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Environmental drivers of human migration in Sub-Saharan Africa

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Review Article

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Non-technical summary. Environmental threats to shelter, livelihoods, and food security are often considered push factors for intra-African human migration. Research in this field is often fragmented into a myriad of case studies on specific subregions or events, thus preventing a more comprehensive understanding of the phenomenon. This paper examines environmental drivers reported in the literature as push factors for human displacement across 32 sub-Saharan African countries between 1990 and 2021. Extensive consultation of past studies and reports with analytical methods shows that environmental migration is complex and influenced by multiple direct and indirect factors. Non-environmental drivers compound the effects of environmental change.

Technical summary. Intra-African environmental migration is a bleak reality. Warming trends, aridification, and the intensification of extreme climate events, combined with underlying non-environmental drivers, may set millions of people on the move. Despite previous studies and meta-analyses on environmental migration within sub-Saharan Africa (SSA), conclusive empirical evidence of the relationship between environmental change and migration is still missing. Here we draw on 87 case studies published in the scholarly literature (from fields ranging from the environmental sciences to development economics and migration research) or documented by research databases, reports, and international disaster datasets to develop a meta-analysis investigating the relationship between environmental changes and migration across SSA. A combination of quantitative, Qualitative Comparative Analyses (QCA), and statistical correlation methods are used to analyze the metadata and investigate the complex web of environmental drivers of environmental migration in SSA while highlighting subregional differences in the predominant environmental forcing. We develop a new conceptual framework for investigating the cascading flow of interdependences among environmental change drivers of human displacement while reconstructing the main migration patterns across SSA. We also present new insights into the way non-environmental factors are exposing communities in SSA to high vulnerability and reduced resilience to environmental change.

Social media summary. Human displacement in sub-Saharan Africa is often associated with the effects of climate change and environmental degradation.

1. Introduction

The movement of people from their habitual residence as a result of environmental change is not a new phenomenon, but it has been part of human history since pre-historical times (e.g. De Blij, 2010; Hinnawi & UNEP, 1985; Ionesco et al., 2014). The permanent or circular movement of people in response to climate change has been documented with climate anomalies associated with the North Atlantic Oscillation (Drake, 2017), the late 4th-century drastic drop in temperature across Europe (Sedov, 1995, 1999), the 'Medieval Warm Period' (10th–12th centuries), the 'Little Ice Age' (13th–19th centuries) (Dobrydnev, 2003), extreme climate events in the middle Qing Dynasty (1760–1820) (Li et al., 2017), the modern warm stage (20th century) (Klimenko, 2016), the 1930s 'Dust Bowl' in the USA (McLeman, 2006), and many other cases. This process continues today, leading to border expansion, new land acquisitions, formation of new nations (Drake, 2017), and is often motivated by people's desire to ensure better living conditions for generations to come.

However, it is in recent decades that global environmental changes in the form of gradual and sudden environmental events started receiving wider recognition as a driver of permanent or seasonal internal or cross-border migration (de Campos et al., 2017; Groth et al., 2020; Laczko & Aghazarm, 2009), a phenomenon defined and described with a variety of terms (Table 1). According to the International Organization for Migration (IOM), the environmental drivers of human migration are often divided into two broad groups as climate events associated with the sudden onset of extreme climate events (typhoons, storms, monsoon floods, glacial lake outbursts, hurricanes, and floods), and climate processes underlying slow and accumulated changes (desertification, and land-use processes, food insecurity, sea-level rise, and aridity trends) (Brown, 2014). Non-climate factors such as societal vulnerability and low adaptive capacity transform natural hazards into natural disasters (Brown, 2014; Hesse & Cotula, 2006; IFRC, 2004; McLeman, 2006).

Several frameworks have been developed to address migration and displacement concerning climate change and environmental disasters. Some notable examples of frameworks, conventions, and treaties are shown in Table 2 (Abdiker et al., 2019; IOM, 2018; Kraler et al., 2020; UN, 2018). The goal of these frameworks is often not only to contribute to the prevention and reduction of internal displacement risks globally but to serve as a template for regional or country-level initiatives, to promote regional or state engagement in environmental migration and research advancement. The African Union Convention for the Protection and Assistance of Internally Displaced Persons (or 'Kampala Convention') is the first legally binding regional convention in the world (Abdiker et al., 2019). This agreement, which was ratified by 28 African states and represents their commitment to prevent and address the conditions underlying internal displacement, still lacks systematic translation into action by individual states (ICRC, 2017).

According to recent reports by the African Union Commission (AUC) and IOM, African migrants account for only 14% of global migration while Asia and Europe account for 41 and 24%, respectively (Achieng et al., 2020; McAuliffe et al., 2020). Despite the horrific stories of migration through the Mediterranean Sea that are brought to the attention of the public by the media, the majority of African migrants do not cross the oceans but rather cross land borders, a phenomenon that often remains understudied and poorly reported by the media. People from Africa typically move in search of better economic opportunities and a safe place for their families. It is still unclear to what extent the movement of people from and within Africa is influenced by environmental changes (Borderon et al., 2017). While various migration studies have tried to evaluate whether and to what extent migration is amplified by ongoing global environmental change, the debate still remains at large (Groth et al., 2020). There is a need for a better understanding of the role played in the migration and internal displacement process by other underlying non-environmental factors such as slow economic development, unemployment, corruption, lack of integrated natural resources management, demographic conditions, insufficient preparedness, lack of climate change policy and law, poor infrastructures, and other threats to livelihoods. Hydroclimatic changes may increase or decrease the plausibility of migration, but these outcomes highly depend on the underlying non-environmental contexts. How are these factors contributing to exposing communities in sub-Saharan Africa (SSA) to high vulnerability and associated susceptibility to migration in response to environmental change? Could migration as a result of environmental drivers be prevented with more efforts in planning for (and investing in) improved infrastructures and preparedness? It is still unclear to what extent migration occurs as an adaptive strategy for people dealing with adverse environmental conditions (Mcleman & Smit, 2006; Müller-Mahn & Gebreyes, 2019; Warner, 2010). In the context of SSA, little is known to fully support one of these arguments (Ferris, 2020). Previous studies and meta-analyses have investigated different cases of environmental migration in SSA providing a wealth of information on socio-environmental conditions underlying relatively recent migrations in Africa (Borderon et al., 2019; Hoffmann et al., 2020; Kaczan & Orgill-Meyer, 2019; Laczko & Aghazarm, 2009; Lilleør & Van den Broeck, 2011; Marchiori et al., 2012; Naudé, 2010; Neumann & Hilderink, 2015; Rigaud et al., 2018). In most cases, however, conclusive empirical evidence of the causal relationship between environmental change and migration is still missing. Most of the empirical frameworks and statistical data published are based on the extrapolation of values from a small number of people residing in affected areas (Gemenne, 2011; Marchiori et al., 2012; Neumann & Hilderink, 2015; Trenberth et al., 2007). Despite the comprehensive reviews on environmental migration in 20 countries in Africa (Borderon et al., 2019), robust evidence regarding the relationship between migration and climate anomalies is still missing. The recently published Intergovernmental Panel on Climate Change (IPCC) report also highlights the lack of extensive socioeconomic data, which limits our ability to evaluate whether African nations exhibit particularly strong exposure and vulnerability to environmental migrations or low adaptive capacity to respond to this phenomenon. The limited availability of socioeconomic data makes the understanding of the climate impacts and risks in the African continent particularly challenging (Trisos et al., 2022; Zhao et al., 2021).

SSA strongly depends on hydroclimatic conditions for its food production (Collier et al., 2008) and has low adaptive resilience (Downing et al., 1997) to the high levels of hydroclimatic variability, which expose the region to extreme conditions marked both by excess water (long wet seasons, flood, cyclone) and water-deficiency events (extended dry seasons, drought) (Brown et al., 2010). This meta-analysis explores whether and how hydroclimatic variability has affected internal migration flows across SSA, a topic of growing interest that has remained understudied largely due to the lack of holistic spatiotemporal datasets. So far, the most comprehensive scientific studies published on environmental migration/climate displacement in Africa are the meta-analyses by Borderon et al., 2019, Grote and Warner (2010), and the Groundswell report (Abdiker et al., 2019; Borderon et al., 2019; Grote & Warner, 2010; Rigaud et al., 2018). Grote and Warner (2010) compiled very good evidence of environmental change triggering migration, but the evidence was directly taken from various organizations and newsagent websites and can no longer be retrieved to further support their findings. Most scientific studies on the topic focus on one country, one sample community, or a group of countries from one region. In contrast, evidence from international migration organizations and humanitarian actors directly working with affected people provide a more integrated picture of human mobility in Africa (CRED, 2020; IOM, 2019). This meta-analysis overcomes the above shortcomings by consulting multidisciplinary data sources with detailed evidence showing the interaction between human movement and various environmental changes.

Here we draw on 87 case studies published in the literature (ranging from the environmental sciences to development economics, and migration research) or documented by research databases, reports, and international disaster datasets to develop a meta-analysis investigating the relationship between environmental changes and migration in 32 SSA countries. One of the main goals of this research is to identify the direct and indirect environmental changes causing migration while considering non-environmental underlying drivers. Direct environmental change drivers are defined as being a prompt reason/cause for a displacement of people while indirect drivers are defined as slowly emerging or accumulated environmental changes putting pressure on already vulnerable communities. Non-environmental underlying drivers are fundamentally political, economic, administrative, social, and development processes that lead to the depletion/degradation of natural resources. We develop a new conceptual framework for understanding the cascading flow of environmental change drivers on migration while reconstructing the movement pattern in SSA.

