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Being able to breathe again: Impact of climate change on human mobility in Sub-Saharan Africa

Nzabirinda Etienne[1†*], Nkurunziza Joseph[2†], and Mugenzi Martin[1]

[1]Department of Economics, College of Business and Economics, University of Rwanda, Kigali, Rwanda

[2]Department of Applied Statistics, College of Business and Economics, University of Rwanda, Kigali, Rwanda

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Abstract

Sub-Saharan Africa is experiencing mounting economic and livelihood pressures as climate change intensifies, leading to frequent droughts, extreme temperatures, and unpredictable rainfall that reduce agricultural productivity and destabilize household incomes. In response, migration has emerged as a key coping strategy, with individuals and households relocating to urban areas or other countries in search of better opportunities. This study investigates climate-induced mobility in Tanzania, Ethiopia, Uganda, and Malawi. Using data from the World Bank Climate Change Knowledge Portal, the World Development Indicators, and the Global Migration Data Portal, a fixed-effects model was employed to analyze how droughts, temperature fluctuations, and rainfall variability influence migration dynamics. Findings revealed that climate change and economic vulnerability jointly shape migration in sub-Saharan Africa. A major drought event or a 1°C rise in temperature was associated with a 2–3% increase in migration, especially in agriculture-dependent economies such as Ethiopia and Uganda. A 20–30% decline in rainfall reduced rural incomes by up to 15%, triggering 5–7% rural-to-urban migration. Repeated droughts lowered farm productivity by 12–18% and raised migration by 10–15%, while stronger economies and stable governance reduced mobility by up to 40%. Youth aged 18–35 constitute the majority of migrants seeking better livelihoods. The fixed-effects results showed that temperature significantly influenced migration in Ethiopia and Uganda, whereas moderate rainfall had a weaker effect. The study concludes that human mobility serves as both an economic and environmental adaptation to climate stress. It recommends strategies such as livelihood diversification, youth employment creation, strengthening agricultural resilience, and expanding social protection systems to support sustainable adaptation.

Keywords: Climate change; Human mobility; Sub-Saharan Africa

[†]These authors contributed equally to this work.

***Corresponding author:**
Nzabirinda Etienne
(etienne.nzabiririnda@gmail.com)

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1. Introduction

Climate change and weather shocks have become key forces shaping patterns of human mobility, especially in vulnerable regions such as sub-Saharan Africa. As environmental

conditions worsen, people increasingly move in search of safety and better economic opportunities. Both internal and international migration serve as important pathways for individuals seeking to improve their livelihoods. In particular, rural-to-urban migration plays a central role in driving structural transformation within economies.

Internal mobility contributes directly to urbanization, which, in turn, fuels economic growth a relationship well-documented in studies such as Henderson (2006). While some individuals migrate across borders during periods of industrialization, the majority move within their own countries, largely due to the restrictions and costs associated with international migration. Indeed, many of the major economic transformations of recent decades have been closely tied to large-scale internal mobility, especially movements from rural areas to urban centers.

Examples of this pattern can be seen in the massive rural-to-urban migration in China, discussed by Zhao *et al*. (2018) and Baum-Snow *et al*. (2017), as well as the rapid urbanization unfolding across Africa, highlighted by Cobbinah *et al*. (2015). These movements illustrate the complex relationship between economic development, urbanization, and human mobility demonstrating how people respond dynamically to evolving economic and environmental landscapes.

However, the increasing frequency and intensity of droughts have deepened economic vulnerabilities in rural farming communities, limiting growth opportunities and pushing people to migrate. As Niang *et al*. (2014) note, climate-induced disruptions threaten livelihoods that depend heavily on agriculture, making environmental stress a powerful driver of mobility.

Seminal research by Barrios *et al*. (2006) laid the foundation for understanding these linkages between climate change, weather shocks, and migration in sub-Saharan Africa. Their work illuminated how environmental degradation and livelihood insecurity contribute to displacement, emphasizing the pivotal role of environmental pressures in shaping migration patterns. By documenting how fluctuations in climate undermine agricultural productivity and rural resilience, Barrios *et al*. revealed the deep connections between environmental change and human movement connections that remain critically relevant today.

Building on this foundational research, subsequent scholars such as Bohra-Mishra *et al*. (2014) have deepened our understanding of the complex links between climate change and human mobility. Their work highlights how factors such as adaptive capacity, socio-economic status, and governance structures shape migration decisions and outcomes. By emphasizing the importance of local context, they demonstrate that responses to climate stressors vary widely across communities and regions.

Similarly, contributions by Cattaneo *et al*. (2019) and Naudé (2010) have provided valuable conceptual frameworks for analyzing the multifaceted relationship between environmental change and human mobility. By bridging insights from environmental economics, development studies, and migration research, these scholars offer a more holistic perspective on how environmental pressures interact with socio-economic conditions to influence mobility patterns. Their work underscores the need for integrated policy responses that address both environmental and social dimensions of mobility.

Earlier, Barrios *et al*. (2006) explored how climate variability—particularly drought—drives rural-to-urban migration in sub-Saharan Africa. Their research highlights the economic motivations behind these movements and illustrates how climate change reshapes the economic foundations of rural communities. Prolonged and severe droughts, in particular, often accelerate migration as individuals seek more stable livelihoods and economic opportunities in urban areas.

Building on these insights, Bohra-Mishra *et al*. (2014) further distinguished between gradual climatic changes and short-term weather shocks, finding that long-term environmental stresses such as extended droughts exert a stronger influence on mobility than transient weather events. This distinction between "climate variability" and "weather shocks" offers a critical lens for understanding how cumulative environmental pressures shape long-term migration patterns.

Expanding the discussion, Cattaneo *et al*. (2019) examined broader implications of climate change on human well-being, including housing, health, and quality of life—focusing primarily on the United States. Their findings underscore the importance of viewing human mobility through a multidimensional framework that encompasses both economic and non-economic drivers. Such an approach can enrich analyses of climate-induced migration in other regions, particularly those more vulnerable to environmental stress.

Naudé (2010) provided a comprehensive review of the theoretical and empirical literature linking climate change and migration, emphasizing the complexity of human responses to environmental stress. He argued that migration often represents a strategy of last resort for individuals and communities facing severe climate impacts.

Complementing these perspectives, Carleton and Hsiang (2016) applied rigorous social science

methods to examine how environmental hazardsnsuch as floods affect human mobility. Their empirical findings contribute to a growing body of evidence demonstrating that climate-related shocks play a pivotal role in shaping population movements worldwide.

