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Climate Change Impact on Migration and Food Security: An Existential Threat in Africa

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ABSTRACT

Climate change's impact on migration and food security are two of Africa's most urgent challenges in recent years. Climate change disrupts weather patterns and agricultural production, leading to food insecurity and displacement. This study uses a mixed-methods approach to examine the relationship between climate migration and food security in Africa. The qualitative component of the study involves a review of existing literature on climate migration and food security in Africa. The quantitative component of the study involves descriptive analysis of climate displacement data extracted from the Internal Displacement Monitoring Center (IDMC) database, and data for food security were extracted from the Food and Agriculture Organization (FAO) statistical database. The displacement data were used to plot graphs of climatic factors that influence climate migration. The food security data were used to build a food security index from principal component analysis (PCA) and panel data to examine the relationship between climate change and food security. Findings from the qualitative review reveal that climate mobility has heightened peoples' movement, leading to an increase in rural-urban migration, the proliferation of peri-urban settlements, and pressure on social amenities in destination communities. The quantitative analysis finds that there is a negative correlation between climate change, migration, and food security. Also, there is a negative association between food security, food price shock(s), and an increase in population in host communities due to climate stressors such as droughts, floods, storms, and temperature shifts. Despite the alarming negative impacts of climate change on human mobility and food security, there are policy gaps regarding what stakeholders do and what is expected of them to address this existential threat. Stakeholders should therefore establish holistic climate adaptation mechanisms such as climate-resilient agriculture and sustainable resource management for people to cope and adapt to climate stress.

1. Introduction

Climate change's impact on human mobility and food insecurity have continued to increase in Africa and many other parts of the world. The consequence of this problem forces many people to migrate to find livelihood and survival support elsewhere for their families (Clement et al., 2021; Hall et al., 2017; Kabasa and Sage, 2009; Pickson and Boateng, 2022; Conte, 2022; Kniveston et al., 2012).

According to a World Bank examination, the entire world is projected to have 216 million climate migrants by 2050, with Africa alone expected to have 105 million (Clement et al., 2021). According to Conte, climate change has displaced about 12 percent of the population in sub-Saharan Africa, which has significantly affected economic development in the region. Climate change has increased population outflow from the rural to the urban centers and heightened food insecurity in many places within sub-Saharan Africa (Conte, 2022).

Also, climate change continues to have a negative influence on agricultural activities due to drought, which causes crop failure and low production, pests and diseases, and soil erosion, worsening livelihood issues, and food insecurity in Africa (Pickson and Boateng, 2022; Mutengwa et al., 2023).

In some cases, migration is considered an adaptation strategy to deal with the adverse effects of climate change. However, in most cases, it fails due to the challenges facing the vulnerable population and the destination communities (Vinke et al., 2022; Teye et al., 2021). There are also immobility challenges due to some people's inability and unwillingness to move due to financial and socio-cultural reasons (Teye, 2022). Although migration is classified as an adaption strategy for climate stress, it is sometimes considered a weak adaption strategy, and it is mainly for people who do not have other coping strategies. Additionally, the remaining population encounters numerous difficulties in sustaining their means of living, including scarcities in food supplies and inadequate availability of nourishment, impoverishment, and joblessness (Vinke et al., 2022).

In an epoch characterized by unprecedented global challenges, the intersectionality of food security, climate change, and human mobility has emerged as a critical nexus that demands urgent attention. The imperative to comprehend, analyze, and develop effective strategies to address this convergence has never been more pressing. This investigation embarks on a comprehensive exploration, aiming to forge a pathway toward "Resilient Futures" (Kahiluoto, 2020).

Food security, defined as the accessibility, availability, and affordability of nutritious and safe food for all, constitutes a fundamental pillar of sustainable development (Clapp et al., 2022). Food security's significance is magnified in a world grappling with the ramifications of climate change, which has ushered in an epoch of unpredictable weather patterns, escalating temperatures, and extreme climate events (Myers et al., 2017). These shifts disrupt conventional agricultural practices, modify food production landscapes, and jeopardize the livelihoods of millions, particularly in vulnerable regions (Oakes et al., 2016). Consequently, food systems' resilience and security are now intrinsically linked to the broader discourse surrounding climate resilience.

However, this nexus extends beyond agriculture and climate in isolation. Human mobility, driven by various factors, including environmental stressors, economic opportunities, and geopolitical instability, has emerged as a significant dynamic that shapes food security landscapes (Stavi et al., 2022). Climate-induced migration, whether it occurs internally or across borders, necessitates a re-evaluation of existing paradigms of food security. It introduces novel challenges about equitable resource distribution, demographic shifts, and socio-political tensions that necessitate innovative policy responses (Schraven et al., 2019).

Moreover, this investigation acknowledges the pivotal role that socio-economic determinants play in mediating climate change's impacts on food security and human mobility. Understanding these socioeconomic determinants is crucial for developing targeted interventions to strengthen food security in the face of dynamic, interconnected challenges.

Considering this context, establish the relationship between climate change, migration, and food security. To achieve this comprehensive Food Security Index that encapsulates the intricate network of variables encompassing food resource availability, access, utilization, and stability is constructed. Simultaneously, the study dissects the complex relationship between climate-induced human mobility and climatic factors that influence migration and food security. By interweaving these threads, this study aspires to delineate a pathway towards resilient futures-futures in which communities and nations are equipped to withstand the impact of environmental change and flourish in the face of adversity (Kahiluoto, 2020). Through this inquiry, the study offers recommendations for durable solutions.

2. Climate Change and Human Mobility in Africa

Climate change is increasingly having several negative impacts on many African countries. Climate-induced migration has therefore become one of the most pressing concerns on the continent due to several environmental and climatic factors that force people to migrate. It is observed in many studies that the earth's ecosystems are becoming increasingly stressed because of biodiversity loss, river and ocean pollution, degradation of land, drought, and destruction of rainforests. These stresses continue to force people in Africa to move from one geographical place to another. Although in some places there are preexisting migration flows, the impact of changing climate conditions tends to heighten the existing problems that influence migration in such geographical areas (McLeman, 2018; Boas et al., 2019; Piguet et al., 2011; McLeman and Gemenne, 2018; Obokata et al., 2014; Mayer, 2016; Marandi and Main, 2021; Oakes et al., 2023; Felipe Pérez and Tomaselli, 2021).

The environment and its impact on population sustenance has become one of the major concerns in both Global South and North countries. For instance, the sub-Saharan, Middle Eastern, and North African (MENA) countries are faced with high drought, changes in rainfall patterns, and many other climatic changes, making these countries prone to severe heat conditions, water crises, and food challenges, hence forcing some people to migrate. These problems affect the region's agriculture, which is highly climate-based. This problem worsens the livelihood issues many people face in these countries. Additionally, increasing the dependency on food importations is expected to rise, causing challenges to the vulnerable population (Waha et al., 2017; Mugambiwa and Makhubele, 2023). The Small Island Developing States (SIDS) are also severely affected. In this region, climate change impact is threatening the territorial existence of people, forcing most people to migrate or relocate. However, this region lacks an adequate mechanism for displacement and climate-related migration (Thomas and Benjamin, 2018).

In most developing countries, like those in sub-Saharan Africa, most farmers practice subsistence farming due to inadequate capital to engage in large-scale farming. As a result of these fluctuations and changes in climatic patterns, food insecurity, and human mobility continue to be the primary threats (Mugambiwa and Makhubele, 2023; Ogundeji, 2022). The African continent, especially in the Sahel region and the Horn of Africa, continues to face drought and severe heat waves affecting food security and other livelihood activities (Clearinghouse, 2021). Due to different demographic, geographic, and economic factors, the Sahel region continues to face food insecurity. There is a severe food shortage, and it is expected to worsen soon. This observation was established about a decade ago, and the whole can attest that it is not far from reality regarding the (food crisis) currently happening globally (Lifland, 2012).

Not to mention Africa alone, other places in the Americas (San Miguel et al., 2021; Marandi and Main, 2021; Felipe-Pérez and Tomaselli, 2021), the Pacifics (Thomas and Benjamin, 2017), Asian and many other parts of the world face severe climate problems that affect food security and human mobility. Environmental challenges such as drought, changes in rainfall patterns, storms, and temperature changes influence and cause livelihood challenges such as food insecurity which also force people to migrate (IOM, 2015).

