveness or the capacity of a territory to retain migrants – in particular in rural areas. Overall, the results confirm what is expected from existing research on the selected area. Water deficits caused by droughts, rising temperatures and precipitation tend to reduce the attractiveness of the territories considered, hence to be associated with population losses (i.e. decreasing positive net migration or negative net migration becoming more negative in absolute values). It should be noted that the results refer to 5-year net migration. Hence, shorter-term mobility – occurring within the 5-year interval - related to changes in climatic conditions is not captured in this analysis.

As a further caveat, it should be mentioned that the analysis does not consider the effects of extreme climatic conditions - such as extreme rainfall or heat waves – on net migration. Similarly, we do not take into account possible non-linear effects of climatic conditions on net migration. In other words, the negative effect of mean temperatures on net migration that we document is the same for all the levels of temperatures. This may not be the case for all areas within Africa or climatic conditions. The onset of migration or mobility, as a response to climate change, may not be contemporaneous to the changes in climatic conditions. These aspects will be addressed in CLICIM project by either including several indicators of extreme climatic conditions or taking into account non-linearities in the regression models. Possible lagged effects in the onset of migration will be also considered. When analysing broader territories than the one selected in this study, further refinements will be introduced (such as corrections for the possible geographical correlations of climatic conditions within certain areas). Finally, the CLICIM project will explore other aspects not introduced in this case study for simplicity: the interaction between climate change and the other migration drivers and how the effect of climate change on net migration depends on socio-economic and agricultural conditions in the areas examined. Specifically, CLICIM project will look at broader areas within Africa and analyse the effect of climate change on net migration across areas with different socio-economic development or agro-ecological characteristics.

7 Concluding remarks

This report has mapped population exposed to adverse climatic conditions focusing on a territory between Senegal, Mali and Mauritania. The report has also sought evidence of climate induced migration over the period 1975–2015. Existing research suggests that severe droughts and increasing temperatures would be related to internal mobility within African continent and to international migration toward EU since the 70s. In particular, extreme drought in the 80s has contributed to food shortages putting populations under stress. This, in turn, has contributed to consider migration as a population adaptation strategy to deteriorating conditions.

By combining population estimates from JRC GHSL data to climatic indicators, the report has identified population exposed to adverse climatic conditions. The analysis of JRC net migration data and climatic indicators has also confirmed that that increasing drought severity is associated with lower (in absolute values) 5-year net migration. The association between drought severity and net migration tends to be more pronounced in rural areas, where worsening drought severity is associated with lower (in absolute values) net migration than in more densely populated areas. The model also suggests an inverse relationship between temperatures and precipitation and 5-year net migration.

The contribution of the report has been twofold. First, to validate the new JRC net migration estimates by reproducing existing evidence on climate related migration. Second, to show the possibilities offered by the analysis of climate, population and related mobility at high geographical detail. As further steps, CLICIM project will refine and extend the proposed analysis for broader areas in Africa. It will also take into account how population response in terms of mobility to climate change varies with socio-economic development, poverty, and agricultural conditions.

Appendix

Figure 12 Bakel territory: SPEI (1980- 1985)