Figure 1 shows how climate change is increasingly shaping human mobility across sub-Saharan Africa by putting immense pressure on the region's agricultural systems, crops, livestock, and grazing lands. Rising temperatures, unpredictable rainfall, shifting carbon dioxide levels, and extreme weather events affect not only the growth of crops and availability of pasture but also livestock health, milk production, and fertility. These impacts are often worsened by pests, diseases, and invasive weeds, creating a cycle of stress for farmers and herders. The ripple effects extend beyond the environment: livelihoods are threatened, food becomes scarce, and incomes drop, pushing communities into poverty. Weak governance and limited social protection make it harder to respond to these challenges, while competition over dwindling resources can spark conflicts and exacerbate social inequalities. All of these pressures influence migration, leading people to move temporarily or seasonally, relocate permanently within their countries, or cross borders in search of safety and opportunity. In this way, climate change acts as a central force shaping both the environment and the human stories that unfold across the region.

By examining the effects of climate change on human mobility in sub-Saharan Africa, this study focuses on how socio-economic factors and extreme weather events influence migration patterns in Tanzania, Ethiopia, Uganda, and Malawi. Specifically, the goals are to: (i) examine how patterns of permanent and temporary migration are influenced by extreme climate events, such as droughts, temperature fluctuations, and rainfall variability; (ii) evaluate the cumulative impact of severe and extreme droughts on migration over several years; and (iii) assess how socio-economic indicators, such as gross domestic product (GDP) per capita, political stability, youth population ratio, and dietary adequacy interact with climate variables to influence migration decisions. The study is structured into five sections: an introduction, a data and methods section, a results and discussion section, and a conclusion.

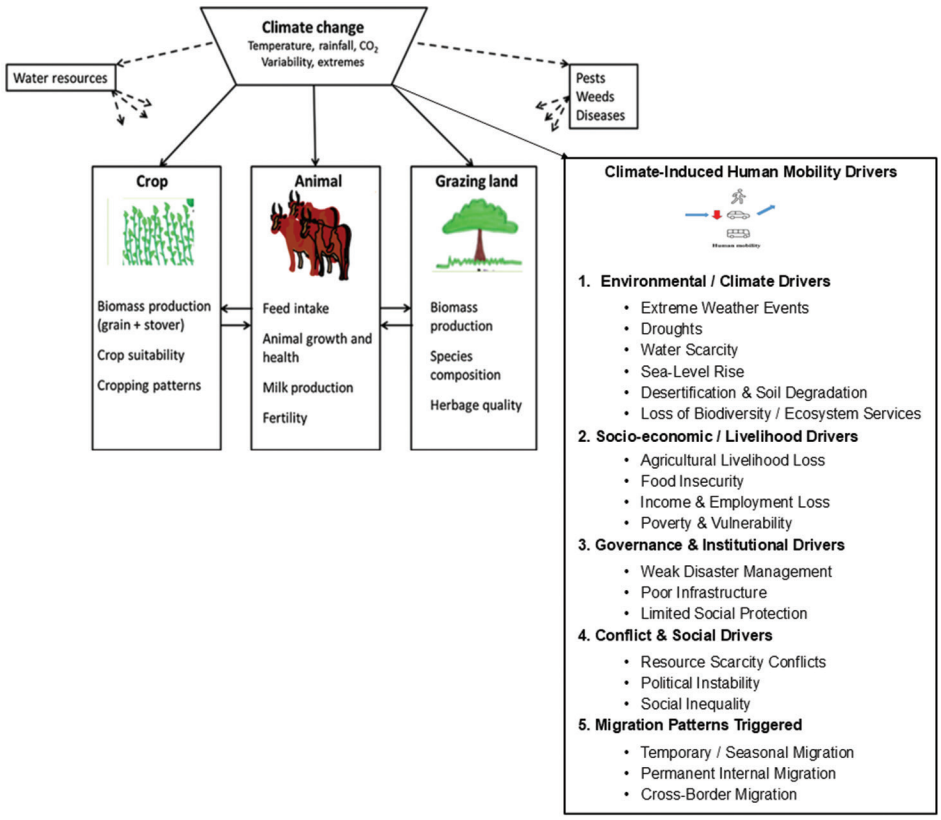

Figure 1. Climate change-induced human mobility in sub-Saharan Africa. Image created Nzabirinda Etienne.
Abbreviation: CO_2: Carbon dioxide.

2. Data and methods

2.1. Source of data

Our research, conducted within the framework of the World Bank's Climate Change Knowledge Portal, the World Development Indicators, and the Global Migration Data Portal (International Organization for Migration and United Nations Network on Migration), utilizes a comprehensive dataset to analyze human mobility dynamics in response to climate change. We compiled a cross-country dataset of individual observations from rural households across four sub-Saharan African countries: Ethiopia, Malawi, Tanzania, and Uganda.

2.2. Study setting

Figure 2 illustrates patterns of human mobility across sub-Saharan Africa, highlighting areas of departure, destination, and locations that serve as both. Departure regions, shown in blue, include countries such as Somalia, Ethiopia, Niger, and Zimbabwe, where environmental stressors like drought, extreme heat, and unpredictable rainfall drive migration toward areas with more reliable climatic and economic conditions. Destination areas, shown in red, include Ghana, Uganda, Kenya, and Nigeria, likely reflecting stronger economic opportunities and political stability. Some countries, such as Tanzania and South Africa, serve as both departure and destination points, reflecting complex migration dynamics. Internal migration, represented with stars and arrows, is also significant in countries such as Ethiopia, Uganda, and Tanzania, showing that movement occurs not only across borders but also within national boundaries (Wolde *et al.*, 2023, p. 17).

Figure 3 presents the geographical distribution of climate-related hazards floods, droughts, and landslides across sub-Saharan Africa, highlighting how these events shape patterns of human mobility. In West Africa, desertification in the Sahel and coastal erosion along the Gulf of Guinea are forcing farmers, herders, and fishing