Notwithstanding migration issues, climate impact and its consequences influence local conflicts in many countries, plausibly due to people's struggle for limited natural resources such as water, fertile agricultural lands, and pastoralist grazing lands. The issues mentioned earlier have resulted in a high unemployment rate and exacerbated people's movement toward socio-economically and environmentally secure areas. Without better intervention by the current government administration, the humanitarian condition in the region is likely to worsen due to the increase in displacement of the people and the struggle for scarce resources (Price, 2019; Akhtar and Shah, 2023; Issifu et al., 2022). It is important to stress that climate crises are likely to exacerbate the challenges already faced by the least-developed countries (Clement et al. 2021). Additionally, the relationship between climate change and migration is complex in Africa (Borderon et al. 2019; Clement et al. 2021).

Climate and environmental-related factors continue to displace many people globally. For instance, according to IOM (2022), at the end of 2020, about 89.4 million people were displaced globally. It is widely observed that African countries contribute less to global carbon emissions. Even though African countries contribute less to greenhouse gas emissions, the continent faces most climate change consequences such as health, food, and water problems (Rigaud et al., 2018; Clement et al., 2021; Teye and Nikoi, 2022). Many African countries face numerous climate challenges that compel many people to migrate. Climate impact on human mobility is alarming, especially in the Horn of Africa. According to the International Organization for Migration (IOM), by the end of 2020, Somalia had the most disaster displacement, followed by Ethiopia owing to excessive rainfall, flooding, and drought (IOM, 2022).

In other parts of Africa, like West Africa, especially in the Sahel region, climate impact on migration is increasing significantly. It is also important to note that not only does climate influence migration, but climate change also leads to conflict and food insecurity (Leal Filho et al., 2022; Teye and Owusu, 2015; Teye, 2022; Yaro et al., 2016). It is also observed that flood severely impacts the region; a typical example is Lagos in Nigeria, thereby hurting people's livelihoods (Odunsi et al., 2023). In many places in African states climate, and mobility have increased pressure on social amenities, heightening slums and ghettos settlements.

Climate migrants are often drawn to peri-urban settlements (synonymously known as ghettos or slums). They are characterized by poor infrastructure, inadequate social amenities, and high levels of poverty and unemployment and are relatively affordable and offer access to few basic social amenities. However, the rapid growth of peri-urban settlements has put a strain on existing social amenities, leading to congestion, overcrowding, and shortages of essential services (Teye and Owusu, 2015; Teye, 2022; Mensah and Teye, 2021). Leading to tensions between climate migrants and host communities over access to resources and social services. For example, in Kenya, climate migrants from drought-stricken regions have settled in peri-urban areas around Nairobi, putting pressure on water resources and leading to conflicts between the new-comers (climate migrants) and the host community members (Tubi and Israeli, 2023).

In Nigeria, climate migrants from the Niger Delta have settled in peri-urban areas around Lagos, putting pressure on housing and infrastructure and leading to conflicts with residents over access to jobs and opportunities (Elon et al., 2022). Also, in Ghana, climate change impacts such as severe floods negatively affect the livelihood of people who live in slums in Accra suburbs such as Old Fadama (Adam and Nyantakyi-Frimpong, 2021). The proliferation of peri-urban settlements due to climate migration has also led to an increase in crime and violence in these areas. This is due to several factors, including the lack of job opportunities, the high cost of living, and the lack of access to essential services.

Additionally, in the Horn of Africa, prolonged drought-induced water scarcity continues to influence the conflict situation in the region. Also, along the Lake Chad Basin, there is always a conflict between farmers and pastoralists due to limited water resources in the area (Schraven et al., 2019). It is also important to stress that the involuntary forced migration as a result of climate in West Africa is most intraregional (Leal Filho, 2022). It is essential to mention that climate-related migration in West Africa used to be seasonal and short-term migration, where migrants moved to neighboring countries and other parts of the same country due to irregular rainfall partners. However, in recent times, the migration pattern has changed to long-term and permanent migration (Teye, 2022; Vinke et al., 2022). Climate change continues to threaten people on the continent despite the continent's lower contribution to global carbon emissions (Teye and Nikoi, 2022; Teye, 2022).

Similarly, climate change continues to force many people to migrate due to food insecurity and environmental hazards. However, African governments' policies still need to address the issue (Yahaya, 2022) adequately. This problem necessitates the African Union and other subregional organizations to establish means to protect climate migrants, especially the vulnerable ones in the climate hotspots (Amadi and Vundamina, 2023). Even though migration is used as a means of adapting to climate shocks, several people are trapped due to poverty, social factors, and other related factors, such as lack of social networks in the host communities, making them unable to migrate (Teye and Nikoi, 2022; IOM, 2022). For instance, some integration programs enshrined in the ECOWAS protocols and the Intergovernmental Authority on Development (IGAD) for the West and East African states, respectively. Through these programs, climate-affected people could secure themselves elsewhere on the continent. However, due to ineffective regional policies, climate migrants still lack protection on the continent (Amadi and Vundamina, 2023).

These policies also need to control the mass increase of rural-urban migration on the continent. Although climate impact on migration is a critical issue and millions of people are expected to move, sub-Saharan African policymakers still need to pay attention to the issues (Ibrahim and Mensah, 2022; Clement et al., 2021). The map below indicates the climatic factors that influence climate migration in Africa.

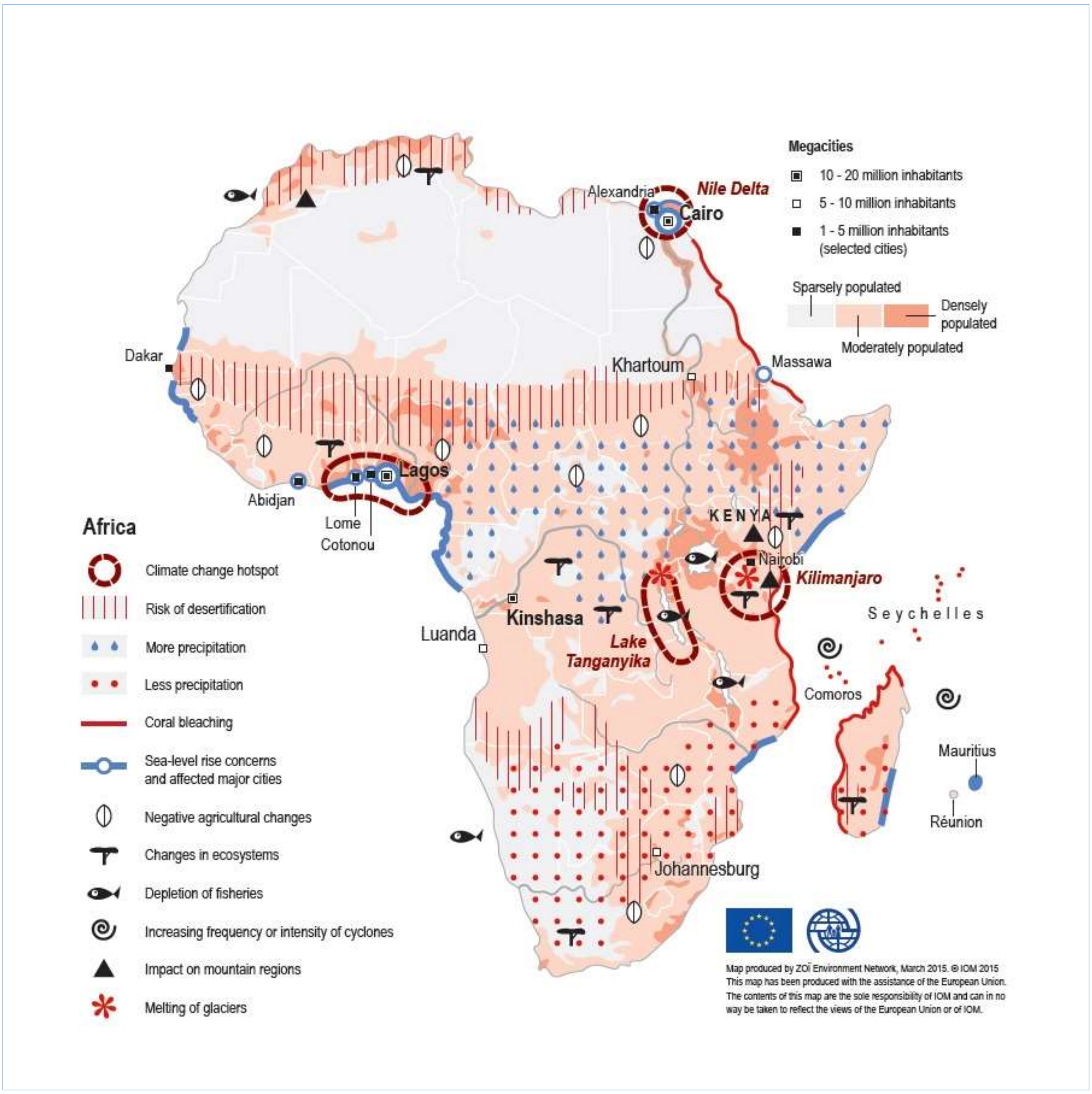

Fig. 1. Map of climate hazards and environmental impact in Africa (IOM, 2015)

The map depicted in Fig. 1 illustrates the climatic hazards and their environmental consequences on Africa. The figure presents a comprehensive overview of the complex relationship between climate change, adverse agricultural changes, and modifications in the agroecological composition of Africa. It is noteworthy that resource depletion coincides with climate fluctuations and engenders a plethora of issues. These hazards influence the movement of people. Specifically, drought and flood, as evident in Fig. 2, impact the displacement and mobility of individuals. These factors jeopardize food security and water resources, thereby prompting individuals to migrate.