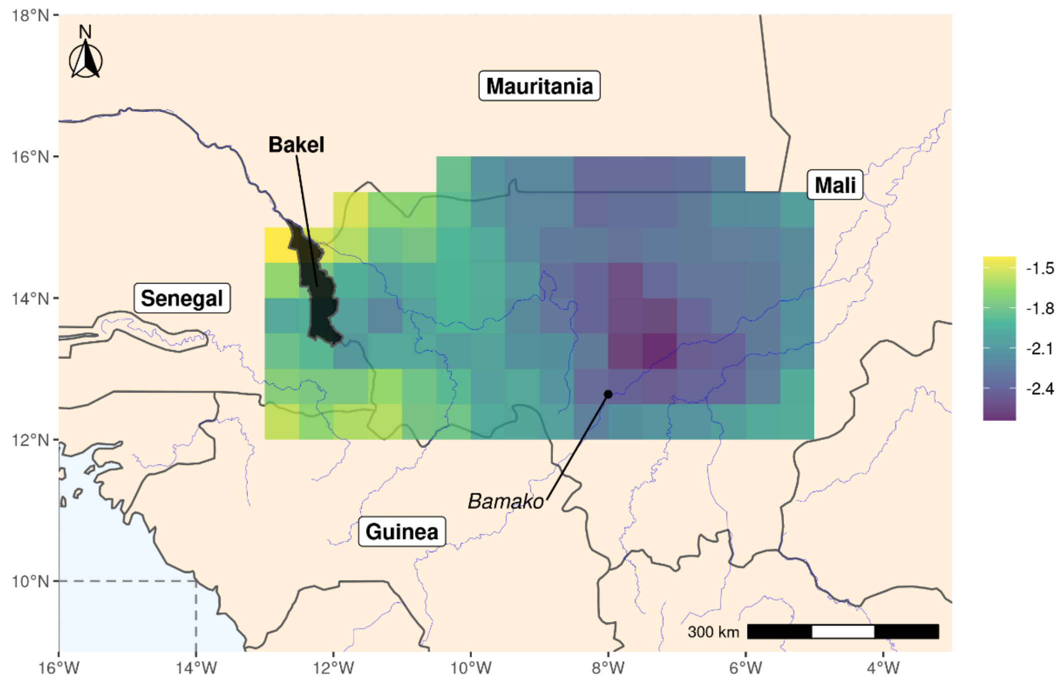


Figure 13 Drought indicator in Western Africa

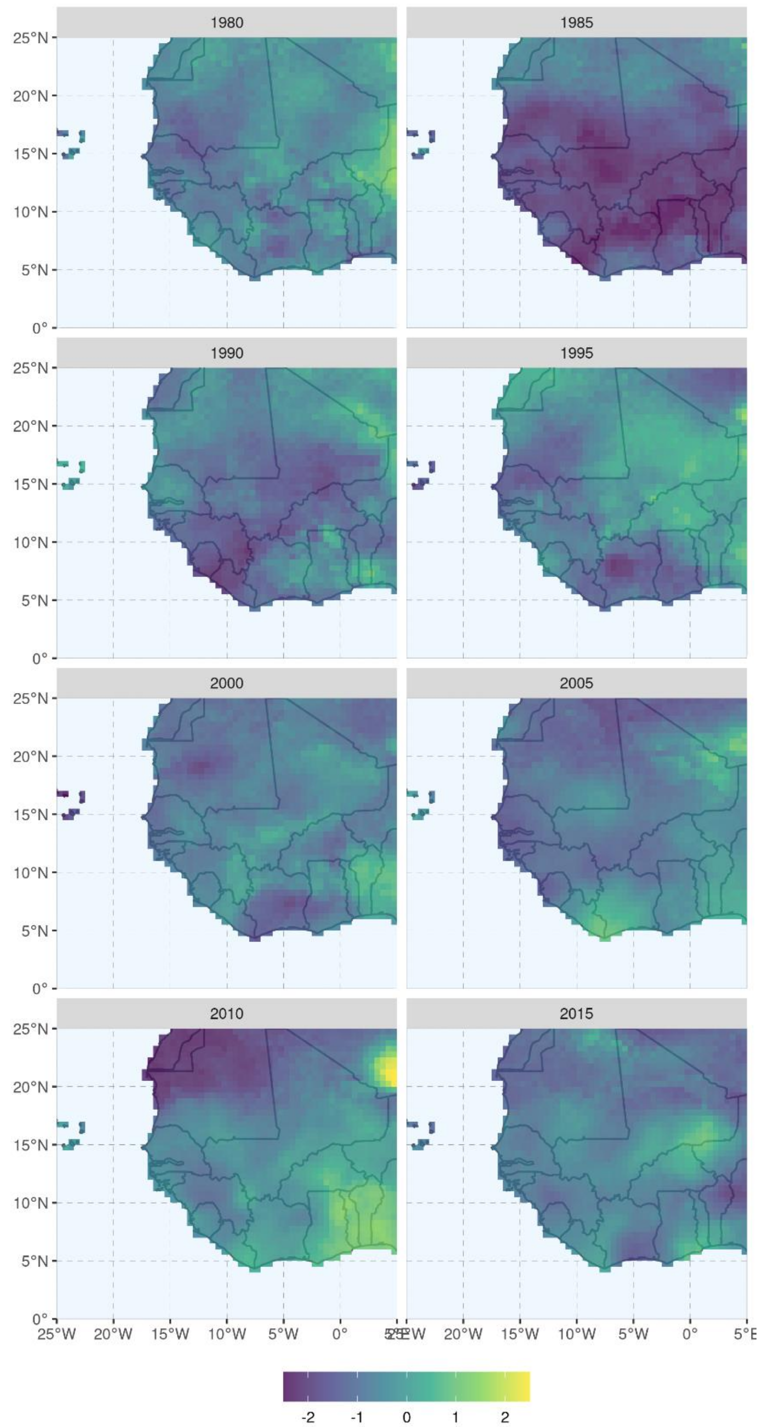