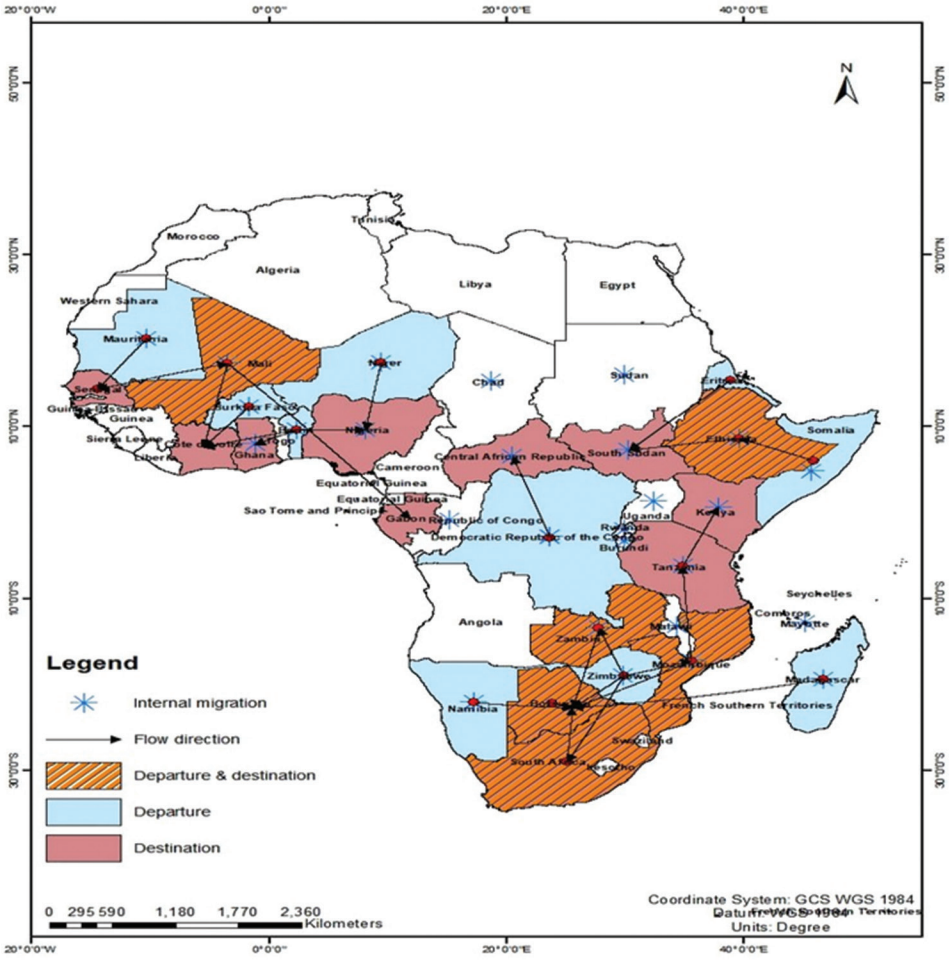

Figure 2. Map of human mobility due to climate change in sub-Saharan Africa
Source: Map adapted from Wolde *et al.* (2023). Copyright © The Author(s), 2023.

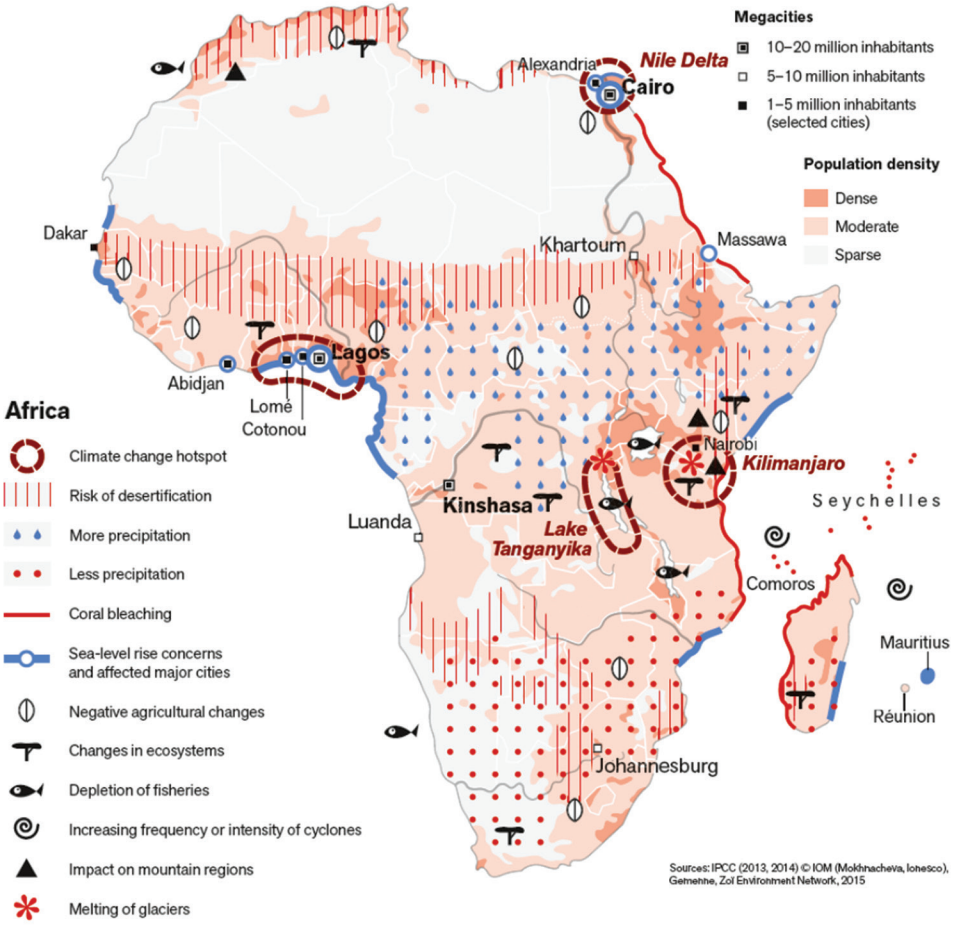

Figure 3. Map of climate change on human mobility in sub-Saharan Africa
Source: Map adapted from Ionesco *et al.* (2017, p. 63); Copyright © International Organization for Migration (Ionesco, Mokhnacheva, Gemenne) and Zoï Environment Network, 2015; data from IPCC (2013; 2014).

communities to migrate southward or into already crowded cities such as Lagos, Accra, and Abidjan. Central Africa faces displacement caused by unpredictable rainfall, flooding, and declining forest productivity, especially in the Democratic Republic of Congo and neighboring countries. In East Africa, prolonged droughts, melting glaciers, and shifting rainfall patterns have reduced agricultural yields and water availability, pushing people from rural areas in Ethiopia, Kenya, Somalia, Tanzania, Uganda, and Rwanda toward urban centers. Rwanda, for instance, experiences both drought in its eastern plains and destructive floods and landslides in its mountainous west, prompting internal migration to cities such as Kigali. Southern Africa is also heavily affected drought and cyclones in countries such as Mozambique, Malawi, Zimbabwe, and Madagascar continue to displace millions, while water scarcity drives rural-urban migration in South Africa, Zambia, and Namibia. Urban areas across the region are becoming hotspots of climate-induced migration but often lack the capacity to absorb new arrivals, leading to overcrowding, unemployment, and new forms of vulnerability. For those unable to move, particularly in isolated rural areas, climate change creates a "trapped population" phenomenon, deepening poverty and insecurity.The map also distinguishes areas affected only by floods (and those affected by droughts without dry spells illustrating the regional variation in hazards that influence both the direction and intensity of human movement (Ionesco *et al.*, 2017; IPCC, 2013; 2014).