As depicted in Fig. 1, the risks of desertification and high precipitation are prevalent in numerous regions of the continent. Desertification and high precipitation result in drought and flooding in many parts of Africa, leading to population movements. Moreover, low precipitation and rising sea levels are common in the southern and coastal areas, and these climatic factors impact people's habitats and sources of livelihood. For instance, as more precipitation leads to flooding, and the risk of desertification is frequent in densely populated areas (Fig. 1), many individuals are frequently affected by these events (Fig. 2). This implies that if stakeholders fail to take appropriate action, the situation could threaten large-scale population displacement.

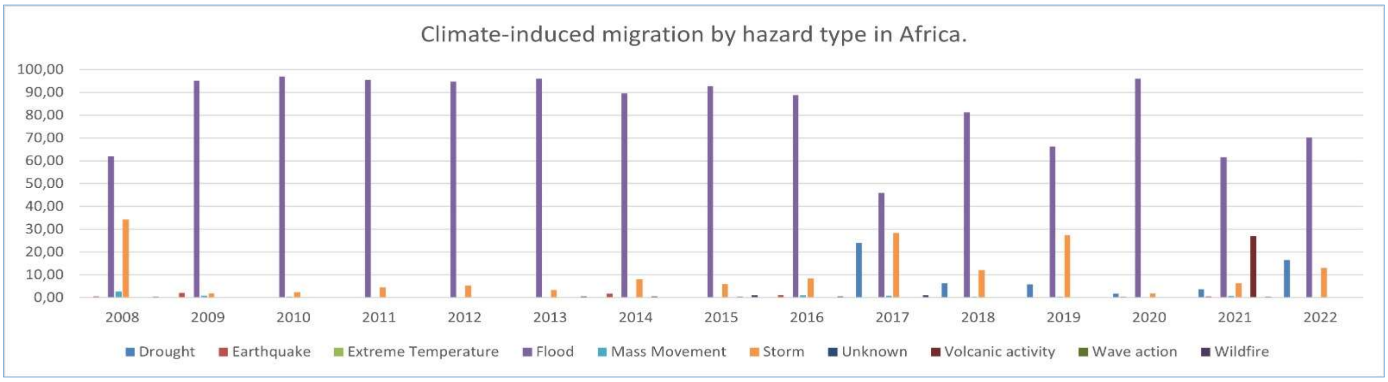

Fig. 2. Number of climate-induced displacements in Africa (Sources: Authors construct)

Table 1. Percentage of climate-induced displacements in Africa from 2008 to 2022 (Sources: Authors' calculations)

Year	Drought	Earthquake	Extreme Temperature	Flood	Mass Movement	Storm	Unknown	Volcanic activity	Wave action	Wildfire	Total
2008	0,00	0,62	0,00	62,00	2,71	34,26	0,00	0,00	0,00	0,41	100
2009	0,00	1,98	0,00	95,20	0,96	1,85	0,00	0,00	0,00	0,01	100
2010	0,00	0,00	0,00	97,05	0,43	2,35	0,00	0,00	0,00	0,17	100
2011	0,00	0,00	0,00	95,55	0,00	4,45	0,00	0,00	0,00	0,00	100
2012	0,00	0,01	0,00	94,67	0,00	5,32	0,00	0,00	0,00	0,00	100
2013	0,00	0,00	0,00	95,97	0,00	3,41	0,00	0,00	0,00	0,62	100
2014	0,00	1,72	0,00	89,54	0,07	8,05	0,00	0,57	0,00	0,05	100
2015	0,00	0,00	0,00	92,67	0,03	5,95	0,00	0,37	0,00	0,99	100
2016	0,00	1,28	0,00	88,69	1,09	8,45	0,00	0,00	0,00	0,48	100
2017	24,01	0,00	0,00	45,84	0,81	28,30	0,00	0,00	0,04	0,99	100
2018	6,26	0,02	0,00	81,18	0,36	12,05	0,01	0,00	0,00	0,12	100
2019	5,86	0,00	0,05	66,33	0,38	27,28	0,00	0,00	0,00	0,10	100
2020	1,69	0,32	0,00	95,92	0,10	1,95	0,00	0,00	0,00	0,02	100
2021	3,66	0,59	0,00	61,45	0,64	6,39	0,00	26,96	0,00	0,31	100
2022	16,43	0,00	0,00	70,16	0,15	13,07	0,00	0,00	0,00	0,19	100

According to Fig. 2 and Table 1, the trend in climate-induced displacement indicates an upward trajectory. Between 2008 and 2022, floods were the primary cause of climate-induced-migration in Africa, with storms also playing a significant role in the phenomenon. The trend suggests that, except for 2017, climate-induced migration has worsened in Africa over the years.

3. Climate Change and Food Security in Africa

Food security remains a pervasive challenge in Africa, with recent estimates indicating that approximately one-fifth of the population faces severe undernourishment (Oduoye et al., 2023). Several factors have been identified as major contributors to food insecurity in Africa, including conflicts, poverty, and population growth. Additionally, climate has become a significant factor influencing agricultural production and exacerbating food crises in many parts of Africa (Wudil et al., 2022).

Similarly, food insecurity has worsened in Sub-Saharan Africa due to weak economic growth, gender inequality, and the impact of climate change (Mahlatsi, 2023). According to Wudil et al. (2022), climate change is a major threat to Africa, as it leads to climate uncertainties that have a ripple effect on food insecurity. The consequences of climate change on food insecurity include competition for scarce resources, which can lead to conflicts, as evidenced by instances such as the civil war in the Ivory Coast and hunger-triggered conflicts in the Sahel region (Mahlatsi, 2023).

The link between food security and climate-induced migration has emerged as a pressing global concern, especially considering environmental changes that exacerbate food insecurity and drive displacement in today's world. However, there is growing recognition of the need for comprehensive assessment programs for food security, as demonstrated by the Global Food Security Index (GFSI) launched in 2012. Due to the lack of historical data before 2012, the GFSI cannot be used to look further back than 2012, thus emphasizing the need for an index that investigates food security beyond this time frame. Our study utilizes the Principal Component Analysis method to build such an index, providing a historical overview that goes back to 2001.

The study's objective is to contribute to the understanding of this issue by examining the relationship between climate-induced migration and food security, as well as identifying the determinants of food security. In the subsequent part, the study established the relationship between food insecurity and climate migration as well as the determinants of food security in Africa.

4. Methodology

Measuring food security at the national level presents a significant challenge due to its multifaceted nature, which cannot be captured by a single indicator (Food and Agricultural Organization (FAO, 2023). Therefore, it is necessary to develop indicators for each dimension of food security to create an overall food security index. However, creating such an index involves making trade-offs, which may require compromising the use of certain food security indicators based on their dimensions (World Food Summit; WFS, 1996). To provide a comprehensive understanding of the complex relationship between climate change, food security, and climate-induced migration, the study aims to construct a food security index that predates 2012, extending further back than the GSFI.

4.1. Data

The data for climate displacement was obtained from the Internal Displacement Monitoring Center (IDMC) Displacement database, which is available to the public. This information was utilized to create the climate migration bar graphs and percentage tables. The study used climate-related internal displacement data for African countries, with only 2008 to 2022 data being available due to constraints in data availability. On the other hand, data for food security was primarily sourced from the Food and Agriculture Organization (FAO) Statistical database, which is also publicly accessible. In cases where there was missing data, the World Bank Indicator database was utilized as a secondary data source.