Figure 14 Mean minimum temperature (in °C) in Western Africa

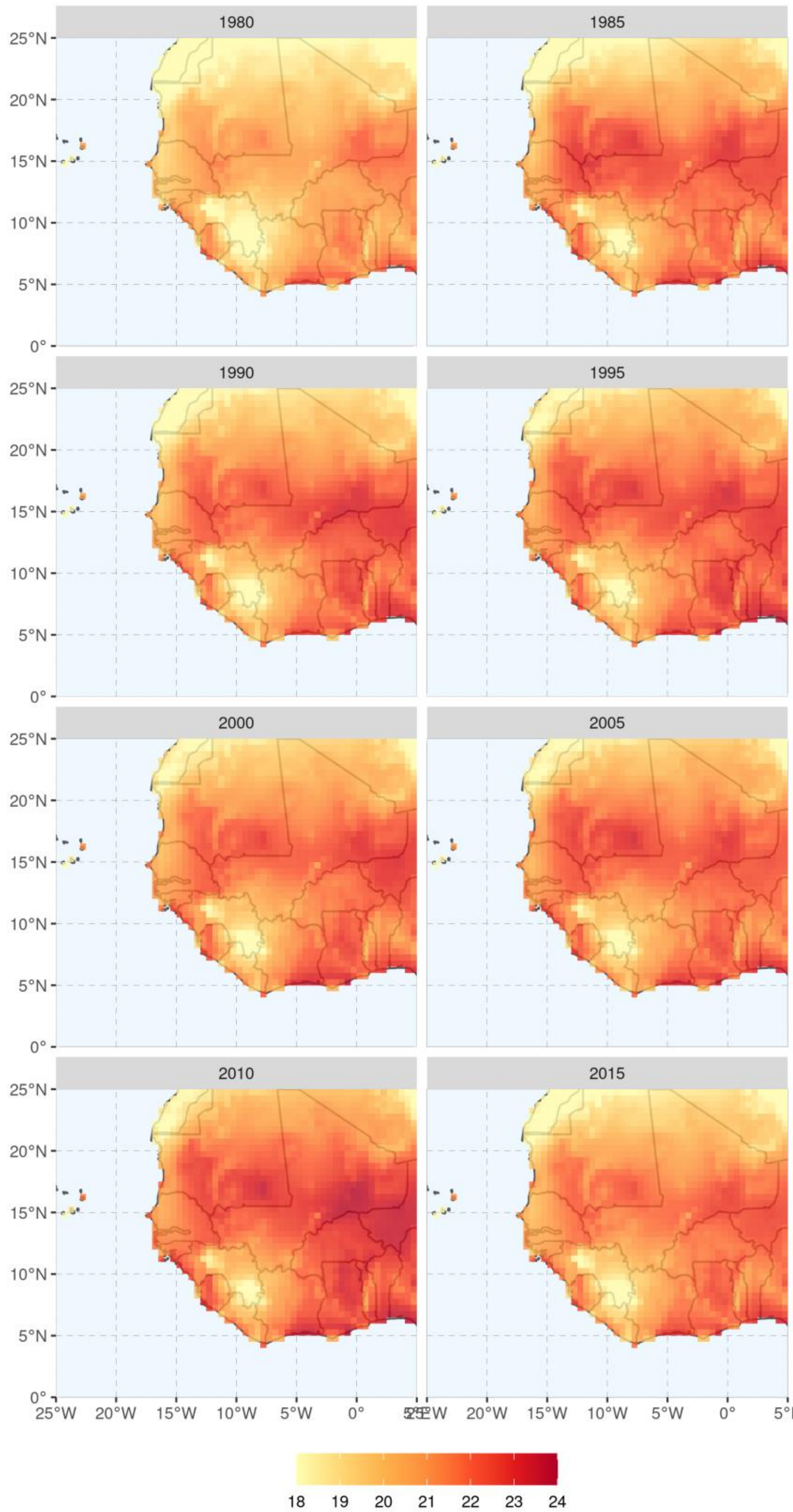