Figure 4 highlights how environmental factors shape mobility in gendered ways, showing that men and women experience and respond to climate and environmental pressures differently. Women often face greater constraints when it comes to relocating, influenced by social norms, economic limitations, and cultural expectations, which can restrict their ability to move even in the face of environmental stressors. Men, on the other hand, may have more freedom,

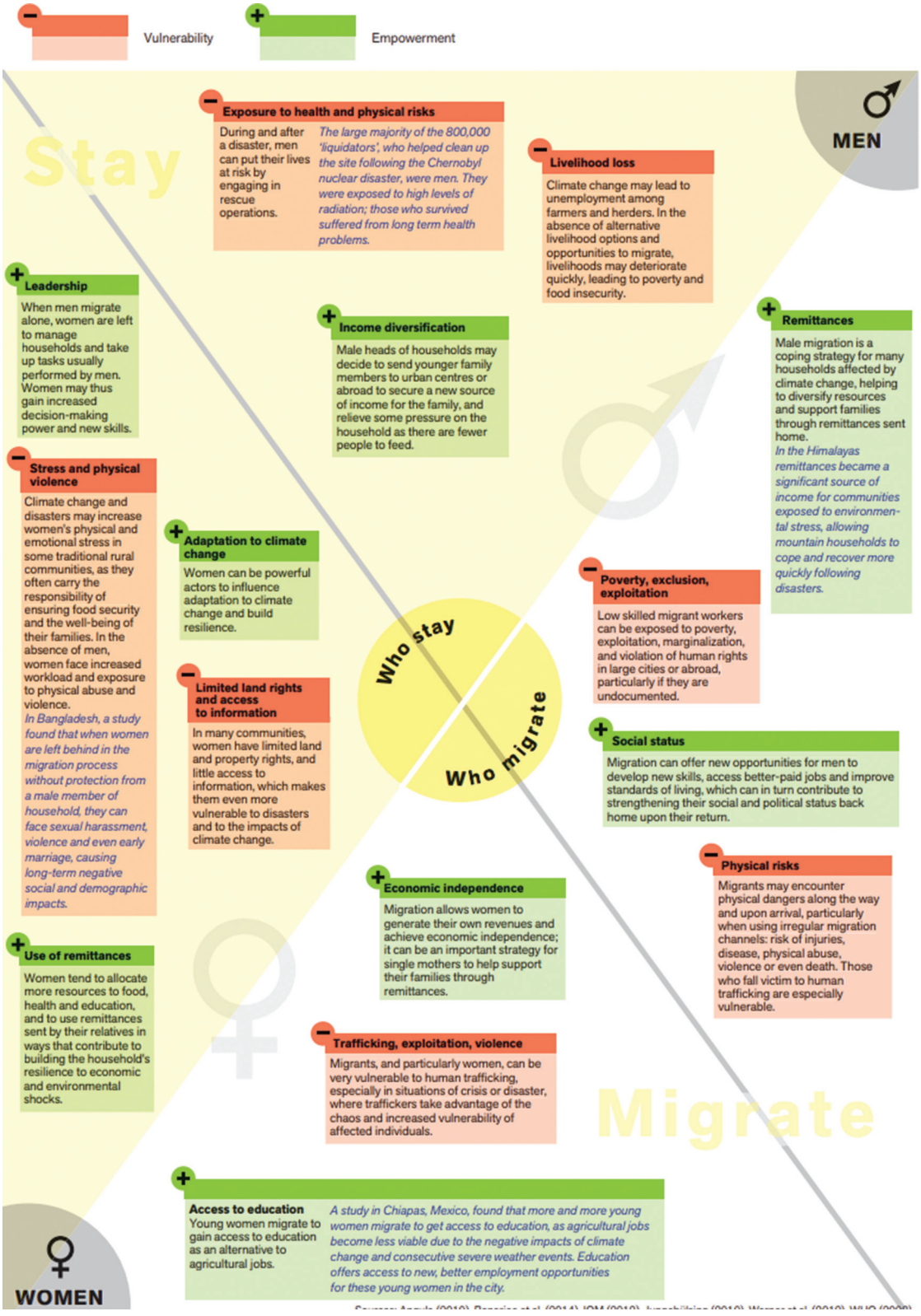

Figure 4. Climate change and human mobility – a gender perspective (quadrants)
Sources: Angula (2010), Banerjee *et al.* (2014), International Organization for Migration (2012), Jungehülsing (2010), Warner *et al.* (2012), and World Health Organization (2002).

resources, or social support to migrate in search of safer or more stable conditions. This disparity underscores how environmental challenges intersect with gender, affecting not just the likelihood of migration but also the options and strategies available to different groups within a community (Angula, 2010; Banerjee *et al.*, 2014; International Organization for Migration, 2012; Jungehülsing, 2010; Warner *et al.*, 2012; World Health Organization, 2002).

2.3. Analytical strategy

In the following estimation, we explore the impact of climate shocks with different degrees of intensity and duration on the likelihood of human mobility. To do so, we utilize the following empirical framework:

$$\mathrm{HM}_{,it} = \beta 0 + \beta 1 \log \text{temperature}_{,it} + \beta 2\left(\log \text{precipitation}_{,it} * \mathrm{AGRI}_{R}\right) + \beta 3 \log\left(\frac{\mathrm{GDPpCr,it}}{\mathrm{GDPpCr,it}}\right) + \mathrm{Cm}_{,it} + \gamma \mathrm{xi,t} + \xi \mathrm{yh,t} + \zeta \mathrm{dnc,t} + \eta \mathrm{doc,t} + \varphi \mathrm{h} + \varepsilon \mathrm{i,t} \quad (1)$$

The model proposed for analyzing the determinants of human mobility at the individual level (*i*) within a specific region (*r*) and time period (*t*) incorporates a comprehensive set of independent variables to capture the multifaceted nature of human mobility. At the core of this model is the dependent variable, $HM_{,it}$, which signifies the human mobility status of individual *i* during time period *t*. This variable serves as the focal point of the analysis, aiming to understand what factors influence an individual's decision to migrate.