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Table 1. Glossary of the terms used to define people's migration and displacement and the environmental dimension of these phenomena

Term	Definition	Source
Displacement	The movement of a person who has been forced to flee their place of residence to avoid the consequences of violence, armed conflict, and natural or human-made disasters.	Deng (1998); IOM (2019)
Migration	'The movement of persons away from their place of usual residence, either across an international border or within a State', temporarily or permanently and for a variety of reasons.	IOM, (2019)
Emigration	'From the perspective of the country of departure, the act of moving from one's country of nationality or usual residence to another country, so that the country of destination effectively becomes his or her new country of usual residence'.	IOM (2019)
Immigration	'From the perspective of the country of arrival, the act of moving into a country other than one's country of nationality or usual residence, so that the country of destination effectively becomes his or her new country of usual residence'.	IOM (2019)
Disaster displacement	'The movement of persons who have been forced or obliged to leave their homes or places of habitual residence because of a disaster or to avoid the impact of an immediate and foreseeable natural hazard'.	IOM (2019); The Nansen initiative (2015)
Forced migration	'A migratory movement which, although the drivers can be diverse, involves force, compulsion, or coercion'.	IOM (2019)
Climate migration (working definition)	'The movement of a person or groups of persons who, predominantly for reasons of sudden or progressive change in the environment due to climate change, are obliged to leave their habitual place of residence, or choose to do so, either temporarily or permanently, within a State or across an international border'.	Chazalnoël and Ionesco (2016); IOM (2016)
Environmental migration	'The movement of persons or groups of persons who, predominantly for reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are forced to leave their places of habitual residence, or choose to do so, either temporarily or permanently, and who move within or outside their country of origin or habitual residence'.	IOM (2019)
Migrants	A person who migrates.	IOM (2019)
International migrant	'Any person who changes his or her country of usual residence' excluding movements that are due to 'recreation, holiday, visits to friends and relatives, business, medical treatment or religious pilgrimages'.	UN DESA (1998)
Refugees	A persons who, owing to a well-founded fear of persecution for reasons of race, religion, nationality, membership of a particular social group or political opinion, are outside the country of their nationality and are unable or, owing to such fear, are unwilling to avail themselves of the protection of that country; or who, not having a nationality and being outside the country of former habitual residence as a result of fear, are unable or unwilling to return to it.	Convention and Protocol Relating to the Status of Refugees (1951); IOM (2019)
Environmental migrant (working definition) Environmental refugee	A person or group(s) of persons who, predominantly for reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are forced to leave their places of habitual residence, or choose to do so, either temporarily or permanently, and who move within or outside their country of origin or habitual residence. Used by few scholars but not widely accepted because of the definition of refugees.	IOM (2007, 2014)
Internally displaced persons (IDPs)	'Persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognized State border'.	(Deng (1998); IOM (2019)
Climate/environmental refugee	Refer to environmental migrant, displaced persons. A category of environmental migrants whose movement is clearly of a forced nature. Individuals forced to leave their country because of environmental or climatic processes or events would not necessarily meet the definition of a refugee under (Convention and Protocol Relating to the Status of Refugees, 1951). Most of those who flee environmental degradation or disaster, including when due to climate change, do not cross an international border, which is an additional requirement for the application of the refugee definition.	McAdam (2009)

The terms migration and displacement are interchangeably used in this paper.
The term environmental migration represents the movement of people because of extreme sudden events, slow-onset events, or accumulated events altogether or separately.

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Table 2. Overview of initiatives/tools on environmental migration and displacement

Name of framework/convention/treaties	Date of adoption	Agency	Scope	Type of situation addressed
Organization of African Unity (OAU) Refugee Convention	Adopted in 1969	OAU – Africa Union (AU)	Regional – Africa	Events severely disturbing public order in part of or the entire country leading to displacement across the border.
Cartagena Declaration on Refugees	Adopted in 1984	Colloquium on the International Protection of Refugees in Central America, Mexico, and Panama	Regional – Latin America	Across border displacement because of circumstances that severely disturb public order.
Guiding Principles on Internal Displacement	Presented in 1998	United Nations (UN)	Global	'IDPs who have been compelled to leave their homes, including because of or to avoid natural disasters'.
Kampala Convention	In effect as of 2012 (adopted in 2009)	AU	Regional – Africa	'IDPs who have been compelled to leave their homes for reasons including natural disasters '
Agenda for the Protection of Cross-Border Displaced Persons in the Context of Disasters and Climate Change	Endorsed in 2015	Nansen Initiative and Platform on Disaster Displacement (PDD)	Global	'Cross-border displacement due to climate change and natural disasters'.
Sendai Framework for Disaster Risk Reduction	Adopted in March 18, 2015	United Nations Office for Disaster Risk Reduction	Global	Prevention of new and reduction of existing disaster risks by in-depth understanding and strengthening of risk governance through investment and preparedness.
The New York Declaration for Refugees and Migrants	Adopted in September 2016	UN	Global	Integration of various actors working on refugee response and providing support to countries and communities hosting a large number of refugees.
The Nansen Initiative Protection Agenda	Endorsed in October 2015	Norway and Switzerland	Central America, the Pacific, South America, Greater Horn of Africa, Southern Africa, Southeast Asia, and South Asia.	The protection needs of persons displaced across international borders by disasters, including the adverse effects of climate change.
The Paris Agreement on climate change	December 2015	United Nations Framework Convention on Climate Change (UNFCCC)	Global	The migration of people due to climate change.
The Comprehensive Refugee Response Framework (CRRF)	September 2016	United Nations High Commissioner for Refugees (UNHCR)	Africa and Central America	Set of guidelines providing reception and admission measures for refugees/migrants; support for immediate and ongoing needs; support for host countries; and enhanced opportunities for durable solutions.
Guidelines to Protect Migrants in Countries Experiencing Conflict or Natural Disaster	Released in 2016	Migrants in Countries in Crisis (MICIC)	Global	'Migrants already in countries experiencing conflict or natural disasters'.
Regional guidelines regarding protection and assistance for persons displaced across borders and migrants in countries affected by natural disasters	Adopted in 2018	South American Conference of Migration (CSM)	Regional – South America	'Cross-border displacement due to climate change or natural disasters and migrants already in countries experiencing natural disasters'.
Global Compact for Safe, Orderly and Regular Migration (GCM)	Adopted in 2018	UN	Global	'International migration, including in the context of natural disasters, climate change, and environmental degradation'.
Global Compact on Refugees (GCR)	Adopted in 2018	UN	Global	'Refugees, including those whose drivers of displacement were impacted by climate, natural disasters or environmental degradation'.
Protocol on Free Movement of Persons in the IGAD region	Endorsed in 2020 (awaiting signing by Heads of State)	IGAD	Regional – East Africa	Free cross-border movement of persons, including due to disasters.

Source: Abdiker et al. (2019); IOM (2018); Kraler et al. (2020); UN (2018).

1.1. The debate

The term 'environmental migration' is not internationally agreed upon (Table 1). Therefore, researchers in this field used a variety of other terms to describe persons displaced as a result of extreme or slow-onset environmental conditions, including climate change refugees or migrants and environmental refugees or migrants (Ferris, 2020; Hinnawi & UNEP, 1985; IOM, 2007, 2014; McAdam, 2009; McNamara et al., 2017), while the phenomenon has been referred to as environmental migration, climate migration (Chazalnoël & Ionesco, 2016), and disaster displacement (Table 1). The use of 'climate refugees' status to represent migration in the context of climate change fails to recognize human mobility from environmental degradation and more generally environmental change as well as voluntary migration from slow-onset processes (Chazalnoël & Ionesco, 2016). In agreement with the definitions given by Brown (2014) and Brown et al. (2007) here we use the terms 'environmental migration' and 'environmental displacement' as the most comprehensive terminology for this research. It should be noted that the term includes people who migrate in response to environmental drivers that are not related to climate change (Table 1), such as volcanic eruptions, earthquakes, tsunamis, and also extreme hydrometeorological events that are not necessarily induced by climate change (Ferris, 2020).

The nexus between migration and environmental change is of great interest to many research fields addressing the human dimension of global change and related mitigation and adaptation strategies (Carr, 2005). Scientists from these different fields have tried to document and explain this link. The heavily critiqued theory published in the early 1990s presents the maximalist point of view, whereby the environment is the primary cause of migration (Suhrke, 1994). While the author failed to explain that not all migrations relate to environmental change, in the same manner, other authors (Adamo, 2014; Black, 1998; Castles, 2002) highlighted that a community's vulnerability to environmental change exposure and the lack of adaptive capacity are the causes of migration rather than the changing environment itself. Black used his review to describe how migration caused by slow-onset events in the Sahel region is a coping cyclical mechanism rather than permanent displacement (Black, 1998). On the contrary, Myers and Kent argue that rapid population growth especially in developing countries is depleting resources and is a more critical push factor for people to migrate to a new place than slow-onset environmental changes (Myers & Kent, 1995). Other scholars (Czaika & Godin, 2021; Lee, 2001) tried to disentangle the complex drivers of environmental migration by exploring the migration–development nexus and its connection with environmental security. Their conclusions emphasized how the terms used to describe environmental migration have little to do with the understanding of the complexity of specific cases and how they are influenced by non-environmental factors (Czaika & Godin, 2021; Lee, 2001). In response to the need for a better understanding of the environmental migration phenomenon, research in this field has been blooming, providing a number of empirical analyses and case studies linking the environment to migration (see Figure 1) (McLeman, 2012; Neumann & Hilderink, 2015). The notion that environmental change may contribute to migration has gained more acceptance and support from scholars working in this field (Black et al., 2011; McLeman, 2006; Piguet, 2012; Piguet et al., 2011). These scholars largely recognize that migration cannot be caused by environmental change alone except in the case of extreme events (Black et al., 2011; Castles & Miller, 1998; Parnell & Walawege, 2011). Some scholars are slowly moving from addressing the question of how environmental change influences migration to asking how migration might contribute to planned relocation as a climate-change adaptation measure (Ferris, 2020; Gemenne & Blocher, 2017; McLeman, 2006) to build resilience (Rockenbauch & Sakdapolrak, 2017; Sakdapolrak et al., 2016; Tebboth et al., 2019). Climate change scientists often perceive migration and human displacement as a negative result of climate change that foregrounds the severity of the climate change threat. This view motivates disaster risk research with its focus on reducing the migration risk associated with environmental disasters by influencing policies and international funding (Ferris, 2020). On the contrary, some scholars look at migration as a coping mechanism or adaptation strategy to climate change (Ferris, 2020).