The food security data was gathered from the Food and Agriculture Organization (FAO) Food Security database. Due to data availability constraints, 14 food security indicators were chosen from the FAO (2023). Most of these indicators are only accessible as three-year averages. As a result, all variables are three-year averages to ensure consistency. The aim was to evaluate food security and its dimensions on climate migration. Data from 2001 to 2021 from 36 African countries were analyzed, resulting in a panel of seven rounds based on three-year averages. These rounds include 2001-2003, 2004-2006, 2007-2009, 2010-2012, 2013-2015, 2016-2018, and 2019-2021. The data was utilized to construct the Food security index using the Principal Component Analysis method, which will be further explained in subsequent sections.

In the subsequent panel data analysis, the study aims to elucidate the relationship between climate change and food security. The data for the explanatory variables employed in the panel data analysis was sourced from the FAO FAOStat database and the World Development Indicator database of the World Bank.

4.2. The Food Security Index (FSI) Method

Principal Component Analysis (PCA) is a multivariate technique used to condense multidimensional data into a composite index. The composite indicator in PCA captures multiple-dimensional concepts that are difficult to represent with a single indicator. The common rule of thumb for PCA is that the ratio of variables to cases should exceed five cases, and any variable with a correlation less than 0.3 is considered unfit for PCA. The determination of the number of factors to be extracted from a PCA analysis depends on established criteria and can be adjusted to achieve the desired extraction. PCA should retain enough of the component to explain the data's total variance, as suggested by Jolliffe (2014).
Expressed generally as:

$$FS_i = \sigma_1 X_{1i} + \sigma_2 X_{2i} \dots \dots . . + \sigma_n X_{ni} \tag{1}$$

Where; FS_i implies the combination of variables used in the PCA and is linear, X_{ni} represents indicators of food security sourced from the FAO (2023) food security suites database, this data ranges from 1 to z for factor i, and finally σ denotes factor loadings.

4.3. FSI Dimensions and Indicators

4.3.1. Food Availability Dimension and Indicators

This dimension of food security describes all the variables that pertain to the tangible accessibility of various food items, irrespective of the sources from which these food items emerge. It encompasses all food resources from local production, imports, inventories, and relief provisions. (Lin and He, 2020). Below are the indicators of food availability.

Average Dietary Supply Adequacy (Av_diet_ene_sup): Percentage of a country's average dietary energy requirement. It depends on the country's population's social and demographic structure. One of the fundamental reasons for consuming food is to derive ample energy to support daily human activities.

Food production Per capita value (Per_capita_ value_food_prod): This is obtained as a function of a country's total food value by its population. Hence per capital. It is a proxy for the per capita access of individuals within a country to food production.

Average Protein Supply (Av_protein_sup): This represents a nation's average protein supply and is expressed in grams per capita. This variable gives an understanding of a nation's access to proteinous food.

4.3.2. Food Access Dimension and Indicators

Accessibility pertains to the multifaceted and intertwined aspects of social, physical, and economic means by which individuals secure access to available food. This domain signifies the demand side of food security, encompassing individuals' physical and economic endowments in their pursuit of gaining access to the available food in the economy (Lin and He, 2020). Below are the variables that are associated with food access.

Prevalence of Undernourishment (Prev_undernourish) (3-year average): The prevalence of undernourishment is the percentage of the population whose habitual food consumption is insufficient to provide the dietary energy levels that are required to maintain an everyday, active, and healthy life. It is expressed as a percentage.

Depth of the Food Deficit (Food_def_PPC): Refers to the difference between a country's food production and consumption. It hinges on the notion that when a country has a food deficit, it does not produce enough food to feed its population and must rely on imports to meet its needs.

GDP Per Capita (Per_Cap_GDP): Measures a country's economic output per person. It is calculated by dividing the country's GDP by its population. GDP per capita is often used as an indicator of a country's standard of living.

4.3.4. Food Utilization Dimension and Indicators

This encompasses the appropriate usage of accessible food, as cited by FAO (2014), and Lin and He (2020). Four indicators intrinsically linked to utilization and have consequences on food security are used as pointers for the food utilization dimension. First, the availability of clean and safe water and sanitation amenities is perceived to influence food utilization directly.

Access to clean water (Perc_pop_ using_basic_drin_water_serv): measures. The percentage of a country's population with easy access to portable and safe drinking water.

Accessed to improved sanitation facilities (Perc_pop_ using_basic_Sani_serv): The percentage of a country's population that has basic access to human waste disposal facilities.

Prevalence of anemia among pregnant women (Prev_anemia_women): The prevalence of anemia during pregnancy periods indicator implies iron deficiency. This indicator captures the proportion of pregnant women who are anemic. It is a common problem among pregnant women, affecting about 30% of pregnant women worldwide.

Percentage of Children Under 5 Years of Age Who are Stunted (Perc_child_5 years stunted): This is defined as the number of children under 5 years of age whose height for age is more than two standard deviations below the median for the international reference population ages 0-59 months.

4.3.4. Food Stability Dimension and Indicators

This is contingent upon the consistent availability of food for individuals. This encompasses a nation's susceptibility to disruptive occurrences that have the potential to hinder the ability to maintain a steady food supply (Lin and He, 2020). Below are the indicators of food stability.

Per Capita Food Production Variability (Per_cap_fd_pd_var): This captures the instability in the value of net food production in the years of the food crisis (2004-2006) and is in US dollars.

Cereal Import Dependency Ratio (Cereal_import_dependency): this measure of the extent to which a country relies on imports to meet its cereal needs. It is calculated by dividing the total amount of cereal imports by the total amount of cereal available for consumption, which includes domestic production plus imports minus exports. Mathematically, it is expressed as a percentage.

Per Capita Food Supply Variability (Per_cap_fd_sup_var): This measures the annual fluctuations in the per capita food supply (kcal), represented as the standard deviation over the previous five years per capita food supply.

Arable Land as a Percentage of land Equipped for Irrigation (Per_arable_irrig): This represents the ratio of the area of arable land furnished with irrigation facilities/equipment to the total area of arable land. It is a measure of the availability of water for agricultural production; irrigation allows uninterrupted food production. Irrigation allows farmers (ultimate food providers) to grow crops in areas with low rainfall or during the dry season.

Table 2. Descriptive statistics of PCA variables (Source: Authors' calculations)

	N	Minimum	Maximum	Mean	Standard Deviation
Av_diet_ene_sup (1)	252	77.00	151.00	112.61	14.79
Av_protein_sup (2)	252	33.30	101.11	65.61	15.11
Per_capita_ value_food_prod (3)	252	31.80	663.04	257.40	140.64
Cereal_import_dependency (4)	252	0.50	1000.00	49.34	67.16
Per_arable_irrig (5)	252	0.00	10.50	0.94	1.84
Per_cap_fd_pd_var(6)	252	1.20	71.60	12.35	10.18
Per_cap_fd_sup_var(7)	252	6.00	224.00	43.30	29.85
Food_def_PPC(8)	252	-1.07	-0.002	-0.13	0.21
Perc_pop_ using_basic_drin_water_serv (9)	252	19.70	99.00	67.18	17.81
Perc_pop_ using_basic_Sani_serv (10)	252	3.10	97.00	39.77	26.18
Perc_child_5 years_stunted(11)	252	8.60	54.70	29.14	10.72
Prev_anemia_women (12)	252	17.20	62.50	41.03	11.82
Per_Cap_GDP(13)	252	265.27	10256.17	2179.06	1983.73
Prev_undernourish(14)	252	2.50	63.13	18.15	11.76

4.4. Stepwise iteration of the PCA Approach

PCA on pooled data has been argued to be a promising approach for analyzing datasets in various fields (Chunovkina, 2017). Using the SPSS 27 version, the study performs a PCA on the data; the data in this study are seven rounds of 3-year averages from 2001 to 2021. The Pooling of the data aids in developing an index that can be used for comparison over time (Caccavale and Giuffrida, 2020).

The first step in conducting PCA is that the variables must be standardized. Next is the sample size adequacy requirement, and variable correlation criteria are met. There is a need to satisfy the ratio of the cases to a variable condition whose minimum should not be less than 5. The study satisfies this criterion with 18 (total cases of 252 averaged by 14 variables).