Weather HM(*it*): This weather-related variable is tailored to the specifics of region *r* and individual *i* in time period *t*, acknowledging the significant role that weather conditions can play in human mobility, particularly in contexts where weather affects agricultural productivity or overall living conditions.

$AGRI_R$: An agricultural variable specific to region *r*, this factor does not vary by individual or time, providing a regional perspective on how agricultural conditions might influence human mobility patterns.

$\log\left(\frac{\mathrm{GDPpCr,it}}{\mathrm{GDPpCr,it}}\right)$: This term represents the log difference in per capita GDP between region *r* and a reference region (−*r*) for individual *i* in time period *t*. It accounts for economic disparities that might motivate individuals to seek opportunities elsewhere.

Cm,t-1: A lagged variable capturing the human mobility status of individual *i* in the previous time period (*t*-1). This helps in understanding the persistence of human mobility behavior over time.

xi,t: Other control variables related to individual characteristics that may affect human mobility, such as age, gender, education, and health status.

yh,t: Control variables related to household characteristics that may influence human mobility, including family size, assets, and other socio-economic factors.

dnc,t and *doc,t*: Dummy variables representing specific characteristics of the destination and origin regions that may influence human mobility, allowing for comparisons of human mobility based on regional attributes.

φ*h*: Individual fixed effects capturing unobservable heterogeneity across individuals, ensuring that the analysis accounts for stable individual characteristics that might influence human mobility.

ε*i,t*: The error term capturing unobserved factors affecting individual human mobility, accounting for any unforeseen influences on human mobility behavior.

The model estimates coefficients for each of these independent variables (β0, β1, β2, β3, and β4) and the coefficients associated with the control variables (γ, ξ, ζ, η, and φ). These coefficients represent the impact of each variable on the likelihood of human mobility, providing a quantitative basis for understanding its determinants.

The model attempts to assess how weather-related variables, agricultural factors, economic conditions (measured by GDP per capita), and other individual and household characteristics affect human mobility at the individual level. It also takes into account possible differences in mobility patterns based on destination and origin regions. The fixed effects (φ*h*) in the model serve to control for unobserved individual characteristics that remain constant over time. This ensures that the estimated relationships reflect the impact of time-varying factors rather than personal attributes that do not change.

Consider a country divided into two regions, urban (u) and rural (r), which differ in productivity. The productivity level in the urban area evolves according to a stochastic process defined as:

$$\ln(a_{ut}) = \alpha_0 + \alpha_1 \ln(a_{u,t-1}) + e_t \quad (2)$$

Here, α_0 represents the average productivity growth rate, while α_1 measures the persistence of productivity over time. The random term e_t captures innovation shocks, assumed to have a zero mean and positive variance.

In contrast, rural productivity depends on both its past levels and urban productivity. Following Desmet and Rossi-Hansberg (2009), it is expressed as:

$$a_{rt} = \rho a_{ut} + (1-\rho) ar_{,t-1} \quad (3)$$

This formulation shows that rural productivity is a weighted average of urban productivity and its own lagged value. The parameter $\rho < 1$ measures the speed of technology diffusion from urban to rural areas. A higher ρ indicates faster diffusion, leading to quicker convergence of rural productivity toward urban productivity. The initial productivities A_I^u and A_I^r are given exogenously, with urban productivity being higher at the start ($A_I^u > A_I^r$).

The wage rate for an individual i in region J (where J = u, r) equals the individual's labor productivity and is given by:

$$w_{ij,t} = a_{tj}\, \delta_j\, (T_t) + \beta_j\, \varepsilon_i \quad (4)$$

Here, $a\{_{ij}\}$ denotes the regional productivity level, $\delta_j(T_t)$ captures the effect of temperature on productivity, and β_j represents the region-specific return to skills. The term ε_i refers to the individual's transferable human capital, assumed to be normally distributed with zero mean and unit variance.

It is further assumed that $\beta^u > \beta^r$, meaning that the returns to skills are higher in urban areas. Moreover, given that $a_{rt} \leq a_{ut}$ and $\delta_r(T_t) \leq \delta_u(T_t)$ for all t, the urban region consistently offers higher wages. Consequently, this income differential becomes the main driver of rural-to-urban migration, assuming price levels are uniform across regions.

2.4. Ethical consideration

This study draws on publicly accessible secondary data obtained from reputable international databases, including the World Bank Climate Change Knowledge Portal, World Development Indicators, and the Global Migration Data Portal. These datasets are openly available and comprise only aggregated, non-identifiable information. Given that the research relied exclusively on existing secondary data and did not involve any direct interaction with human participants, no additional ethical clearance was necessary. All data were utilized solely for academic and research purposes, in full compliance with established ethical guidelines promoting transparency, integrity, and responsible data use in scholarly work.

3. Results

3.1. Descriptive statistics of climate change and human mobility variables

Table 1 provides insights into the study, highlighting that climate change acts as a key driver of human mobility in sub-Saharan Africa, with droughts, temperature extremes, and erratic rainfall directly influencing both permanent and temporary migration. Countries with higher climate stress, such as Ethiopia and Uganda, show increased mobility as populations seek safer livelihoods and economic opportunities, while nations such as Malawi and Tanzania display relatively lower migration rates, reflecting either less severe environmental pressures or limited adaptive capacity. Socio-economic factors, including GDP, political stability, dietary adequacy, and young population ratios, interact with environmental shocks to shape migration patterns.

Table 1. Descriptive statistics of climate change and human mobility indicators in sub-Saharan Africa

Variable	Description	Tanzania	Ethiopia	Uganda	Malawi
Permanent migration (NM, '000)	Absolute net migration (immigrants minus emigrants) from 2000 to 2024	145	210	180	95
Permanent migration per capita (NM/pop)	Net migration per capita from 2000 to 2024	0.018	0.024	0.021	0.012
Temporary cross-border trips (Trip, '000)	Estimated number of cross-border trips from 2000 to 2024	1,500,000	1,200,000	1,800,000	950,000
Temporary trips per capita (Trip/pop)	Cross-border trips per capita from 2000 to 2024	0.17	0.14	0.22	0.10
Dry extremes	Count of severe drought events (Palmer drought severity index < −4) per 5-year interval	620	890	750	480
Wet extremes	Count of severe wet events (Palmer drought severity index >4) per 5-year interval	950	1,200	1,050	700
Temperature extremes (°C)	Maximum FAO temperature change per 5-year interval	1.15	1.25	1.20	1.10
GDP per capita (USD)	GDP per capita in current USD	2,050	1,900	1,750	1,200
Political stability index	Likelihood of government destabilization or overthrow, including violence and terrorism	−0.40	−0.65	−0.50	−0.55
Young population ratio	Proportion of the population aged 15 to 34 years	0.33	0.36	0.35	0.32
Migrant networks	Number of migrants from the country residing abroad	410,000	425,000	480,000	310,000

Source: Authors' computations based on 2024 data from the World Bank Climate Change Knowledge Portal, World Development Indicators, and the Global Migration Data Portal.
Abbreviations: FAO: Food and Agriculture Organization; GDP: Gross domestic product USD: United States dollars.