Scholars have also been raising critical questions trying to broaden the understanding of the nexus between migration and environmental changes. It is still unclear what evidence exists in support of the hypothesis that environmental change may induce large movements of refugees and migrants (Castles, 2002). There are no clear criteria to determine whether in complex situations environmental factors are primary drivers of migration (Myers & Kent, 1995) or whether climatic conditions actually displace people (Beine & Jeusette, 2019). Other studies also raised the question of whether migration is exacerbated as a result of rapid population growth in developing countries rather than occurring in response to climate change alone (Castles, 2002). Indeed, it has been argued that 'environmental conditionalities' imposed by developed nations are condemning some developing countries to remain poor for life thereby triggering human displacement (Castles, 2002). Despite the relatively rich body of literature on this subject, there is still some disagreement on whether environmental conditions may induce migrations. While some authors (e.g. Marchiori et al., 2012) maintain that rainfall and temperature anomalies forced at least 5 million people to migrate from their place of residence in SSA from 1960 to 2000, others (e.g. Parsons & Beine, 2015) argue that there is no evidence that climate change is driving migration in the same period. In support of Marchiori's research, a few recent meta-analyses (Lilleør & Van den Broeck, 2011; Reuveny & Moore, 2009; Warner, 2010) found that climate-related natural disasters and environmental depletion may cause migration in developing countries. A study focusing on SSA (Naudé, 2010) emphasized that environmental pressure may be an indirect driver of migration. Indeed, environmental hazards lower economic growth, fuel conflict, and increase emigration (le Blanc & Perez, 2008; Myers & Kent, 1995; Naudé, 2010). For many scholars, however, the line between climate change acting as a direct or indirect driver of migration in the global south remains blurred.

In recent years, new studies focusing primarily on environmental migration in Africa have addressed some of these unresolved questions about this phenomenon, though there is still a long way to go to collect all the data needed to address these knowledge gaps. Moreover, in recent years the first-ever African migration report by IOM and the AUC highlighted how climate change, disasters, and natural hazards are the leading drivers of migration across Africa (Abdiker et al., 2019). Despite the dominant narrative that migration from Africa results from violence and political conflict, the role of water scarcity and climate change has often been underestimated. Climate change research has shown how extreme weather events are becoming more frequent and intense (IPCC AR6 WGI, 2021; Trenberth et al., 2007). The people who are most affected by these events are always those living in vulnerable locations such as semi-arid and arid regions. For

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this reason, SSA is regarded as a global hotspot of conditions that favor vulnerability to the adverse effects of environmental and climatic stress, as a result of its dependence on rain-fed agriculture and lack of adaptive capacity (Groth et al., 2020; IOM and UN-OHRLLS, 2019; Niang et al., 2014; Serdeczny et al., 2017).

Reports published by the IPCC and Foresight project (Foresight, 2011; IPCC, 2014) showed that migration, which varies in scale and time, is becoming an emergency in the view of the projected climatic changes and the high number of affected people as a result of rapid and slow-onset weather events (Foresight, 2011; IPCC, 2014; Niang et al., 2014; Trisos et al., 2022). There are increasing concerns about the way changes in the severity and frequency of extreme environmental events can enhance human migration in SSA and reshape the associated displacement patterns (Achieng et al., 2020; Black et al., 2013; Clement et al., 2021; IDMC & NRC, 2020; Rigaud et al., 2018). Despite the surge of studies on environmental migrations, it is still unclear to what extent environmental drivers are directly or indirectly contributing to migrations in Africa. The paradox of environmental migration studies is that there is burgeoning literature on environmental refugees and a paucity of empirical research on migration–environment relations (Bates, 2002). The reason why they have carried out little sound empirical work is the complexity of the matter, the multi-causality of the studies, and time lapses in causation (Bates, 2002). To date, knowledge of the nexus between migration and extreme environmental events remains limited and fragmented. Therefore, there is a critical need for a synthesis capitalizing on the numerous existing case studies to achieve a holistic understanding of the environmental migration phenomenon. The drivers of environmental migration also vary from one country/region to another in terms of temporal and spatial distribution. Therefore, a mixed methodology is needed to analyze these dynamics. We use empirical analysis in combination with Qualitative Comparative Analysis (QCA) and statistical correlation methods thereby broadening our perspective on the topic. The main objective of this meta-analysis is to review and examine the various existing cases of migration caused by environmental change. We survey the literature on this topic to identify relevant case studies that can be used in a meta-analysis aiming at identifying primary and secondary environmental drivers of human displacement within SSA, mapping its geographic patterns, and evaluating regional differences in susceptibility to environmental migrations.

1.2. Societal resilience

Many SSA countries are undergoing rapid societal transformation and economic development fueled by agricultural intensification and energy transitions. These transformative changes, besides the increasing population and changing consumption patterns, create a rising demand for natural resources and ecosystem services (Hoff, 2011; Howells et al., 2013). Despite the rapid development, the region remains to be the most dynamic for the examination of human impacts on environmental changes and the pressure exerted on the limited natural resources (Bazilian et al., 2011; Zickgraf et al., 2016). The impact of environmental changes (sudden or slow) on human communities depends on their vulnerability and adaptive capacities directly influencing their societal resilience (Adger et al., 2009; Niva et al., 2021). Historically migration has been an adaptive response to various environmental changes, social deprivation, hardship, and conflict but it also offers an opportunity to increase income, expand knowledge, have access to better resources and living conditions, and increased societal resilience (Scheffran et al., 2011). Social resilience is 'the ability of a community to withstand external shocks and stresses without significant upheaval' (Adger et al., 2002). Our research also investigates the extent of societal resilience of SSA countries through evidence gathering from past environmental migration studies and how communities have coped with the magnitude and occurrence of individual or cumulative climate stressors. The severe drought event between 2010 and 2011 affected over 13 million people in the Intergovernmental Authority on Development (IGAD) region (FAO, 2018). As a result, stakeholders in these countries developed IGAD Drought Disaster Resilience and Sustainability Initiative (IDDRSI), aimed at improving regional capacity to withstand future drought events and environmental shocks. As the unprecedented number of global refugees and internally displaced people (IDPs) prompted the UN to develop the New York Declaration for Refugees and Migrants (Table 2) (UN, 2018), the combination of an increased number of IDPs and recurrent droughts in the African region also led to the creation of the regional initiative 'Building resilience in Africa's drylands' to strengthen the resilience of vulnerable pastoralist and farming communities (FAO, 2018). Environmental migration is a critical resilience strategy for communities affected by climate change, when the study of it is coupled with resilience-building strategies, it will contribute to reducing vulnerability and promoting sustainable growth in the region.

2. Method and data analysis

2.1. Literature search and filtering

This meta-analysis (e.g. Ahn & Kang, 2018) collects all the available case studies on environmental migration in SSA we were able to find in the scholarly literature. It analyses each one of them to extract data on the magnitude of human displacement, its direct and underlying environmental drivers, timing, and geographic patterns (Table 3). Data harvested from this collection of published studies are then analyzed with a variety of methods to provide an integrated understanding of the phenomenon across regions and migration events. This approach connects the dots among in-depth case studies that look at the broader pattern characteristic of environmental migrations in SSA. Specifically, we present and analyze findings from the literature to investigate the relationship existing between extreme climate events, sudden and slow-onset environmental changes as drivers for migration in SSA (Figure 1).

The identification of literature started with Scopus (668 articles), Science Direct, Web of Science, and Google Scholar search engines, leading to the source journals (combined 207 articles) (Figure 1). More details on the way the literature was surveyed, and the relevant articles and case studies were selected are presented in Supplementary materials, Annex 1.

Identified literature abstracts were skimmed and screened as per the eligibility criteria. Out of the 188 studies identified through search engine selection followed by prescreening, 94 papers were then excluded after further reading. The eligible studies were then examined to extract the following primary data and metadata: region/country, date of the event, type of extreme event or environmental change drivers, and the number of people displaced/migrating as a result of the event. Additional secondary information was also coded, including additional effects (e.g.