Meanwhile, the correlation between variables was perused to see if the variables have enough correlation to perform PCA. 14 variables were initially included, and the correlation structure was checked. Table 3 gives an overview of the matrix of correlation.

Furthermore, to check the association between the variables included in the initial analysis, Bartlett's test of Sphericity, is not a test of sphericity, but for the equality of variances in normal populations, the test rejects the null hypothesis as shown in Table 4. The study records a P-value of 0.000 and thus confirms that the null hypothesis of the zero-identity matrix is rejected and therefore confirms the appropriateness of PCA.

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is a commonly used measure in factor analysis to assess the suitability of the data for analysis. It helps determine if the variables in the dataset are appropriate for factor analysis. A KMO value within the range of 0.6-0.7 is generally considered good for factor suitability (Nkansah, 2018). The KMO statistic of 0.823 (Table 3) reflects the adequacy of the study's sample for PCA.

Table 3. Correlation matrix (Source: Authors' calculations)

Correlation Matrixa

	Zscore(Av_diet_ene_sup)	Zscore(Av_protein_sup)	Zscore: Per_capita_value_food_prod	Zscore: Cereal_import_dependency	Zscore: Per_arable_irrig	Zscore(Per_cap_fd_pd_var)	Zscore(Per_cap_fd_sup_var)	Zscore(Food_def_PPC)	Zscore: Perc_pop_using_basic_drin_water_serv	Zscore: Perc_pop_using_basic_Sani_serv	Zscore: Perc_child_5 years_stunted	Zscore(Prev_anemia_women)	Zscore(Per_Cap_GDP)	Zscore: Prevalence of undernourishment
Zscore(Av_diet_ene_sup)	1.000													
Zscore(Av_protein_sup)	0.78 (0.0000)	1.000												
Zscore: Per_capita_value_food_prod	0.330.0000)	0.19 (0.0000)	1.000											
Zscore: Cereal_import_dependency	0.09 (0.0000)	0.03 (0.0000)	0.01 (0.0000)	1.000										
Zscore: Per_arable_irrig	0.36 (0.0000)	0.45 (0.0000)	0.20 (0.0000)	0.07 (0.1420)	1.000									
Zscore(Per_cap_fd_pd_var)	0.32 (0.0000)	0.28 (0.0000)	0.10 (0.0000)	0.08 (0.0000)	0.21 (0.0000)	1.000								
Zscore(Per_cap_fd_sup_var)	0.19 (0.0000)	0.26 (0.0000)	0.07 (0.0000)	0.13 (0.0000)	0.13 (0.0000)	0.05 (0.0000)	1.000							
Zscore(Food_def_PPC)	0.20 (0.0000)	.024 (0.0000)	0.06 (0.0000)	0.31 (0.0000)	0.17 (0.0000)	0.19 (0.0000)	0.05 (0.0000)	1.000						
Zscore: Perc_pop_using_basic_drin_water_serv	0.53 (0.0000)	0.58 (0.0000)	0.25 (0.0000)	0.24 (0.0000)	0.41 (0.0000)	0.16 (0.0000)	0.17 (0.0000)	0.28 (0.0000)	1.000					
Zscore: Perc_pop_using_basic_Sani_serv	0.52 (0.0000)	0.67 (0.0000)	0.23 (0.0000)	0.22 (0.0000)	0.57 (0.0000)	0.28 (0.0000)	0.12 (0.0000)	0.27 (0.0000)	0.75 (0.0000)	1.000				
Zscore: Perc_child_5 years_stunted	0.51 (0.0000)	0.58 (0.0000)	0.31 (0.0000)	0.24 (0.0000)	0.40 (0.0000)	0.18 (0.0000)	0.17 (0.0000)	0.323	0.78 (0.0000)	0.68 (0.0000)	1.000			
Zscore(Prev_anemia_women)	0.06 (0.0000)	0.30 (0.0000)	0.07 (0.0000)	0.15 (0.0000)	0.45 (0.0000)	0.04 (0.0000)	0.01(0.0000)	0.27 (0.0000)	0.28 (0.0000)	0.50 (0.0000)	0.19 (0.0000)	1.000		
Zscore(Per_Cap_GDP)	0.30 (0.0000)	0.49 (0.0000)	0.18 (0.0000)	0.20 (0.0000)	0.49 (0.0000)	0.01 (0.0000)	0.15 (0.0000)	0.33 (0.0000)	0.68 (0.0000)	0.68 (0.0000)	0.62 (0.0000)	0.35 (0.0000)	1.000	
Zscore: Prevalence of undernourishment	0.88 (0.0000)	0.74 (0.0000)	0.30 (0.0000)	0.02 (0.0000)	0.35 (0.0000)	.223 (0.0000)	0.15 (0.0000)	0.05 (0.0000)	0.60 (0.0000)	0.53 (0.0000)	0.58 (0.0000)	0.07 (0.0000)	0.41 (0.0000)	1.000

Table 4. KMO and Bartlett's Test (Source: Authors Calculations)

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.823
Bartlett's Test of Sphericity	Approx. Chi-Square	1595.769
	Df	28
	Sig.	0.000

Sample adequacy in PCA is an essential consideration in determining the reliability of observed estimates. Testing for sample adequacy stipulates that the diagonal cells of the correlation and anti-image correlation matrix be perused keenly. Observations from the study's correlation matrix show that all variables in grey in Table 3 above have values less than 0.3, which is unsuitable for PCA. These two variables (Cereal_import_dependency and Per_cap_fd_sup_var) were subsequently dropped for having values less than 0.3. The two variables dropped in this analysis are the Stability dimension variables. Further, the anti-image matrix is derived from the symmetry of the correlation function and is used to build the initial correlation/covariance matrix. Using the anti-image matrix instead of the central point value significantly improves the accuracy of PCA (Chen and Zhou, 2018). In this study, the anti-image matrix is in Table 6; the details suggest that all the variables satisfy the correlation requirement of PCA of 0.5.

Table 5. Correlation matrix of the variables used in the food security index (Source: Authors' calculations)

Correlation Matrix of included variables												
	1	2	3	4	5	6	7	8	9	10	11	12
Zscore(Av_diet_ene_sup)	1.000											
Zscore(Av_protein_sup)	0.783	1.000										
Zscore: Per_capita_value_food_prod	0.328	0.186	1.000									
Zscore: Per_arable_irrig	0.355	0.447	0.196	1.000								
Zscore(Per_cap_fd_pd_var)	0.320	0.283	0.100	0.211	1.000							
Zscore: Perc_pop_using_basic_drin_water_serv	0.533	0.582	0.246	0.412	0.156	1.000						
Zscore: Perc_pop_using_basic_Sani_serv	0.519	0.665	0.225	0.570	0.275	0.749	1.000					
Zscore: Perc_child_5 years_stunted	-0.508	-0.575	-0.310	-0.395	-0.183	-0.781	-0.677	1.000				
Zscore(Per_Cap_GDP)	0.303	0.492	0.175	0.492	0.002	0.681	0.675	-0.623	1.000			
Zscore: Prevalence of undernourishment	-0.878	-0.738	-0.297	-0.351	-0.228	-0.598	-0.531	0.577	-0.411	1.000		
Zscore(Prev_anemia_women)	-0.056	-0.304	-0.068	-0.453	-0.042	-0.275	-0.503	0.191	-0.349	0.073	1.000	
Zscore(Food_def_PPC)	0.196	-0.024	-0.062	-0.174	0.185	-0.283	-0.267	0.323	-0.334	0.050	0.270	1.000
All variables are significant at 1%												

Table 6. Anti-image matrix of included variables (Source: Authors' calculations)