Figure 15 Precipitation (in mm) in Western Africa

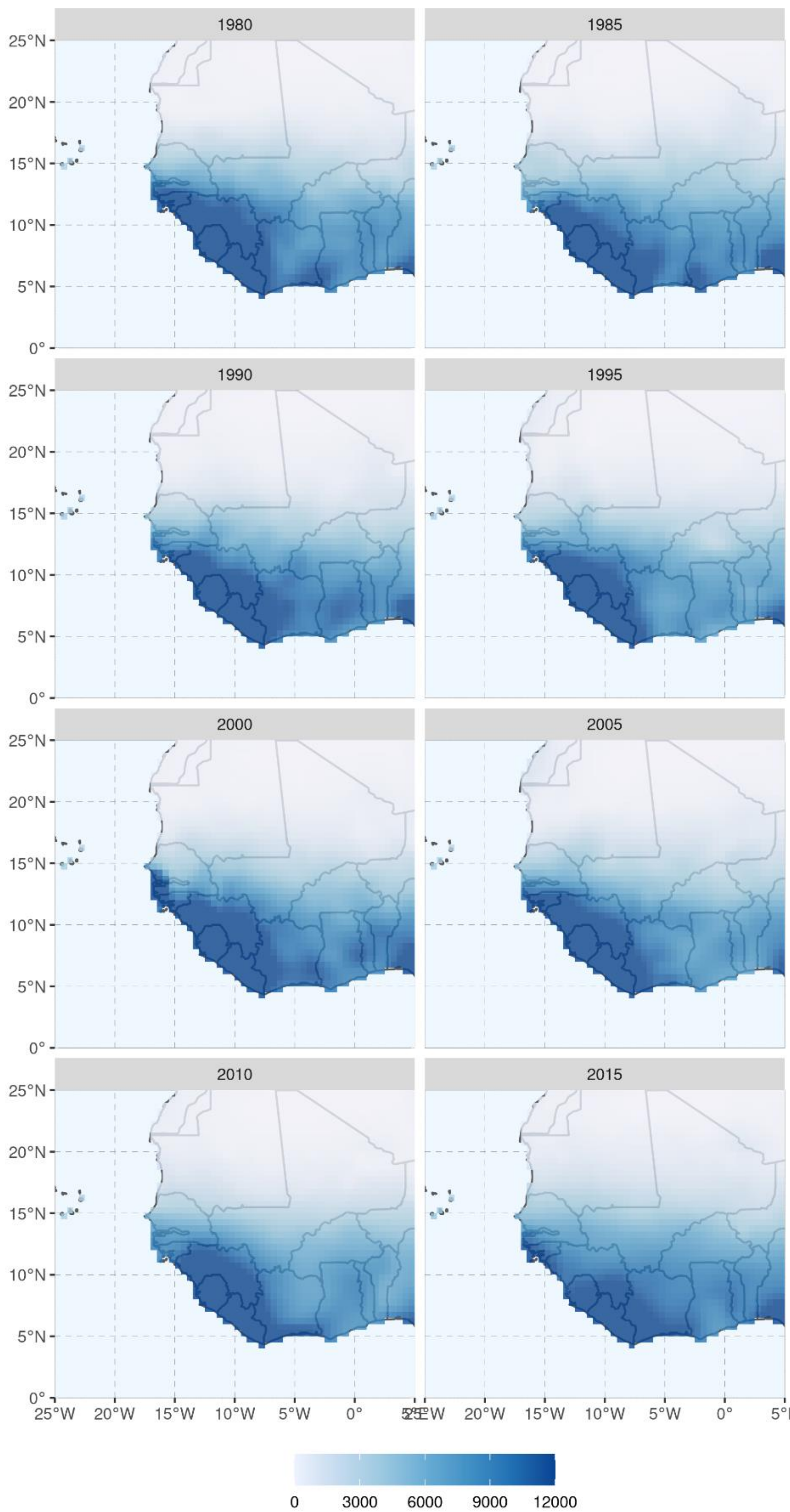


Figure 16 Net migration in Western Africa