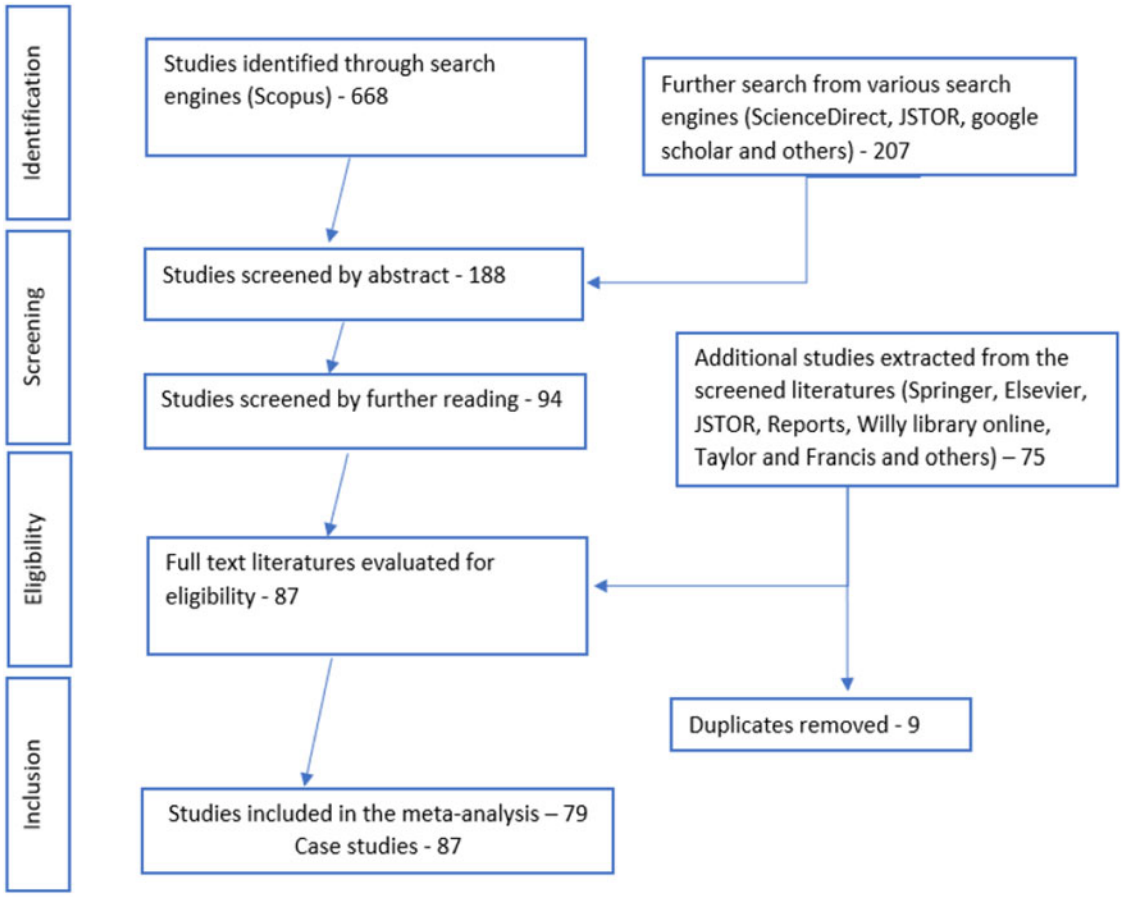

Figure 1. Flow diagram of research procedure and article selection.

losses, consequences of environmental changes and exacerbating factors), type of relocation, type of migration, the profession of IDPs and migrants, land ownership status of IDPs, and migrants, hydrological data analysis or modeling techniques used, source of data and destination countries/regions were also extracted. Further reading of all these publications (94 + 75 = 169), led to the removal of duplicated studies and of other articles with exclusion criteria (articles that lack the above-mentioned primary data) leaving us with 79 papers, documenting 87 case studies that were included in this meta-analysis, see Figure 1 and Table 3.

All the information gathered through screening of different kinds of literature on environmental change-induced migration in SSA is compiled in Table 3. The table reports the country of the migrants when the environmental change/event started and ended, the type of events, additional exacerbating drivers, the number of people displaced because of these events, destination country/region (depending on the type of migration: internal/external), the author and date of the publication and some remarks as additional information.

2.2. Qualitative comparative analysis

Many of the sudden and slow-onset environmental changes are directly responsible for the internal displacement of people in SSA, while others exacerbate migration outcomes through a complex network of causal links (Foresight, 2011; Mastrorillo et al., 2016). The difficulty of grasping the complex interplays of the causal links arises from the use of quantitative and qualitative analysis methods separately by oversimplifying the causalities relation without acknowledging the complexity of multiple mutually interacting drivers with possible domino effects (Bilsborrow & Henry, 2012; Groth et al., 2020). Several scholars attempted to overcome the shortcomings of understanding the complex migration linkages, such as the use of agent-based model simulations (e.g. Hassani-Mahmooei & Parris, 2012; Kniveton et al., 2011) or integration of survey/census data with Bayesian belief networks (e.g. Drees & Liehr, 2015). In recent years to overcome the lack of scaling options in ethnographic studies, participatory methods such as mobility mapping were employed (de Campos et al., 2017) or mobile network data were used to capture short-term migration patterns for large areas (Lu et al., 2016). Another under-utilized but critical deciphering method that incorporates the benefits of qualitative and quantitative approaches and overcomes the existing methodological challenges is QCA (Groth et al., 2020; Haeffner et al., 2018; Ide, 2015; Kirchherr et al., 2016; Ragin, 1984).

Charles Ragin developed QCA in the 1970s as a research method (Simister & Scholz, 2017). QCA is used to analyze multiple cases in a complex setting, and it helps to explain why some factors cause changes but not others. QCA is a very powerful tool for observing the influence of combinations of various factors on a certain phenomenon (Schneider & Wagemann, 2012). The method allows complex causal links to be traced by using a systematic set-theoretic approach. QCA has the potential to improve our understanding of the interactions between direct, indirect, and underlying migration drivers, which still have a substantial knowledge gap in the field of environmental migration.

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Table 3. Summary of 87 migration cases induced by environmental changes in SSA

No.	Country	ISO	Departure region	Event start date	Event end date	Extreme event_1 (primary driver)	Extreme event_2 (secondary driver)	Exacerbated by	No. of people displaced	Destination country	Destination region	Reference	Remark
1	Benin	BEN	Bialaba – Dassari watershed	2013	2013	Soil infertility and high or low rainfall – crop failure	Heat wave and drought	Water scarcity and food insecurity	All 36 interviewed migrants	Nigeria, Benin, Ivory Coast, and Ghana	Benin (Borgou and Zou North, Ogun, Issangue and Adjuba, Abeokuta, oyo)	Dreier and Sow (2015)	
2	Benin	BEN	Northwest Atacora region	01.11.2000	01.05.2005	Environmental and soil degradation	Poor harvest and land scarcity	Subsistence farming, animal husbandry issues, and lack of access to fertilizers	250 HH ≈ 1250 people	Benin		Doevenspeck (2011)	3/4 migration caused by soil degradation
3	Botswana, South Africa, Zimbabwe, Zambia, and Madagascar			22.02.2000	01.03.2000	Cyclone	Flood	Drought	290,000		Southern African region	Brouwer and Nhassengo (2006); Holloway et al. (2013); NRC (2015); Parkinson (2013)	Specific country destination is hard to trace
4	Burkina Faso	BFA		1970	1998	Severe drought		Low rainfall	346	Côte d'Ivoire	Rural to rural and rural to urban	Henry et al. (2004)	4% of 8644 ppl
5	Burkina Faso	BFA	N: Soum and Oudalan provinces S: Nahouri and Bougouriba	1960	1998	Severe drought	Variable rainfall	Dry spell	Around 10,000	Burkina Faso	North-south and south-north	Henry et al. (2004)	Observed migrants flow and number is mapped in the source paper
6	Burkina Faso	BFA	Northeastern region Seno and Oudalan provinces	2000	2002	Drought	Variable rainfall		101/204 HH ≈ 505 ppl	Burkina Faso and Côte d'Ivoire	Burkinabe, Burkina Faso	Konseiga (2006; Mccarthy et al. (2002)	
7	Burundi	BDI		11.2019	12.2019	Heavy rain	Storm	Landslides	25,000	Burundi		IDMC (2020); IDMC & NRC (2020)	
8	Central African Republic	CAR	Bangui	10.2019	04.12.2019	Heavy rain	Flood		102,000	N/A		IDMC (2020); IDMC & NRC (2020)	
9	Chad	TCD	Salamat province and south-western Chad, and north-eastern Cameroon	9.2019	9.2019	Floods	Riverbank bursting		30,000			IDMC (2020); IDMC & NRC (2020)	
10	Comoros	COM		2019	2019	Cyclone		Extended drought	19,000	N/A		IDMC (2020)	Cyclone Kenneth
11	Democratic Republic of Congo	DRC	North and South Ubangi, Tshopo, Mongala, Bas-Uélé, Maniema, Kinshasa, Haut-Uélé, Kasai, South Kivu, and Kasaï-Central	12.2019	12.2019	Heavy rain	Flood		233,000	CAR and DRC		IDMC (2020); IDMC & NRC (2020)	