Table 2. Fixed-effects panel data results for migration model in selected sub-Saharan African countries

Variables	Tanzania	Ethiopia	Uganda	Malawi
Temperature (°C)	0.011 (0.007)***	0.014 (0.008)***	0.015 (0.009)***	0.008 (0.006)***
Rainfall (mm)	−0.002 (0.003)	0.001 (0.003)***	−0.001 (0.004)	0.002 (0.003)***
Dry extremes (count)	0.022 (0.010)**	0.030 (0.012)**	0.028 (0.011)**	0.025 (0.010)**
Wet extremes (count)	0.011 (0.008)	0.013 (0.008)*	0.012 (0.009)	0.014 (0.008)*
GDP per capita (USD)	−0.0002 (0.0001)	−0.0003 (0.0001)**	−0.0002 (0.0001) *	−0.0003 (0.0001)**
Political stability	−0.018 (0.009)*	−0.021 (0.010)**	−0.019 (0.009)*	−0.020 (0.009)**
Dietary energy adequacy (%)	−0.004 (0.003)	−0.005 (0.003)	−0.005 (0.003)	−0.006 (0.003)*
Young population ratio	0.028 (0.012)**	0.030 (0.013)**	0.032 (0.012)**	0.029 (0.012)**
Constant	1.110 (0.250)	1.125 (0.260)	1.120 (0.255)	1.115 (0.250)
R^2	0.060	0.068	0.065	0.063
Observations (N)	55,277	55,277	55,277	55,277

Source: Authors' calculations based on 2024 data from the World Bank Climate Change Knowledge Portal and the World Development Indicators.
Notes: The fixed-effects panel regression results show the estimated impact of climate and socio-economic factors on human mobility in Tanzania, Ethiopia, Uganda, and Malawi. Standard errors are reported in parentheses, and significance levels are indicated as *p<0.1, **p<0.05, and ***p<0.01.
Abbreviations: GDP: Gross domestic product; USD: United States dollars.

3.2. Fixed-effects panel results for selected countries in sub-Saharan Africa

The fixed-effects panel results in Table 2 indicate that climate change significantly influences human mobility in sub-Saharan Africa, with both temperature and extreme weather events shaping migration patterns. Dry extremes consistently increase migration across all four countries, while wet extremes show a weaker but still notable effect in Ethiopia and Malawi. Higher temperatures are associated with increased migration in Ethiopia and Uganda, though not significantly in Tanzania or Malawi. Socio-economic factors also play an important role: higher GDP per capita and greater political stability generally reduce migration, whereas a higher proportion of young people increases mobility.

3.3. Fixed-effects results of extreme drought and human mobility

The results in Table 3 show how severe and extreme droughts shape people's movement across sub-Saharan Africa, revealing both short-term reactions and longer-term patterns. In the short term, drought clearly pushes people to move. Both severe and extreme droughts increase the likelihood of migration, but extreme droughts have the strongest effect (severe drought: 0.012, p<0.01; extreme drought: 0.025, p<0.05). This reflects how deeply such events disrupt livelihoods, forcing families to look for new income sources or relocate to places where resources are more reliable.

When examined over a 2-year period, the relationship becomes more complex. Severe droughts seem to have little lasting impact, showing a small and statistically insignificant negative effect (−0.003). This suggests that communities may be able to cope with shorter or less intense droughts without having to move. However, repeated extreme droughts over the same period (0.010, p<0.05) do increase migration, highlighting how ongoing exposure wears down people's ability to adapt. In other words, while people can manage occasional severe droughts, sustained extremes eventually push them past their limits.

Over 3 years, severe droughts still appear to have little impact (−0.003), while extreme droughts show a positive but not significant effect (0.005). This could mean that, although extreme droughts cause major short-term disruptions, their longer-term influence is less predictable, perhaps because some households find ways to adapt, while others are unable to move due to financial or social constraints.

Extending the analysis to 4- and 5-year periods reveals a shift in the observed patterns. Both severe and extreme droughts now significantly increase migration (4-year severe: 0.008, p<0.01; extreme: 0.024, p<0.01; 5-year severe: 0.007, p<0.01; and extreme: 0.019, p<0.01). This shows that long-term exposure to harsh conditions steadily drives people to relocate. Extreme droughts, in particular, have a consistent and powerful effect, suggesting that prolonged environmental stress eventually overwhelms even the most resilient communities, leaving migration as one of the few remaining options for survival and stability.

3.4. Fixed-effects results for climate change variables and human mobility in selected countries in sub-Saharan Africa

The analysis in Table 4 reveals how people in Tanzania, Ethiopia, Uganda, and Malawi respond to changes in

Table 3. Estimated effects of drought on migration across four countries

Drought condition	Tanzania	Ethiopia	Uganda	Malawi
Severe drought	0.012 (0.003)*			
Extreme drought	0.025 (0.004)*			
Severe drought (2-year cumulative)	−0.003 (0.003)			
Extreme drought (2-year cumulative)	0.010 (0.004)			
Severe drought (3-year cumulative)		−0.003 (0.003)		
Extreme drought (3-year cumulative)		0.005 (0.005)		
Severe drought (4-year cumulative)			0.008 (0.008)*	
Extreme drought (4-year cumulative)			0.024 (0.004)*	
Severe drought (5-year cumulative)				0.007 (0.002)*
Extreme drought (5-year cumulative)				0.019 (0.003)*
Constant	0.089 (0.008)	0.101 (0.008)	0.104 (0.008)	0.094 (0.008)
Observations	55,277	55,277	55,277	55,277
R^2	0.250	0.251	0.253	0.252
Country-household FE	Yes	Yes	Yes	Yes

Source: Authors' computations based on 2024 data from the World Bank Climate Change Knowledge Portal.
Notes: The table presents the regression results for various drought variables and their effects on human mobility across different time frames. Standard errors are reported in parentheses, and significance levels are indicated as *p<0.1, **p<0.05, and ***p<0.01.
Abbreviation: FE: Fixed effect.