Anti-image Matrices

	1	2	3	4	5	6	7	8	9	10	11	12
Zscore(Av_diet_ene_sup)	.697[a]	-0.435	-0.239	-0.117	-0.017	-0.100	-0.126	0.011	0.256	0.732	-0.131	-0.503
Zscore(Av_protein_sup)	-0.435	.886[a]	0.215	0.024	-0.057	0.119	-0.155	0.117	-0.177	0.039	0.224	0.050
Zscore: Per_capita_ value_food_prod	-0.239	0.215	.775[a]	-0.044	-0.012	0.054	0.022	0.164	-0.037	-0.051	0.067	0.089
Zscore: Per_arable_irrig	-0.117	0.024	-0.044	.898[a]	-0.128	0.103	-0.140	0.004	-0.235	-0.031	0.259	0.063
Zscore(Per_cap_fd_pd_var)	-0.017	-0.057	-0.012	-0.128	.735[a]	0.033	-0.225	0.077	0.230	-0.017	-0.085	-0.166
Zscore: Perc_pop_using_basic_drin_water_serv	-0.100	0.119	0.054	0.103	0.033	.886[a]	-0.313	0.421	-0.261	0.083	0.010	0.051
Zscore: Perc_pop_using_basic_Sani_serv	-0.126	-0.155	0.022	-0.140	-0.225	-0.313	.885[a]	0.116	-0.236	-0.110	0.348	0.110
Zscore: Perc_child_5 years_stunted	0.011	0.117	0.164	0.004	0.077	0.421	0.116	.894[a]	0.126	-0.024	0.186	-0.209
Zscore(Per_Cap_GDP)	0.256	-0.177	-0.037	-0.235	0.230	-0.261	-0.236	0.126	.863[a]	0.136	-0.047	-0.049
Zscore: Prevalence of undernourishment	0.732	0.039	-0.051	-0.031	-0.017	0.083	-0.110	-0.024	0.136	.790[a]	0.073	-0.376
Zscore(Prev_anemia_women)	-0.131	0.224	0.067	0.259	-0.085	0.010	0.348	0.186	-0.047	0.073	.732[a]	-0.100
Zscore(Food_def_PPC)	-0.503	0.050	0.089	0.063	-0.166	0.051	0.110	-0.209	-0.049	-0.376	-0.100	.520[a]

Table 7. Initial communalities (Source: Authors' calculations)

Communalities

	Initial	Extraction
Zscore(Av_diet_ene_sup)	1	0.895
Zscore(Av_protein_sup)	**1**	**0.756**
Zscore: Per_capita_ value_food_prod	1	0.24
Zscore: Per_arable_irrig	1	0.315
Zscore(Per_cap_fd_pd_var)	1	0.343
Zscore: Perc_pop_ using_basic_drin_water_serv	1	0.772
Zscore: Perc_pop_ using_basic_Sani_serv	1	0.82
Zscore: Perc_child_5 years_stunted	1	0.755
Zscore(Per_Cap_GDP)	1	0.693
Zscore: Prevalence of undernourishment	1	0.814
Zscore(Prev_anemia_women)	1	0.324
Zscore(Food_def_PPC)	1	0.667

Table 8. Final communalities (Source: Authors' calculations)

Final Communalities		
	Initial	Extraction
Zscore(Av_diet_ene_sup)	1.000	0.928
Zscore(Av_protein_sup)	1.000	0.789
Zscore: Perc_pop_ using_basic_drin_water_serv	1.000	0.796
Zscore: Perc_pop_ using_basic_Sani_serv	1.000	0.751
Zscore: Perc_child_5 years_stunted	1.000	0.751
Zscore(Per_Cap_GDP)	1.000	0.696
Zscore: Prevalence of undernourishment	1.000	0.808
Zscore(Food_def_PPC)	1.000	0.709

4.5. Procedure for Creating the FSI

To extract the food security index using PCA, a series of iterative steps were followed. The process began by examining the communalities of the indicator's factor loadings, which is the sum of the squared values. The larger the communalities, the better, and PCA requires a minimum of 0.5. Initially, twelve variables were included in the factor extraction, but four were excluded due to low commonalities. Tables 7 and 8 show the communalities of these variables. Only one variable, 'Prev_anemia_women,' did not meet the requirement of 0.5, so it was removed. Two factors were retained using Kaiser's criterion and scree plot, but since the study aimed to simplify the food security dimensions into a single index, it was logical to retain the first-factor component. Based on the results presented above, the variance obtained from the first component was found to be 59.2% of the total variance in the variables, which is a noteworthy improvement compared to previous studies. Specifically, this value exceeds the findings of Demeke et al. (2011) who reported a variance of 32.5% in their study on the impact of climate change on food security in Ethiopia, and Reig (2012) who obtained a variance of 56.2% in their study on food security in African and Arabic countries. However, the variance obtained in the present study falls short of the 63.0% reported by Cavatassi et al. (2004) in their research on food insecurity in developing countries.

Table 9. Variance of all the variables (Source: Authors' calculations)

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.737	59.219	59.219	4.737	59.219	59.219
2	1.491	18.632	77.850	1.491	18.632	77.850
3	0.577	7.208	85.059			
4	0.394	4.931	89.989			
5	0.316	3.950	93.939			
6	0.240	3.000	96.939			
7	0.171	2.133	99.072			
8	0.074	0.928	100.000			

Table 10. Loading of the variables (Source: Authors' calculations)

Loadings	
Zscore(Av_diet_ene_sup)	0.770
Zscore(Av_protein_sup)	0.836
Zscore: Perc_pop_ using_basic_drin_water_serv	0.868
Zscore: Perc_pop_ using_basic_Sani_serv	0.848
Zscore: Perc_child_5 years_stunted	-0.838
Zscore(Per_Cap_GDP)	0.735
Zscore: Prevalence of undernourishment	-0.819
Zscore(Food_def_PPC)	-0.807

The component matrix of PCA represents the relationship between the original variables and the principal components (Liu et al., 2022). The sign and value of a variable's loadings show the correlations between the nature of its correlation and its relationship with other factors. There appears to be a meaningful observable pattern in the loadings of the variables. As can be seen from Table 9, "Av_diet_ene_sup," "Av_protein_sup," "Perc_pop_ using_basic_drin_water_serv," "Perc_pop_ using_basic_Sanir_serv," and "Per_Cap_GDP" are positive. While "Perc_child_5 years_stunted", "Prevalence of undernourishment", and "Food_def_PPC" are negative. From these relationships, the first component reflects the country's 'food security' status. Therefore, this component is used as the study's composite food insecurity index.

5. Food Security Index of Africa

After obtaining the FSI index, the study categorized countries based on their percentile ranking. There are four percentiles as indicated in Figs. 4 and 5: 1 represents the 25 percentile, 2 represents the 50 percentile, 3 represents the 75 percentile, and 4 represents the 100 percentile (>75 percentiles). This attempt compares the food security index of African countries relative to other African countries and offers insight that is distinct to the African continent's situation. From Fig. 4, it is apparent that many African countries' FSI fall between 25 and 50 percentiles. This indicates a need for a holistic approach to address the African food security situation.

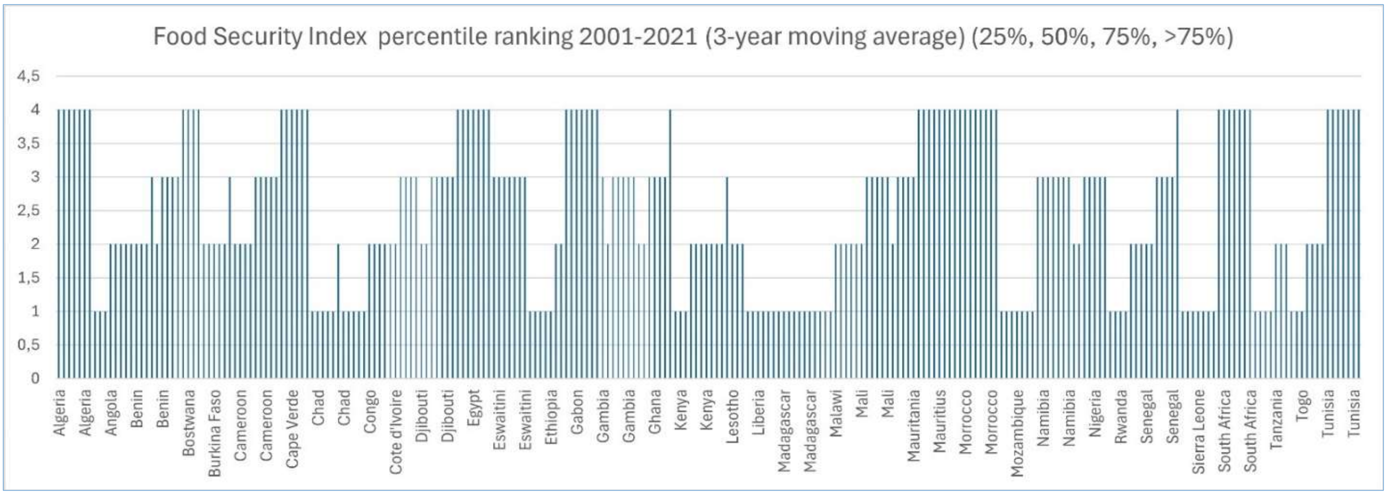

Fig. 3. Food security index decomposition by percentile for African countries 2001-2021 (Source: Authors' construct)