12	Ethiopia	ETH		1994	2009	Severe drought			1035	Ethiopia		Gray and Mueller (2012)	10% of adult male from 1500 HH approximately 10,350 ppl
13	Ethiopia	ETH	Oromia, the Southern Nations, Nationalities, and Peoples' (SNNP), and parts of the Afar region	4.2019	6.2019	Flood		Drought	190,000	Ethiopia		IDMC (2020); IDMC & NRC (2020)	
14	Ethiopia	ETH	Oromia, SNNP, and parts of the Afar region	10.2019	11.2019	Flood		Drought	177,000	Ethiopia		IDMC (2020); IDMC & NRC (2020)	
15	Ethiopia	ETH	Somali region	2019	2019	Drought			131,000	Ethiopia		IDMC (2020); IDMC & NRC (2020)	
16	Ethiopia	ETH	Central/northern Ethiopia, Awash and Afar River basin	1984	1985	Drought	Forest fire	Famine, locust invasion, dry land expansion, and ecological degradation	600,000	Ethiopia	Southwest, western Ethiopia, and Wollo region	Ezra and Kiros (2001); Otunnu (1992); Rahmato (1991)	
17	Ethiopia	ETH	Northern Ethiopia	1984	1994	Ecological degradation	Drought, famine	Destructive farming	647 HH = 1004	Ethiopia		Ezra (2000, 2001)	1004 aged 10–34. 2000 HH surveyed
18	Ethiopia	ETH	Tigray	1999	1999	Drought/dry spell	Water scarcity		All 104 interviewed	Ethiopia		Meze-hausken (2000)	
19	Ethiopia and Eritrea			1960	1980	Drought	Famine		1,100,000	Southern Sudan		Bilsborrow and DeLargy (1990); Jacobsen and Wilkinson (1993); Kane (1995a)	
20	Ghana	GHA	Northwestern Ghana, Nadowli district	2010	2011	Dry spell	Food insecurity	Fertile land scarcity	26.9% upper west, 22.2% upper East, and 13% of North region population	North-south Ghana	Brong-Ahafo and Ashanti regions	Abdul-Korah (2011); Rademacher-Schulz et al. (2013); van der Geest (2011)	2000 population census. Further illustration of number of migrants shown on graph in the source paper
21	Ghana	GHA	(Northwest, Dagara, and northeast), Brong Ahafo Region and Upper West Region (Nandom)	2007	2008	Fertile land scarcity	Low crop yield	Low rainfall	1063	Ghana	Brong Ahafo region, Ashanti, Greater Accra, Central, Eastern, Western, and Volta	van der Geest (2009)	Poor agro-ecological conditions and economic hardships were exacerbating factors
22	Ghana	GHA	Central region Dominase and Ponkrum	1970	1980	Low rainfall	High soil degradation	Loss of crop/ canopy	35 HH ≈ 175	Ghana	Yesunkwa	Carr (2005)	Logging since 1960
23	Kenya	KEN	West Pokot counties	15.10.2019	12.2019	Landslides	Floods	Disaster	10,000	Kenya		IDMC (2020); IDMC & NRC (2020); UNOCHA (2019)	

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Table 3. (*Continued.*)

No.	Country	ISO	Departure region	Event start date	Event end date	Extreme event_1 (primary driver)	Extreme event_2 (secondary driver)	Exacerbated by	No. of people displaced	Destination country	Destination region	Reference	Remark
24	Kenya	KEN	Wajir county (Moyale and Bute)	15.10.2020	12.2019	Landslides	Floods	Disaster	5000	Kenya		IDMC (2020); IDMC & NRC (2020) UNOCHA (2019)	
25	Kenya	KEN	Garissa and Tana River counties	15.10.2019	12.2019	Landslides	Floods	Disaster	4980	Kenya		IDMC (2020); IDMC & NRC (2020); UNOCHA (2019)	624 HH × 6.9 + 550 ppl
26	Kenya	KEN	Samburu county	2012		Rainfall variation	Dry spell	Drought	960	Kenya	Meru, Isiolo, Nanyuki, Nyeri, Karatina, Thika, and Nakuru	Ng'ang'a et al. (2016)	139/500 HH migrated. In SSA 1 HH = 6.9 ppl
27	Kenya	KEN	West Pokot	2016	2017	Drought		Livestock diseases	92	Kenya		Muricho et al. (2019)	82/104 arid and 10/87 in semi-arid total *n* = 191
28	Kenya	KEN		2004 and 2007	2004 and 2007	Low soil quality			1063 people	Kenya	Rural to rural and rural to urban	Gray (2011)	
29	Madagascar	MDG		17.02.2008	18.02.2008	Cyclone	Heavy rainfall		191,182	Madagascar		IFRC (2009); NRC (2015)	Cyclone Ivan
30	Madagascar	MDG		08.03.2012	22.03.2012	Cyclone	Heavy rainfall	Floods	96,000	Madagascar		UNOCHA (2012)	Cyclones Giovanna and Irina. 16,000 families approximately 96,000 ppl
31	Madagascar	MDG	Central (Analamanga region), south-eastern (Vatovavy Fitovinany and Atsimo Atsinanana), and Western (Menabe region)	16.01.2015	22.01.2015	Cyclone	Heavy rainfall	Floods	20,000	Madagascar		IFRC (2016)	Cyclone Chedza and tropical storm fundi
32	Madagascar	MDG	Besalampy district	11.03.2019	14.03.2019	Cyclone and storm	Floods		500	Madagascar		IDMC (2019, 2020)	Tropical cyclone Idai
33	Madagascar	MDG		13.01.1994	15.03.1994	Cyclone	Floods	Mudslides	40,000		South African region	Naeraa and Jury (1998); NRC (2015)	Cyclone Gerrald, Daisy, Litanne and Nadia
34	Malawi	MWI	Malawi south	04.03.2019	21.03.2019	Cyclone and storm	Floods	Heavy rainfall	86,976		South African region	IDMC (2019, 2020)	
35	Mali	MLI		2019	2019	Severe drought	Rainfall variation	Land degradation	6600			IDMC (2020); IDMC & NRC (2020)	

36	Mali	MLI	Upper Senegal River Valley (Matam, Senegal to Diamou, Mali)	1983	1985	Severe drought	Rainfall reduction	Economic factors	3115	Mali, Senegal, Gabon, Ivory Coast, and France		Findley (1994); Grace et al. (2018)	44% of the sample 7079 ppl migrated because of drought. The number shows both short- and long-term migrations. Destination countries are short-term circular migrants
37	Mali and Senegal		Bandiagara and Linguère	2012	2012	Highly variable rainfall	Crop failure	Environmental changes	190 ppl	Mali and Senegal	Bamako and Dakar	van der Land and Hummel (2013)	
38	Mauritania	MRT		1980	1990	Drought	Desertification	Soil erosion, deforestation, and water scarcity	69,000	Senegal	Senegal river valley	Baechler (1999); Black and Sessay (1998); Westing (1994)	
39	Mayotte	MYT		2019	2019	Cyclone		Extended drought	450	N/A		IDMC (2020)	
40	Mozambique	MOZ	Maputo	27.01.2000	01.03.2000	Heavy rain	Floods	Cyclone	250,000	Mozambique	Lower, middle, and upper Limpopo	NRC (2015)	The dates are not exact. Cyclone Eilene
41	Mozambique	MOZ	Maputo city, Gaza, Zambezia and Inhambane provinces	1.2013	2013	Floods		Environmental degradation	172,479–185,000	Mozambique		Caveirinha (2013); NRC (2015)	
42	Mozambique	MOZ	Cabo Delgado province	04.03.2019	21.03.2019	Cyclone and storm	Floods	Conflict	77,019–93,516	Tanzania and islands off the coast of Cabo Delgado		IDMC (2019, 2020)	Category 2 hurricane (cyclone Idai and Kenneth). Figures were hard to be exact because of the existing conflicts
43	Mozambique	MOZ	Matutuine, Manhica, Magude, Marracune (Maputo province), Chibuto, Chokwe, Mabalane (Gaza province), Inhambane, Sofala, Manica and Tete provinces	2.2001	3.2001	Cyclone	Floods	Increased flow from dams	223,000	Mozambique	462,921	NRC (2015); Wiles et al. (2005)	Cyclone Dera
44	Mozambique	MOZ	Northern Coast, Gaza, Maputo, Inhambane, Sofala, Zambézia, and Nampula provinces	15.01.2012	22.01.2012	Cyclone	Floods	Prolonged rains and increase in river level	119,471	Mozambique		IFRC (2012a); NRC (2015)	Cyclone Funso and storm Dando displaced 30,485 HH

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Table 3. (*Continued.*)

No.	Country	ISO	Departure region	Event start date	Event end date	Extreme event_1 (primary driver)	Extreme event_2 (secondary driver)	Exacerbated by	No. of people displaced	Destination country	Destination region	Reference	Remark
45	Mozambique	MOZ	Manica, Sofala, Tete, and Zambezia provinces	1.2007	2.2007	Floods	Heavy rainfall	High water level	120,790	Mozambique		NRC (2015); UNICEF (2007)	Heavy rain in Zambia, Zimbabwe, and Malawi raised the water level
46	Mozambique	MOZ	Southeast of Beira	12.2007	23.2007	Cyclone	Floods	Heavy rain	120,000			Gary Padgett (2007); Klinman and Reason (2008)	Tropical cyclone Favio
47	Namibia	NAM	Caprivi, Kavango, Ohangwena, Omusati, Oshana, and Oshikoto	3.2009	17.03.2009	Heavy rain	Floods	Water-level rise	50,000	Namibia and farther		GFDRR (2009)	It caused water-level rise in Angola and Zambia
48	Niger	NER	Maradi region (south-central)	1972	1973	Drought	Famine		40,000/ 110,000 people	Nigeria and Niger	Southcentral Niger and Nigeria	Campbell and Berry (1977; Grolle (2015)	Northern Nigeria also experienced the same out-migration
49	Niger	NER	Niamey and Daff state	2019	2019	Floods		Severe drought	121,000	Niger and farther		IDMC (2020); IDMC & NRC (2020)	
50	Niger	NER	Southern Niger, Babban Doka and Yan Sawaiyu	1983	1985	Low rainfall	Crop failure	Famine	400,230 (46 HH ≈ 230)	Nigeria and Niger	Nigeria (Dansadau Emirate) and Niger	Grolle (2015); Timberlake (1988)	
51	Nigeria	NGA	Adamawa, Niger, and Borno states	8.2019	9.2019	Floods	Heavy rainfall		157,000	Nigeria and farther		IDMC (2020); IDMC 7NRC (2020)	Flooding of Niger river basin
52	Nigeria	NGA		1998	2008	Heat shocks	Drought	Floods	149 HH = 745			Dillon et al. (2011)	Detailed number for each year is found in the source paper
53	Nigeria	NGA	Jos city, plateau state	1970	1990	Floods	Soil/water/air pollution, silted rivers, land scarcity, and environmental degradation	Conflict	345	Nigeria	Rural to urban and north to South migration	Ajaegbu (1994); Olagunju et al. (2021)	50 HH = 345 were displaced and destroyed in 1994. The migration led to conflict over resources
54	Nigeria	NGA	Niger state	1998	1998	Floods		Environmental degradation	100,000	Nigeria	Rural to urban and north to south migration	Ajaegbu (1994); Olagunju et al. (2021)	
55	Nigeria	NGA	Jalingo, Taraba state	2005	2005	Floods		Environmental degradation	50,000	Nigeria	Rural to urban and north to south migration	Ajaegbu (1994); Olagunju et al. (2021)	