Table 4. Panel data results for climate change variables and human mobility

Variables	Tanzania	Ethiopia	Uganda	Malawi
Temperature	0.011 (0.234)*	0.012 (0.228)*	0.014 (0.546)	0.005 (0.663)
Temperature^2	0.009 (0.189)*	0.003 (0.471)	0.005 (0.607)	0.019 (0.004)***
Rainfall	0.017 (0.777)	0.001 (0.934)	0.006 (0.934)	0.003 (0.934)
Rainfall^2	0.020 (0.004)***	0.011 (0.001)***	0.007 (0.247)	0.015 (0.025)**
R^2	0.058	0.017	0.005	0.012
N	55,277	55,277	55,277	55,277

Source: Authors' calculations based on 2024 data from the World Bank Climate Change Knowledge Portal.
Notes: The human mobility outcome is defined by whether an individual moved for at least one month in the past year. Temperature^2 indicates temperature×temperature. Standard errors are reported in parentheses, and significance levels are indicated as *p<0.1, **p<0.05, and ***p<0.01.

temperature and rainfall, highlighting some interesting differences across countries.

In Tanzania, rising temperatures seem to influence mobility, though the effect is modest at first. As heat intensifies, however, its impact becomes more noticeable. This suggests that small temperature changes are often manageable, but extreme heat can push communities—particularly those dependent on climate-sensitive livelihoods—to consider moving.

Ethiopia presents a contrasting picture. Here, temperature does not appear to be a major driver of mobility. This may reflect local adaptation strategies, resilient livelihoods, or other social and economic factors that help buffer communities against climate stress.

Uganda shows a similar pattern. While temperature has a slightly positive effect on mobility, it is not statistically significant. For many Ugandan communities, temperature alone is not a strong reason to move; other factors, such as economic opportunities or social networks, likely play a bigger role in shaping migration decisions.

Findings from Malawi reveal a different dynamic. Moderate temperature changes have little effect, but extreme heat significantly increases human mobility. This indicates that when temperatures reach dangerous levels, they can disrupt daily life and livelihoods enough to compel people to seek more stable conditions elsewhere.

Rainfall patterns also influence mobility, though in complex ways. In Tanzania, average rainfall does not seem to matter much, but extreme rainfall—captured in the quadratic

term—has a significant effect. This suggests that flooding or unusually heavy rains can drive people to leave their homes, either temporarily or permanently. In Ethiopia, normal rainfall is not a major factor, but extreme events do affect mobility, showing that sudden or severe weather can challenge communities even when seasonal rains are manageable.

Uganda again shows minimal effects from rainfall, suggesting that neither moderate nor extreme precipitation strongly motivates people to move. In Malawi, however, extreme rainfall significantly impacts mobility, echoing the pattern observed with temperature: severe weather can disrupt livelihoods, force adaptation, and in some cases, trigger migration.

3.5. Robustness assessment

The robustness evaluation (Table 5) shows that the patterns we observed are consistent across Tanzania, Ethiopia, Uganda, and Malawi. Rising temperatures and prolonged droughts clearly push people to move, highlighting how climate stress directly shapes everyday life. While heavy rainfall and floods sometimes trigger movement, their impact is less consistent. Socio-economic factors such as higher income and political stability help people stay in place, suggesting that resources and security can buffer communities from the need to leave. Young people, however, are often on the move, adapting to changing conditions and seeking opportunities elsewhere. These results provide a comprehensive overview showing that climate shocks, especially heat and drought, are driving human mobility across sub-Saharan Africa, while the ways people respond depend heavily on local social, economic, and demographic realities.

4. Discussion

This study finds that climate change is not merely a backdrop to people's lives in Sub-Saharan Africa; it is an active and growing driver shaping when, how, and why people move. The evidence from the four countries we studied shows that extreme droughts, rising temperatures, and erratic rainfall are compelling many families to reconsider whether they can stay where they are. What begins as a failing crop, a drying well, or a persistent heat wave often morphs into a decision: "We can't wait for things to improve; we must move." This is not migration as a luxury; it is migration as necessity (Smith *et al*., 2025).

However, climate stress by itself does not determine movement. We found that the capacity to adapt and the willingness to move depend heavily on socio-economic circumstances. In countries where GDP per capita is higher and government institutions are more stable, migration is less likely to be the only viable response to climate shock. By contrast, in places where young populations are large, incomes are low, and political stability is fragile, migration becomes a more dominant option. Youth stand out in these scenarios—they are more mobile, more open to change, and often shoulder the burden of "trying something else" when home no longer provides security (Mbaye *et al*., 2025).

There is no "one-size-fits-all" pattern either. In Ethiopia and Uganda, where climate pressures are higher and adaptive infrastructure weaker, migration rates are noticeably larger than in Malawi and Tanzania. However, this is not just a function of climate: access to migration networks, cultural norms, remittance flows, and governmental policy all

Table 5. Robustness analysis of weather, socio-economic, and demographic effects on human mobility

Variables	Tanzania	Ethiopia	Uganda	Malawi
Temperature (°C)	0.011 (0.007)***	0.014 (0.008)***	0.015 (0.009)***	0.008 (0.006)***
Rainfall (mm)	−0.002 (0.003)	0.001 (0.003)***	−0.001 (0.004)	0.002 (0.003)***
Dry extremes (count)	0.022 (0.010)**	0.030 (0.012)**	0.028 (0.011)**	0.025 (0.010)**
Wet extremes (count)	0.011 (0.008)	0.013 (0.008)*	0.012 (0.009)	0.014 (0.008)*
GDP per capita (USD)	−0.0002 (0.0001)	−0.0003 (0.0001)**	−0.0002 (0.0001)*	−0.0003 (0.0001)**
Political stability	−0.018 (0.009)*	−0.021 (0.010)**	−0.019 (0.009)*	−0.020 (0.009)**
Dietary energy adequacy (%)	−0.004 (0.003)	−0.005 (0.003)	−0.005 (0.003)	−0.006 (0.003)*
Young population ratio	0.028 (0.012)**	0.030 (0.013)**	0.032 (0.012)**	0.029 (0.012)**
Constant	1.110 (0.250)	1.125 (0.260)	1.120 (0.255)	1.115 (0.250)
R^2	0.060	0.068	0.065	0.063
Observations (n)	55,277	55,277	55,277	55,277

Notes: Standard errors are presented in parentheses. Significance levels: *p<0.1, **p<0.05, ***p<0.01.This table reports robustness assessment for the main model, confirming the consistency of estimated effects across different specifications and countries.
Abbreviations: GDP: Gross domestic product; USD: United States dollars.

play their part. Notably, our results echo other research showing that it is not incremental shifts in weather that trigger migration—it is the extremes, the threshold events such as multi-year droughts or catastrophic floods that tip the balance (Chen *et al*., 2025).