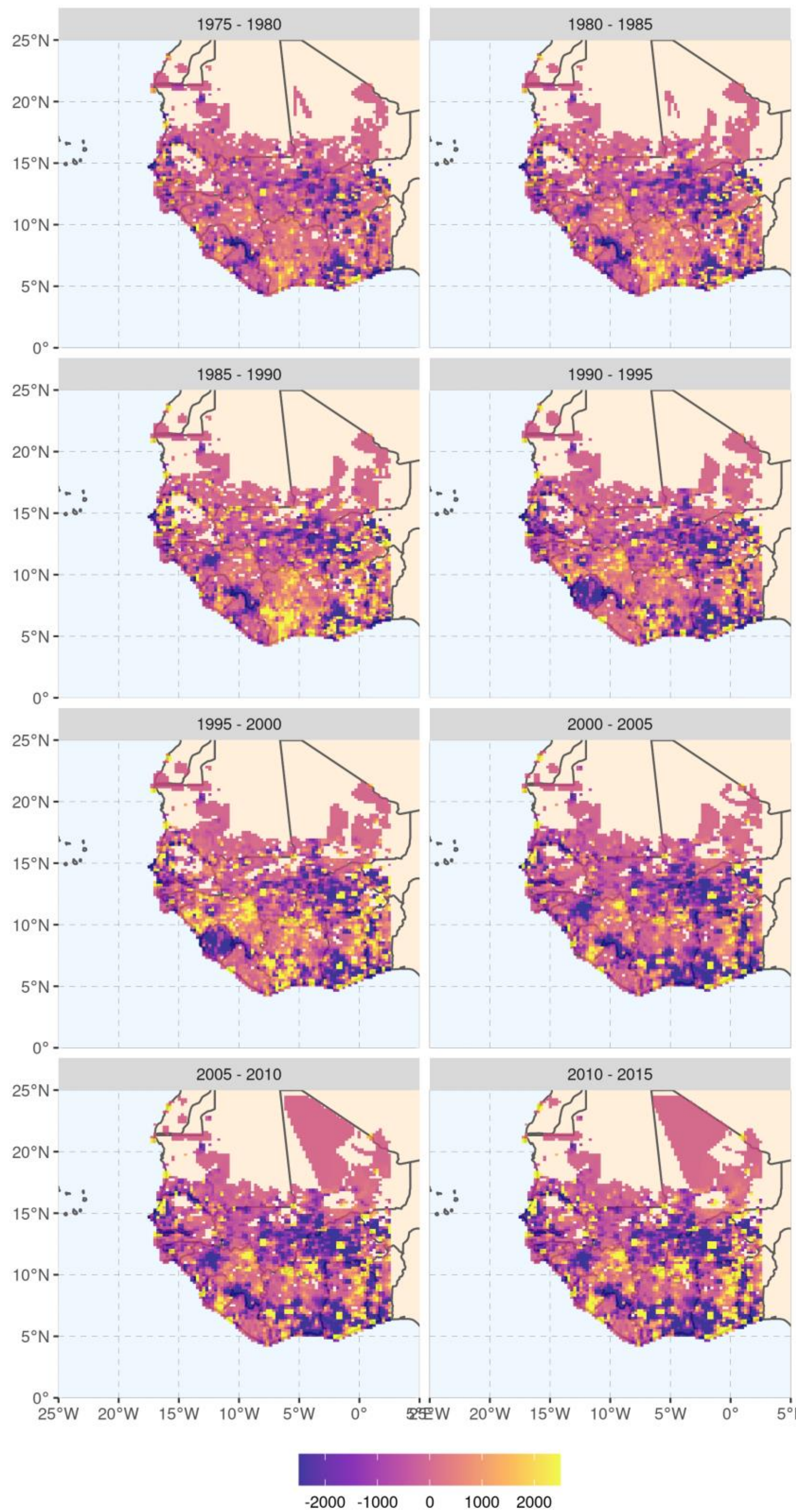


Figure 17 Net migration in selected region excluding area of Bamako, 1980-2015.