56	Nigeria	NGA	Plateau, Nasarawa, Bauchi, Yobe, and Borno states	2007	2007	Floods		Environmental degradation	2500	Nigeria	Rural to urban and north to south migration	Ajaegbu (1994); Olagunju et al. (2021)	
57	Nigeria	NGA	Lagos state	2010	2010	Floods		Environmental degradation	1000	Nigeria	Rural to urban and north to south migration	Ajaegbu (1994); Olagunju et al. (2021)	
58	Nigeria	NGA	Adamawa, Anambra, Bauchi, Benue, Cross River, Ebonyi, Gombe, Jigawa, Nasarawwa, Niger, Kaduna, Kano, Katsina, Kebbi, Lagos, Plateau, Taraba and Yobe states	15.09.2012	29.09.2012	Floods	Heavy rain	Reservoir overflow and riverbank bursting	64,473	Nigeria		IFRC (2012b)	
59	Nigeria	NGA	Northern Nigeria (Amarawa, Lakoda, Maganawa, Dan Dala, and Nasarawa)	1983	1985	Low rainfall	Crop failure	Famine	75 HH ≈ 375 ppl	Nigeria and Niger	Nigeria (Dansadau Emirate) and Niger	Grolle (2015); Timberlake (1988)	
60	Nigeria and Niger		Nigeria, northwest, Sokoto province, and Niger (Birnin Konni)	1953	1954	Heavy rain	Crop failure	Famine	≈85,000 people	Nigeria	South and east of the province (Dandume, Unguwar Gwandu)	Grolle (2015)	An increase in food price led to distress migration
61	Republic of Congo	COG	Cuvette, Likouala, Plateaux, and Sangha	2019	2019	Heavy rain	Riverbank overflow and bursting		163,000			IDMC (2020); IDMC & NRC (2020)	
62	Rwanda	RWA		12.2019	2019	Storms	Heavy rains	Landslides	6000			IDMC (2020); IDMC & NRC (2020)	
63	Rwanda	RWA	South and central regions	1990	1990	Arable land and water scarcity	Land degradation	Agricultural intensification	1,700,000	Rwanda	Easter, northern Rwanda, and Kigali	Kane (1995a, 1995b); Uvin (1996)	Civil war also contributes to this number
64	Somalia	SOM	Wabi Shebelle and Genale basin	1998		Heavy rain	Floods		Over 2000	Somalia		Magadza (2000)	
65	Somalia	SOM		1973	1975	Severe drought			300,000	Somalia		Tsui et al. (1991)	
66	Somalia	SOM		1970	1970	Arable land degradation	Water scarcity		400,000	Somalia and Ethiopia	Boarder region, Ogaden	Gebremedhin (1991); Molvær (1991); Westing (1994)	Leading to the Ogaden war
67	Somalia	SOM		2019	2019	Drought	Food insecurity	Locust infestation	60,000	Somalia		IDMC (2020); IDMC & NRC (2020)	

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Table 3. (*Continued.*)

No.	Country	ISO	Departure region	Event start date	Event end date	Extreme event_1 (primary driver)	Extreme event_2 (secondary driver)	Exacerbated by	No. of people displaced	Destination country	Destination region	Reference	Remark
68	Somalia	SOM	Belet Weyn city in Hiraan state, Hirshabelle, Jubaland, and the southwest states	10.2019	10.2019	Heavy rain	Floods		470,000	Somalia and Ethiopia		IDMC (2020); IDMC & NRC (2020)	
69	South Sudan	SSD		2019	2019	Floods	Heavy rain		294,000			IDMC (2020); IDMC & NRC (2020)	
70	Southern Africa (Mozambique, Zimbabwe, Botswana, Namibia, South Africa, Zambia)			03.02.2000	01.03.2000	Cyclone	Heavy floods		1.25 million displaced 250,000 in Mozambique	Southern African region		NRC (2015)	Storm and extratropical cyclone Eline
71	Sudan	SDN	White Nile state	2019	2019	Floods	Riverbank overflow and bursting	Heavy rainfall	272,000	Sudan		IDMC (2020); IDMC & NRC (2020)	
72	Sudan/South Sudan		Abyei area	2019	2019	Heavy rain	Riverbank bursting	Floods	40,000			IDMC (2020); IDMC & NRC (2020)	Area belongs to both countries
73	Uganda	UGA		2004	2009	Temperature increase			994/2000	Uganda		Gray and Wise (2016)	123% increase in migrants
74	Uganda	UGA		2019	2019	Heavy rain	Floods	Landslides	130,000			IDMC (2020); IDMC & NRC (2020)	
75	Uganda	UGA		2003 and 2005	2003 and 2005	Low soil quality	Poor access to fertilizers	Poverty	268 people	Uganda	Rural to rural and rural to urban	Gray (2011)	
76	United Republic of Tanzania	TZA	Vudee, Bangalala, and Ruvu Mferejini	2012	2012	Drought/dry spell	Water shortage/low rainfall	Storm/winds/ floods	445 people	Tanzania and Kenya	Kiteto, Morogoro, Dar es Salam, Lugoba, Kabuku, Tanga, Simanjaro, and Lake Jipe	Afifi et al. (2014)	Percentage of HH with migrants for each region and event is graphed in the source paper
77	United Republic of Tanzania	TZA		2011	2011	Floods	Landslides		10,000	Tanzania		DREF (2012)	
78	United Republic of Tanzania	TZA		2014	2014	Flash floods	Heavy rain		10,000	Tanzania		UNOCHA (2014)	Over 10,000 ppl
79	United Republic of Tanzania	TZA		2008	2009	Heatwave	Temperature shock		969 HH/ 2202 HH	Tanzania	Rural to urban	Maurel and Kubik (2014)	969 HH = around 4845 ppl

80	United Republic of Tanzania	TZA		2002	2012	Drought	Hot temperature	Rainfall season shortening and farmland infertility	523	Tanzania		Atuoye et al. (2020)	10 years study time interval but mainly based on the 2012 census. 1136 people had multistage interviews
81	United Republic of Tanzania	TZA	Usangu plains, southern and northern regions	1950	1990	Land scarcity	Degradation		84,000	Tanzania	Usangu plains and other regions	Charnley (1997); Mwakipesile (1976); Odgaard (1986)	
82	Zambia	ZMB	(Choma, Kalomo, Monze and Sinazongwe) of southern Zambia	1990	2009	Drought	Heatwave	Heavy rainfall with flood	140	Zambia	Lunchu and Mukonchi in Central Zambia	Simatele and Simatele (2015)	Survey was made from 30 HH = 207 ppl
83	Zambia	ZMB	Magoye (Mazabuka)	01.01.2008	31.01.2008	Heavy rain	Floods		60,000–78,000	Zambia		Simatele and Simatele (2015)	13,000 families
84	Zambia	ZMB	55 districts	2000	2010	Heatwave	Drought spell		Only one three-way interaction for heat but all three-way interactions for drought are significant	Zambia	Inter-district	Nawrotzki and DeWaard (2018)	Detailed values of migrants are graphed in the source paper
85	Zimbabwe	ZWE		1997–2010, 2001–2002, 2000–2008, and 2010	1997–2010, 2001–2002, 2000–2008, and 2011	Severe drought			3 million	South Africa		Kaczan and Orgill-Meyer (2019); Morreira (2010); Worby (2010)	1.5–2 mil in South Africa
86	Zimbabwe	ZWE	Kanyemba, Mbire district	1988	2011	Floods	Drought	Heavy rainfall	144 HH	Zambia and Mozambique		Bola et al. (2013)	720 ppl
87	Zimbabwe	ZWE	Manicaland and Masvingo provinces	2019	2019	Cyclone and storm	Landslides		52,273	Zimbabwe and farther		IDMC (2019, 2020)	

Note: According to the latest United Nations Department of Economic and Social Affairs (UN/DESA) report on 42 countries of SSA, the median average household (HH) size is 4.8 persons (UN/DESA, 2019). For the sake of accuracy of the values in this research, we use the approximated 5 persons per HH.

This research aims to understand the various levels of the complex phenomena between environmental drivers and migration in SSA. The author found QCA to be a more suitable method for this research because of its special design for small to intermediate size cases (5–50), its integration of qualitative and quantitative analysis, and its comparative and configurational abilities (Czaika & Godin, 2021; Kirchherr et al., 2016; Ragin, 1984; Ragin et al., 2017; Schneider & Wagemann, 2012). This research reviewed 87 works on migration induced by sudden, slow onset, and accumulated environmental changes from 32 countries in SSA. Fuzzy-set qualitative comparative analysis software, developed by Charles Ragin and Sean Davey, was used to conduct the combinations of several causal conditions. The number of possible combinations is 2^k, where k is the number of causal conditions (Ragin et al., 2017).