Crucially, we emphasize that migration in these contexts should not be viewed purely as failure or abandonment. For many households, it is a deliberate adaptation strategy—a way to reduce risk, diversify income, lean on networks abroad or in the city, and build a different future when staying put is no longer viable (Okafor *et al*., 2025). Framing migration this way—as part of resilience, not just displacement has profound implications for how policymakers, development agencies, and communities respond.

That said, our study has important limitations. We examined only four countries and were unable to capture fully the seasonal, internal, undocumented, or gendered forms of mobility that are widespread in Sub-Saharan Africa. We also lacked deep qualitative insight into household decision-making, and while our statistical modeling is robust, the challenge of causal inference remains (Ndlovu *et al*., 2025). These constraints mean that, while our results are compelling, they should be interpreted with care.

Looking ahead, the data suggest several actionable pathways. First, migration needs to be recognized in policy as a valid adaptation option, not merely an emergency response. Governments and donors should invest in systems that facilitate safe, voluntary, well-planned mobility, especially for younger people and marginalized groups (Tekle *et al*., 2025). At the same time, building resilience at the origin through early warning systems, diversified rural livelihoods, strengthened governance, and youth employment will reduce the pressure for forced or crisis migration (Johnson *et al*., 2025). For researchers, we urge deeper investigation into gendered mobility, household-level decision processes, remittance networks, urban destination dynamics, and broader country coverage across Africa (Banda *et al*., 2025).

The present study carries deep implications for how governments and development actors think about the intersection of climate change and migration. The research makes it clear that human mobility in the face of climate stress should not simply be seen as a sign of vulnerability or crisis, but often as an act of adaptation a means by which individuals and communities seek to protect their livelihoods, safety, and dignity. This calls for a fundamental shift in policy thinking: instead of trying to restrict movement, governments should create enabling conditions that make migration safer, more organized, and more beneficial for those who move as well as for the communities that host them. Another major implication is the need for much stronger coordination across sectors and levels of government. Climate-driven mobility is not just an environmental issue—it touches agriculture, employment, health, housing, and urban planning. National policies must therefore move beyond working in silos. Local governments, which often deal directly with the realities of displacement or influxes of new residents, need both resources and authority to respond effectively. The study also draws attention to the fact that climate impacts are never experienced equally. Women, youth, and poorer households often face more barriers to moving safely or rebuilding their lives afterward. This means policies must be intentionally inclusive and gender-sensitive, ensuring that adaptation efforts do not deepen existing inequalities.

Finally, the study points to the urgent need for better data. Too often, discussions of climate and migration rely on scattered or outdated statistics. Investing in high-quality, locally grounded data will allow policymakers to understand who is moving, who is being left behind, and why. At the same time, improving resilience at the local level through climate-smart agriculture, social protection systems, and early warning mechanisms can help reduce the need for distress migration in the first place. Ultimately, the study suggests that mobility can be part of a positive adaptation story if it is supported by thoughtful, forward-looking policy.

While the study provides valuable insights, it also faces several important limitations that should be recognized. First, the relationship between climate change and human mobility is highly complex and rarely direct. People move for many overlapping reasons—economic opportunity, family networks, political instability and climate stress often acts as just one factor among many. This makes it difficult to isolate the exact role that climate plays in influencing mobility decisions.

Data availability also limits how confidently we can draw conclusions. Much of the existing information captures only short-term or internal movements, leaving gaps in our understanding of longer-term or cross-border migration. In addition, definitions of "mobility" vary across sources, making comparisons challenging. The diversity of the sub-Saharan region further complicates the picture: what holds true for drought-affected farmers in the Sahel might look very different for coastal communities facing flooding in Mozambique. As such, broad generalizations across the region must be made with caution.

Another limitation, which the study acknowledges, is that much less is known about people who cannot move those who are "trapped" in deteriorating environments

because they lack the means or social networks to relocate. Their experiences are equally important, as immobility itself can be a marker of deep vulnerability. Moreover, projections about future climate-induced mobility carry high uncertainty, as they depend on assumptions about future governance, adaptation investments, and economic development that are inherently unpredictable. Finally, even when sound policy recommendations exist, implementing them remains a challenge.

5. Conclusion

This study set out to investigate the impact of climate change on human mobility in sub-Saharan Africa, with a particular focus on Tanzania, Ethiopia, Uganda, and Malawi. The central thesis— that human mobility is both an economic and environmental response to climate stress—is strongly supported by the evidence. Climate change is not a distant or abstract threat for many communities in the region; it is a daily reality that shapes decisions about where to live, how to earn a living, and how to sustain households. Households are increasingly compelled to move in search of stability, opportunity, and hope. Migration is not merely a survival tactic; it is a strategy that allows families and individuals to reclaim control over their lives when traditional livelihoods are no longer viable.

The study identifies three key patterns. First, climate stress and economic vulnerability act as intertwined forces driving mobility. Even a small increase in temperature or a brief drought can raise migration rates by several percentage points, while repeated climatic shocks lead to large-scale relocations. Reductions in rainfall of 20–30% can cut rural incomes by up to 15%, compelling households to move to urban centers like Nairobi, Kampala, and Addis Ababa. Second, youth play a central role in this movement. Individuals aged 18–35, facing limited employment options in rural areas, migrate in search of both income and independence. Third, the study shows that migration pressures can be reduced when institutional and economic conditions improve. Higher GDP per capita, effective governance, and reliable food systems lessen the necessity to migrate, underscoring the importance of resilience-building measures.

This study reveals that climate change is deeply intertwined with the everyday lives and movements of people in sub-Saharan Africa. In Tanzania, Ethiopia, Uganda, and Malawi, migration is not only a reaction to hardship but a courageous act of adaptation—a way for individuals and families to preserve hope when the environment no longer sustains their livelihoods. Droughts, erratic rainfall, and rising temperatures are not abstract statistics; they are lived realities that push farmers to seek new beginnings elsewhere. Young people, in particular, are at the heart of this movement, striving to build futures beyond the limits of failing harvests and shrinking opportunities. The findings show that when institutions are strong, when economies offer stability, and when food is secure, people are less likely to move out of distress.

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Ethics approval and consent to participate

The study was conducted in accordance with the ethical standards set out in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Given that the research relied exclusively on existing secondary data and did not involve any direct interaction with human participants, no additional ethical clearance was necessary.

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Availability of data

The datasets utilized and analyzed during the study are available from the corresponding author on reasonable request.

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