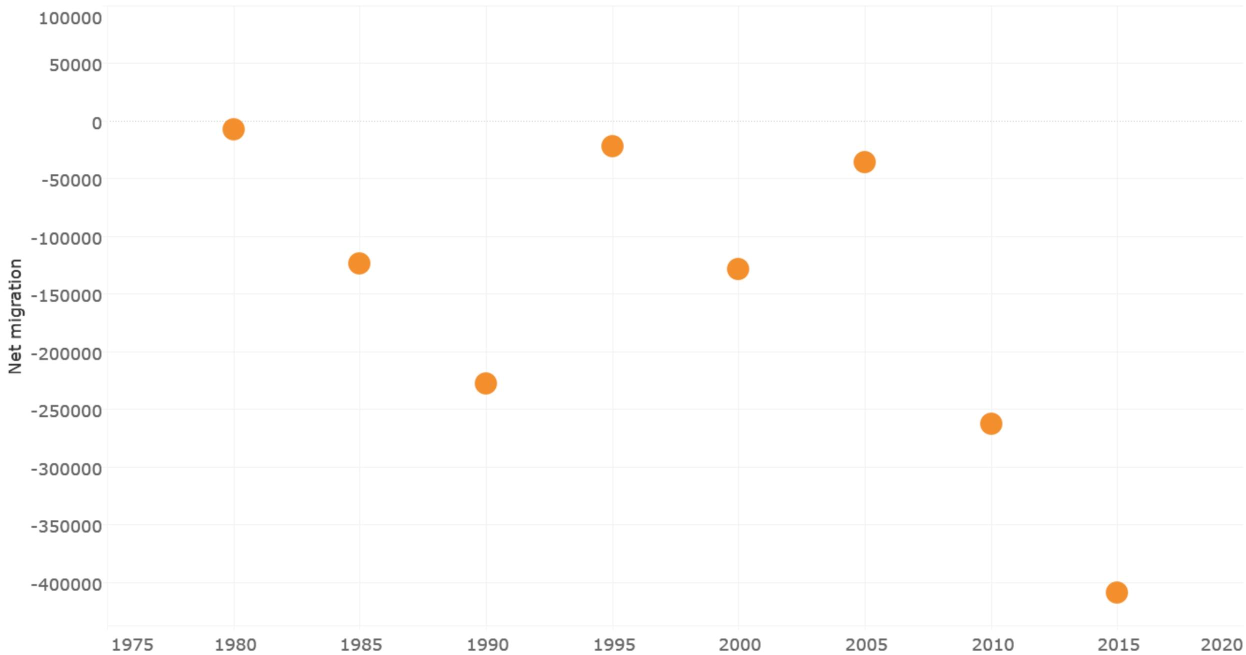


Table 1 Climate indicators used

Indicator	Data Source	Variable definition
SPEI	S. M. Vicente-Serrano et al. (2010)	We use the SPEI of June calculated at the end of each 5-year period. For instance, for the 1985-1990 period, we use the SPEI calculated in June 1990 which refers to water balances or surpluses cumulated in the preceding 48 months.
Temperature	Mistry, Malcolm Noshir (2019)	Minimum temperature is the lowest daily value of air temperature. We use annual mean daily minimum temperature averaged over 5-years.
Precipitation	Willmott & Matsuura (2001)	We use total monthly terrestrial precipitation (i.e. precipitation accumulated over a month). We then average total monthly precipitation over 5-years.

Notes: details on the indicators used are provided in (Petroliagkis & Alessandrini, 2021).

Table 2 Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Net migration	1 147	-188.29	9 273.77	-1 8727.7	1 80441.8
Population density	1 147	18.44	37.80	0	676.16
Minimum temperature	1 147	21.57	0.89	17.85	23.32
Precipitation	1 147	65.25	24.83	16.6	150.6
SPEI	1 147	-0.90	0.58	-2.64	0.40

Notes: Mean indicates the mean value of the variables over the 1975-2015 period.

Table 3 Main regression results

Dependent variable: net migration	(1)	(2)	(3)	(4)
Minimum temperature	-657.1***			
	(132.2)			
Precipitation		-103.8***		
		(20.73)		
SPEI			3,091***	4,186***
			(750.9)	(1,204)
Time trend			-1,232***	-1,160***
			(199.4)	(219.3)
SPEI x time trend			-1,114***	-856.4***
			(319.1)	(291.7)
Population density	137.9***	145.8***	159.9***	118.7***
	(17.95)	(16.51)	(10.78)	(14.25)
SPEI x population density				-101.3***
				(18.75)
Observations	1 147	1 147	1 147	1 147
R-squared (within)	0.182	0.190	0.229	0.283

Notes: Robust standard errors in parentheses clustered at the grid cell level. *** p<0.01, ** p<0.05, * p<0.1. All specifications include a constant term.

Table 4 Regression results, excluding Bamako territories

Dependent variable: net migration	(1)	(2)	(3)
Minimum temperature	-234.8***		
	(45.98)		
Precipitation		-26.17	
		(15.83)	
SPEI			1,655***
			(314.2)
Time trend			-555.1***
			(149.5)
SPEI x time trend			-480.7***
			(116.8)
Population density	-91.79**	-83.80	-41.90
	(46.37)	(50.66)	(62.68)
Observations	1,115	1,115	1,115
R-squared (within)	0.079	0.080	0.131

Notes: Robust standard errors in parentheses clustered at the grid cell level. *** p<0.01, ** p<0.05, * p<0.1. All specifications include a constant term.

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