2.2.1. QCA terminologies

Outcome: The existence of migrants because of one or more environmental drivers' combinations.

Variables: The migration drivers' causal condition: the combination of variables explaining the outcome variable (number of migrants).

Logical remainder: Non-observed cases (migration drivers that have not displaced people).

QCA follows the following six stages to analyze a set of crisp data (Rihoux & De Meur, 2009):

(1) Building a dichotomous data table
  - Constructing a 'truth table'
(2) Resolving contradictory configurations
  - Analysis and Boolean minimization
(3) Consideration of the 'logical remainders' cases
(4) Interpretation

A detailed step-by-step explanation of the analysis method is provided in Supplementary Annex 3. QCA is based on Boolean data type, where cases are either included or not in a set based on presence indication as 1 and absence indication as 0 (Ragin, 1984; Ragin et al., 2017; Schneider & Wagemann, 2012). The list of environmental migration drivers gathered from the 32 SSA countries was coded to binary data, resulting in 98 cases. These cases were categorized into binary values 1 'migration' and 0 'no migration' because of the direct environmental driver. The crisp data passed through 'specify analyses' and 'standard analyses' to produce complex, parsimonious, and intermediate solutions.

In addition to the QCA, mosaic graphs were constructed using the R studio computer program to demonstrate the QCA binary truth table for selected five combinations between the various environmental change drivers. These five categorical combinations were derived from Table 3, Figures 3 and 4, and a careful literature review that highlighted recurrent pathways of human displacement driven by environmental conditions.

2.3. Statistical correlation

The correlation between floods, storms, cyclones, heavy rain, drought, landslides, heat shocks, and other mixed accumulated events helps us to relate the significance of the events as an inducing factor to migration/internal displacement in SSA. The author used an excel data matrix to feed to IBM SPSS software to conduct a bivariate correlation analysis between the above-mentioned environmental migration drivers. This method computes the Pearson correlation coefficient with significant levels based on a two-tailed test. The author related the various events by putting the hydrological extremes in one group and also by grouping high- and low-rainfall events together as a comparison of various relationships. Positive correlation leads to a 'p' value less than and equal to 0.01 or 0.05, indicating the significance of the relationship between the variables.

Our research analyzes cases reported in the literature. Thus, the metadata we have built may be inherently biased toward underreporting, a limitation of our approach which is based on secondary literature data. The empirical analysis of the indirect and underlying drivers of migration is seldom based on a rigorous assessment of causality relationships. The statistical correlation analysis here is used to complement and triangulate the QCA with other research methods in order to generate a better understanding of the interdependence existing among possible drivers (Czaika & Godin, 2019, 2021), despite possible concerns existing about the use of correlation analysis in meta-analyses (Rosenthal & DiMatteo, 2001).

3. Results and discussion

3.1. Migration patterns in SSA

Table 3 includes 27 case studies in which the migration flow directions are reported. We used this metadata to map the migration flows (Figure 2). The rest of the 56 cases are about internal migration within the country's borders, while some cases from Chad, Mali, Mayotte, Republic of Congo, Rwanda, South Sudan, and Uganda had no information on the destination of migrants. The desirability of the destination country/location (pull factor) highly depends on distance/easy access (e.g. Burkina Faso, Ethiopia, Ghana), the opportunity to diversify income sources (e.g. Burkina Faso, Ghana, Kenya, Nigeria, Uganda), food security (e.g. Cote d'Ivoire, Ethiopia, Ghana, Kenya, Mali, Senegal, Uganda, Zambia), safety during sudden extreme events, the location is usually selected by first emergency responders, national and regional administration (Holloway et al., 2013; NRC, 2015) (southern African region, Madagascar, Mozambique, Malawi, Zimbabwe), and reduced exposure to extreme climate conditions (e.g. Namibia, Niger, Madagascar, Mozambique, southern African region, Tanzania). On the contrary, climate migration is considered also a gendered migration from the example of northwestern Ghana and Tanzania. Female migrants in Ghana used to be denied from earning additional income when food insecurity persists during the dry season because of the bride price paid by the husband (Abdul-Korah, 2011; van der Geest, 2011). The bride price gave the husband the right to control the woman from participating in circular migration and diversify income sources for the family. In the case of Tanzania, unmarried female migrants still lack access to land-based livelihood despite the vulnerable state they hold in the society, which led them to only engage in off-farm labor jobs and migrate (Atuoye et al., 2020).

In Figure 2, the southern African region where all the arrows are converging in Botswana represents the centroid of the region. For the purpose of this study, Angola, Zambia, Zimbabwe, Mozambique, Namibia, Botswana, Swaziland, South Africa, and Lesotho are the countries taken into consideration to find the centroid location. In the various articles consulted for this research, people have migrated from Botswana, Madagascar, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe within the South African region with no information on the specific destination, therefore this centroid point used in this figure represents the

South African region at large (Bola et al., 2013; Brouwer & Nhassengo, 2006; Holloway et al., 2013; IDMC, 2019; NRC, 2015; Parkinson, 2013).

The evidence analyzed in this study (Figure 2) demonstrates that environmental migration in Africa has been internal to SSA for the period between 1990 and 2021, particularly clustering on a regional level, in agreement with the first African migration report (Abdiker et al., 2019).

3.1.1. Environmental events triggering migrations

According to the metadata in Table 3, the two main environmental factors leading to human displacement in SSA as a result of environmental change (slow-onset, sudden, and accumulated) are associated either with high rainfall (i.e. heavy rainfall, high-intensity precipitation events) or water scarcity and drought. Figures 3 and 4 show two schematic diagrams with the interrelationship among environmental drivers in the case of high rainfall and water scarcity, respectively.

Excessive precipitation can be associated with cyclones, storms, and heavy rainfall. Cyclone and storm events are becoming a more common and frequent occurrence in islands and coastal countries of SSA and their immediate neighbors. These extreme sudden events caused displacement/migration as individual direct drivers or as a consequence of one another ('domino effect'). Secondary to measures taken by local/regional governments to evacuate affected people, organizations like NRC,

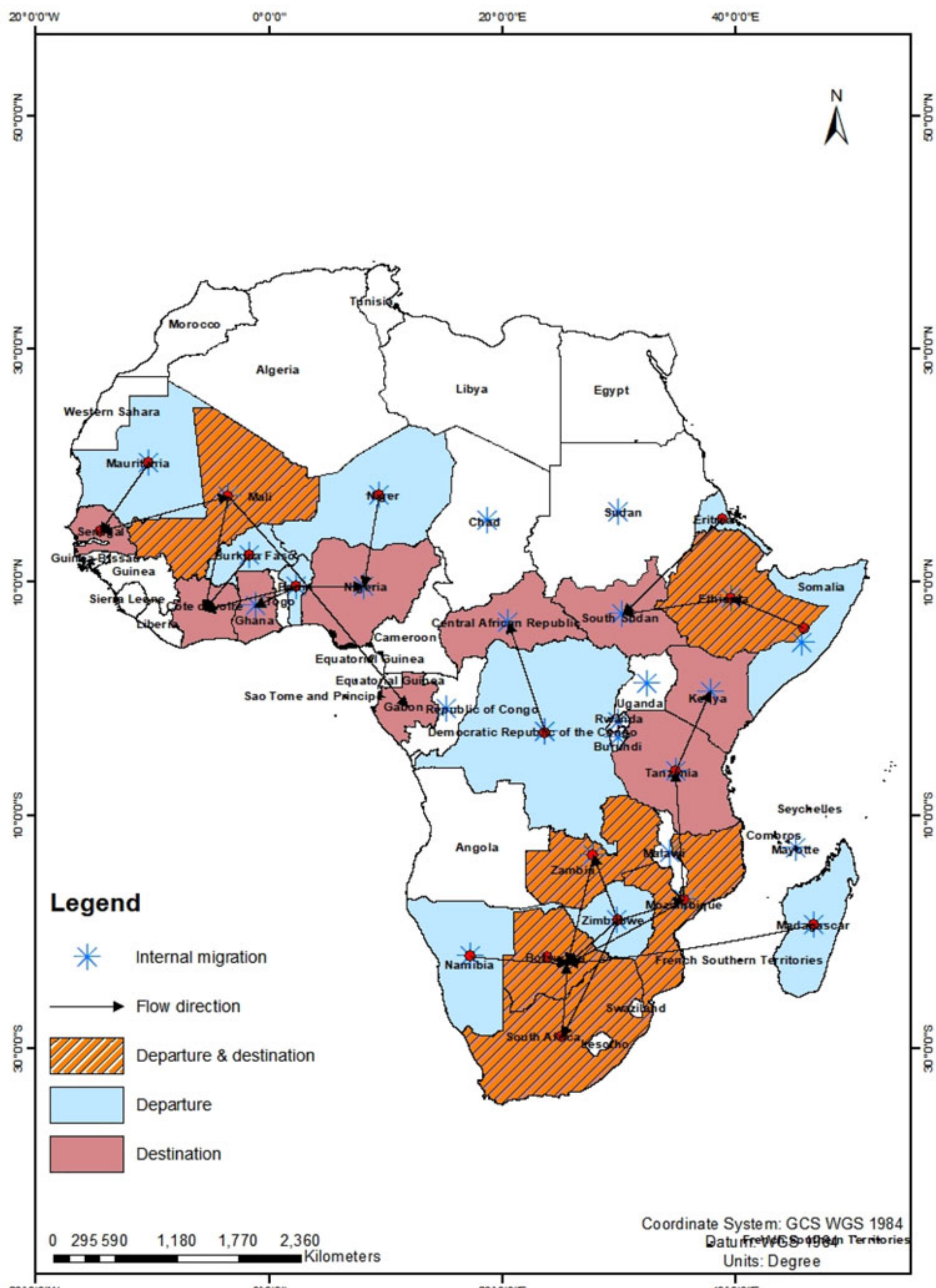

Figure 2. Map of the case studies included in this paper and the known environmental migration flows.