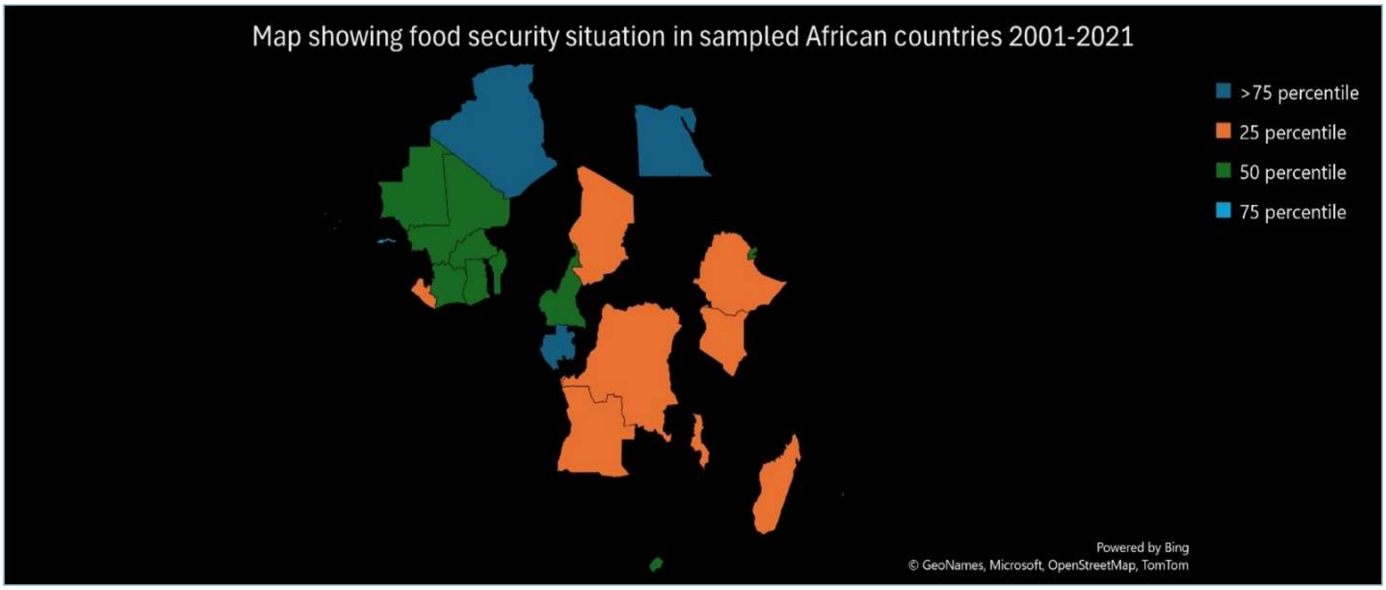

Fig. 4. A map showing the intensity of food security in Africa (Source: Authors' design)

6. Comparisons between Climate-İnduced Migration and Food Security and Empirics from a Panel model estimate

6.1. Relationship Between Food Security and Climate-Induced Migration in Africa

Comparing Figs. 3 and 4 with Fig. 2 and Table 1 above reveals a diverse pattern of natural disaster occurrences across African countries. These disasters include drought, extreme temperature, flood, mass movement, storm, volcanic activity, wave action, and wildfire. Some countries experience multiple types of disasters, while others are relatively spared. For example, Ethiopia is significantly impacted by drought, with a substantial number of occurrences recorded. Madagascar frequently experiences floods, while Nigeria contends with a high incidence of floods and storms. Algeria, Angola, and Botswana are noteworthy for their occurrences of drought.

It is noteworthy that there appears to be a correlation between the frequency and severity of climate-induced disasters and the food security rankings of these countries. Countries with higher occurrences of disasters tend to have lower food security rankings, suggesting a potential link between environmental challenges and food insecurity. For instance, countries like Ethiopia and Mozambique, which frequently experience natural disasters such as droughts and floods, also tend to have lower food security rankings, with their percentile values falling below the 50th percentile. In contrast, countries like Algeria and Egypt, despite facing environmental challenges like drought and extreme temperatures, maintain relatively high food security rankings, consistently scoring above the 75th percentile. This pattern underscores the complex interplay between environmental factors, natural disaster occurrences, and food security outcomes in Africa. It suggests that addressing food insecurity effectively requires considering not only agricultural productivity but also resilience to environmental shocks and disasters.

Fig. 5 gives an overview of climate-induced migration in Africa by country. It reveals a varied pattern of natural disaster occurrences across African countries, including drought, extreme temperature, flood, mass movement, storm, volcanic activity, wave action, and wildfire. Some countries experience multiple types of disasters, while others are relatively spared. For instance, Ethiopia suffers significantly from drought, with a substantial number of occurrences recorded. Madagascar faces frequent floods, while Nigeria contends with a high incidence of floods and storms. Countries like Algeria, Angola, and Botswana experience notable occurrences of drought.

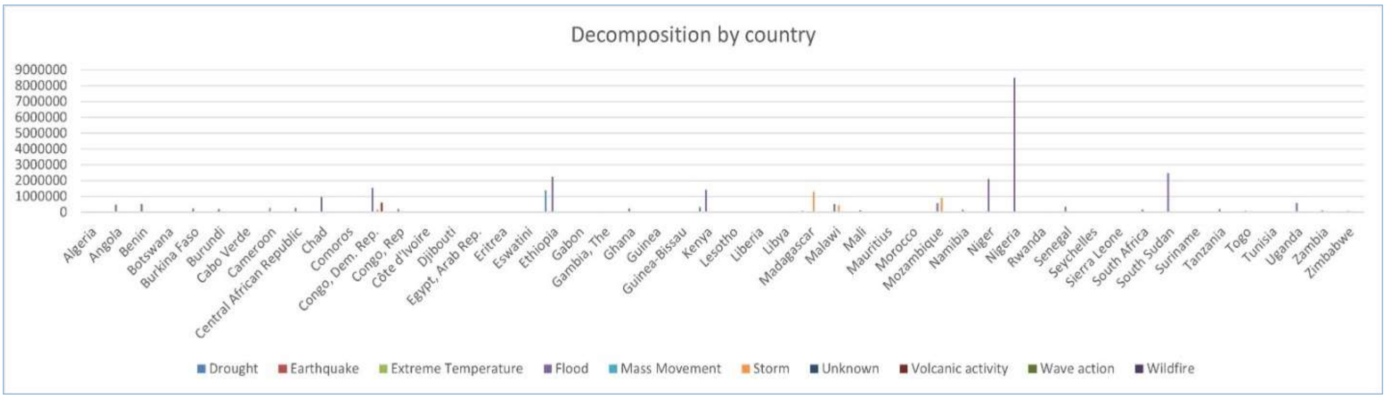

Fig. 5. Decomposition of climate-change-induced migration by countries 2008-2022 (Source: Authors' construct)

Table 11. Descriptives of panel data variables (Source: Authors' Calculation)

	Descriptive Statistics				
	N	Minimum	Maximum	Mean	Standart Deviation
FSI	252	-2.132	2.300	0.009	1.009
Food_Inflation	252	-3.145	109.862	7.528	8.672
POP_Grow_rate	252	-0.273	4.078	2.335	0.816
Unemp_rate	252	0.731	28.363	9.438	7.576
Emission total	252	67.159	66708.821	17487.218	17674.161
Stability	252	-2.19	1.20	-0.398	0.750

From Fig. 5 it can be observed that flood is the predominant climate extremity leading to climate-induced migration and displacements in Africa. The major type of climate-extremity appears to be geophysical, while other types are inconsequential. Amongst the geophysical climate extremities, Floods have resulted in the highest number of displacements in Africa.

6.2. Relationship between Climate Change and Food Security in Africa

Using the Random effect panel model estimation method, the study offers an empirical investigation into the relationship between climate change and food security in Africa. The analysis offers an econometric overview of the interaction between the proxies of climate change and food security.

6.2.1. Dependent Variable

The Food Security Index (FSI) is a standardized index that was previously obtained through Principal Component Analysis (PCA). This index, which has a mean of zero and a standard deviation of one, is derived from the first-factor loading presented in Table 11.

6.2.2. Explanatory Variables

Food Inflation (Food_inflation) is a measure of the rate at which food prices rise over some time. It is calculated by dividing the difference between the current year's food prices and the previous year's prices by the previous year's prices and multiplying the result by 100.

Population Growth Rate (POP_grow_rate) is the annual percentage change in a country's or region's population.

Unemployment Rate (Unemp_rate) is the percentage of individuals in the labor force who are unemployed. The labor force includes both employed and unemployed individuals.

Total Agricultural Emission (Emmission_total) refers to the cumulative emissions of NO2, CO2, and CH4 gases from agricultural systems. This value reflects the intensity of greenhouse gas emissions and is a contributor to global warming.

Political Stability and Absence of Violence (Stability) is a composite measure that captures the likelihood of the government being destabilized or overthrown by unconstitutional or violent means, including politically motivated violence and terrorism.

6.2.3. Panel Data Estimation Procedure

Employing panel data is much more desirable than using cross-section data; this is because panel data gives more efficient estimates by allowing the inclusion of many observations. In this study, the earlier obtained FSI was regressed on other variables using the *Equation 2*.

$$FSI_{it} = \delta_i + \gamma_1 FP_{it} + X_{it}'\gamma + \varepsilon_{it} \dots \quad (2)$$

Where; FSI_{it} is PCA index of food security for country i in time t, δ_i is country I's intercept if the fixed effects model was used to estimate the model. Otherwise, if random effects estimate it, delta sub i. is expressed as part of the error term. ε_{it} is a vector of control variables, and ε_{it} is the error term.

Static panel data are estimated using fixed effect (FE) and Random effect (RE) models. As customary, it is argued that each model should be tested using the Hausman test to determine which suits a data set best; accepting the null hypothesis implies that the random effect is more suitable than the fixed effect, and the reverse is also accurate (Verbeek, 2012).

Therefore, to arrive at the best model for this study, a decision must be reached on which of the fixed (FE)and random effects (RE) models suits our data. To do this, an estimate of the Hausman specification test was carried out. The Hausman test's null hypothesis posits no endogeneity at the examined quantile (Tae-Hwan and Muller, 2010). The test accepted the null hypothesis (p-value = 0.099), meaning that the random effects model is consistent, and the FE model is inconsistent. Table 12 presents the estimates for the panel data estimates.

Table 12. Panel result of the random effect (RE) model (Source: Authors Calculation)

	Dependent variable
	FSI
Unemp_rate	0.001 (0.920)
Food_inflation	-0.014(0.000) ***
POP_Grow_rate	-0.164(0.001) ***
Emmission_tot	5.08e-06(0.165)
Stability	-0.073(0.158)
Within R^2	0.143
F_Stat	40.59 (0.000)

**** represents 1% level of significance*

There was also a need to check for heteroskedasticity; the test of multicollinearity and heteroscedasticity was done using "vif" function, the "imtest (white)", and "hettest" functions on Stata 17 software. The heteroskedasticity test null hypothesis was rejected; for the multicollinearity test, the null hypothesis was accepted for each of the tests at 1%.

Since the dependent variable of this study is a normalized index derived from a PCA analysis, the appropriateness of interpreting the magnitude of the coefficients that result from such regression has been severely questioned in the works of (Demeke et al., 2011; Wineman, 2014). However, the signs of the coefficients and their significance level can give insights into the relationships between food security and these variables. Table 11 below shows the outcome of the panel random effect model.

The interplay between food security estimates and population growth rates presents significant challenges for Africa, particularly within the context of climate-induced migration. Food inflation exacerbates food insecurity, reducing purchasing power and disproportionately affecting low-income households, leading to hunger and malnutrition, which in turn can result in stunted growth, cognitive impairment, and increased disease susceptibility. Moreover, heightened food insecurity can perpetuate poverty cycles, as individuals allocate a larger portion of their income to food, limiting resources for essential needs like housing, clothing, and healthcare, potentially precipitating social unrest, as evidenced by instances such as the wheat shortages and bread riots in Tunisia in late 2010 (Sadok et al., 2019).

As populations grow, the strain on food production systems intensifies, leading to heightened demand and the potential for declining per capita food availability. This discrepancy between demand and supply dynamics can further exacerbate food price increases, making accessibility more challenging. Given the growing populations and the effects of climate change on agricultural output, the need for food continues to rise. This increased demand places additional strain on already limited land and water resources. Climate change's impact, such as altered precipitation patterns and water shortages, places pressure on the availability of arable land and freshwater resources vital for farming. Additionally, heightened demands exacerbate the challenges faced by finite land and water resources, complicating food production efforts and contributing to environmental degradation, including deforestation and soil erosion, which pose long-term threats to sustainable food production (El Bilal et al., 2020). Climate change's consequences, such as extreme weather events and soil degradation, hinder agricultural productivity, making it increasingly difficult to meet the growing food needs. To fulfill the rising food requirements, increased agricultural activities may lead to environmental degradation, including deforestation and soil erosion. These activities contribute to a reduction in habitats, the loss of biodiversity, and soil degradation, exacerbating the effects of climate change. The cumulative impact of these factors presents significant long-term risks for sustainable food production, which could result in food insecurity, displacement, and migration as communities struggle with diminishing resources and environmental deterioration.

7. Findings and Discussions

This study underscores the negative correlation between climate change, migration, and food security. The synthesis of a food security index and the determinants of food security, alongside climate-induced migration, highlights their interdependence. Climate change significantly impacts population movements and food insecurity by inducing environmental stressors such as droughts, floods, and temperature shifts. These events directly affect agricultural productivity, thereby influencing food availability and stability, potentially leading to migration for sustainable living conditions. Policymakers must comprehend the intricate interplay between climate change, food security, and human mobility to devise adaptive strategies such as climate-resilient agriculture and sustainable resource management, addressing the needs of displaced populations.

A comprehensive understanding of these dynamics aids in evaluating policies to mitigate climate change's ramifications on African food security and human well-being, considering existing exacerbating factors and ensuring sustainable agricultural production amidst climate variability (Moktar et al., 2019; Rosalia and Mulyaningsih, 2023; Islam and Kieu, 2021; Pretty and Reddy, 2023; Hertel, 2016). This understanding illuminates the existential threats posed by climatic factors on migration and food security, particularly in Africa, where climate migration can lead to food inflation, unemployment, and marginalization, disproportionately affecting the poor and vulnerable (Tuholske et al., 2024; Kübra, 2023; IMDb, 2023).

8. Conclusion and Recommendations

Although some attempts have been made to investigate climate impact on migration and food security, the existing studies lack a more in-depth analysis of socioeconomic and political factors that influence climate change, leading to human mobility in Africa. It is also important to note that researchers have yet to establish the entire root cause of migration in the continent; our study argues that climate change and food insecurity significantly impact human mobility. Hence, stakeholders need to formulate and implement policies backed by research to find durable solutions that will help to control the alarming increase of climate migration and food insecurity on the continent.

The extensive investigation has brought to light the multifaceted nature of ensuring an adequate food supply, examining the factors contributing to it and climate change's significant impact on human migration. Creating a reliable Food Security Index offers a valuable tool for evaluating and tackling food security challenges within the continent. Furthermore, our discoveries emphasize the urgent necessity for proactive measures to mitigate the detrimental consequences of climate change through resilient and coping mechanisms. Policymakers, stakeholders, and communities should therefore collaborate to implement sustainable strategies, such as enhanced agricultural methods, climate-resilient infrastructure, and targeted social interventions to safeguard food availability for current and future generations. African governments should strive towards a more resilient and equitable global food system by addressing these intricate interactions.

Also, since climate adaptation and mitigation have yet to be given the needed attention in climate change policies and frameworks on the continent, climate problems will continue to increase if stakeholders fail to implement quick and radical actions. This study argues that it will be challenging to mechanize proper mitigation strategies in the immediate short time, and this will end up worsening climate mobility and food crises in many African countries. However, with a priority to address the climate crisis through climate emergency policies, the problem of climate mobility and food security in Africa can be controlled from now through the future. Policy-wise, there should be uniformity among the subregional organizations and governments on the continent to establish a holistic policy agenda and frameworks to find durable solutions to climate change and its impact on food security and human mobility. In this regard, climate change policies should focus on the fundamental human rights of the climate migrants and the climate vulnerable. Finally, there is a need to invest effectively in climate adaptation and resilience in sustainable agriculture, water management, afforestation, and infrastructure.

Conflicts of Interest

The authors declare no conflict of interest.

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