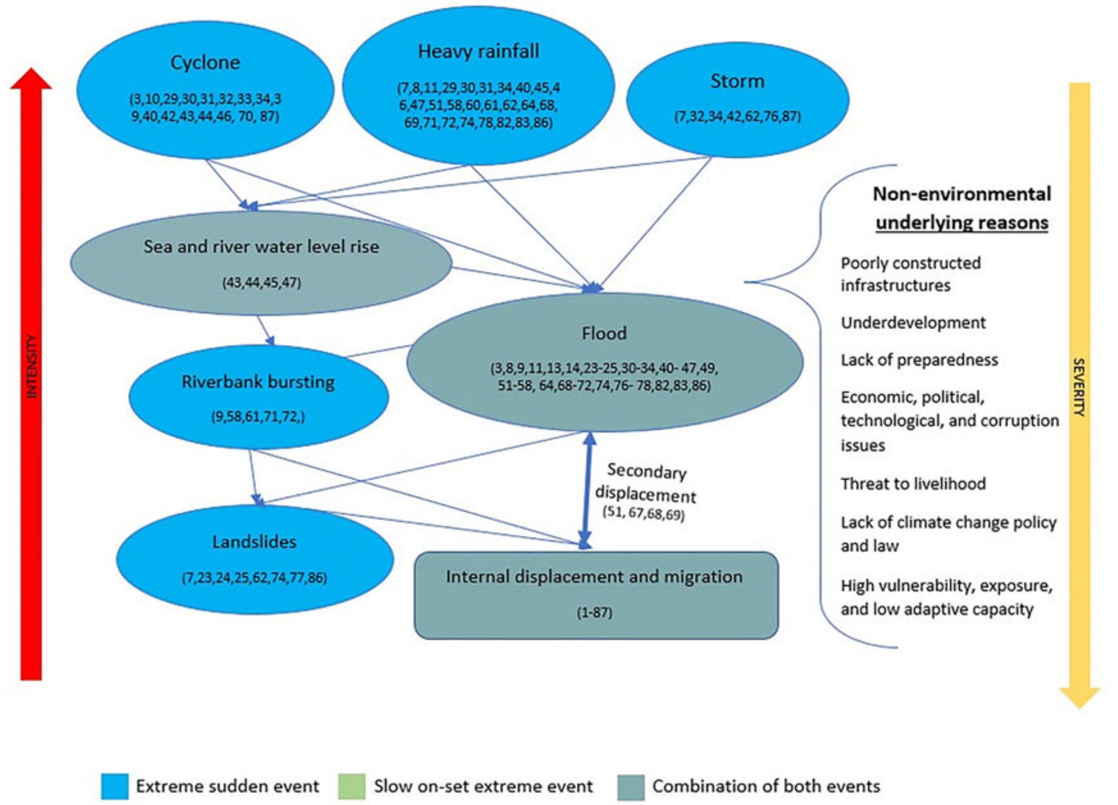

Figure 3. Schematic illustration of migration driven by high-rainfall events (including storms, flooding, cyclone, and heavy rain). In parentheses we indicate the corresponding case study in Table 3. The two arrow bars indicate directions of increasing intensity and severity. For instance, this figure is read by following the arrow starting from each driver. For example, cyclones caused direct displacement (first red arrow) in several case studies (3,10,29,30,31,32,33,34,39,40,42,43,44,46,70,87 (see Table 3)), cyclones (second red arrow) also led to flood which later caused displacement and following the third red arrow cyclone caused sea and river level rise which caused flood, riverbank bursting, and landslides, thereby displacing people.
Note: Severity is defined as the cumulative effect of harsh living conditions created by environmental change that pushes people to abandon their homes. The brown scale arrow on the right side of the figure points toward ascending level of severity. Intensity is defined as the amount of force exerted by and the persistence of environmental change-induced shocks. The orange arrow indicates the increase in intensity.

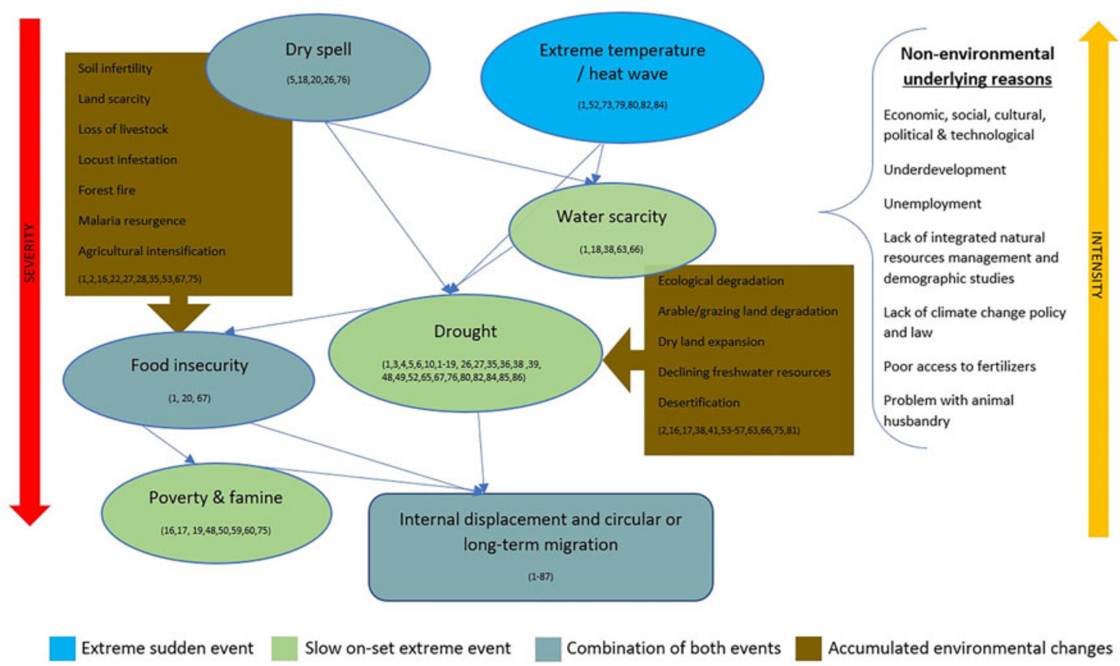

Figure 4. Schematic illustration of migration driven by low rainfall and water scarcity. In parentheses we indicate the corresponding case study in Table 3. The two arrow bars indicate directions of increasing intensity and severity. The number of displaced people for each event is shown in Table 3 and later used for QCA.

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IDMC, IFRC, and UNOCHA are among the first respondents for assistance. The actual number of these migrants is usually published in reports provided by these first respondents and numbers could vary from all migrants who decided to permanently stay in the resettlement centers to those who returned back to what's left of their residence (Brouwer & Nhassengo, 2006; Holloway et al., 2013; IDMC, 2020; IDMC & NRC, 2020; IFRC, 2009, 2012a, 2016; NRC, 2015; Parkinson, 2013; Simatele & Simatele, 2015; UNOCHA, 2012). Heavy rain caused displacement, partially in the Central, East, and South African regions. Heavy rain accompanied by a cyclone and storm-induced displacement in the Central African Republic, Democratic Republic of Congo, Republic of Congo, Burundi, Rwanda, Somalia, Zambia, Mozambique, and Namibia while the variation of heavy rain and lack of rain-triggered migration within Kenya from Samburu to Meru, Isiolo, Nanyuki, Nyeri, Karatina, Thika, and Nakuru counties. The above-listed countries faced large-scale property and infrastructure destruction, loss of life, agriculture, and livestock as the rapid events subsided (Caveirinha, 2013; IDMC, 2019, 2020; IFRC, 2016; NRC, 2015; Wiles et al., 2005). Beside the loss of livelihood, Mozambique's health sector was highly affected by the year 2000 extreme event leaving communities stranded (Brouwer & Nhassengo, 2006). For small island countries like Comoros and Mayotte, the lack of less-exposed resettlement locations to shelter from future events was an additional challenge they had to face alone (IDMC, 2020).

Not only did these extreme low-pressure events displace people from their homes but also triggered a set of other environmental changes such as the rising of river/seawater levels and inundation (see case studies 46, 56, and 57, respectively). In Chad, Nigeria, the Republic of Congo, Sudan, and South Sudan the bursting and overflow of riverbanks and reservoirs (e.g. Kariba and Cabora Bassa dams) led to direct displacement (IDMC, 2020; IDMC & NRC, 2020). In other cases, human displacement was induced by landslides and floods. Mozambique and Namibia were the only two countries that had displacement unrelated to infrastructural damages. Landslides as a consequence of extreme rainfall events displaced many people in East Africa (Burundi, Kenya, Rwanda, Tanzania, Uganda, Zimbabwe) (DREF, 2012; IDMC, 2019; 2020; IDMC & NRC, 2020; UNOCHA, 2019). In Madagascar, the base of the Easter Mountain mudslide caused tremendous damage to 40,000 homes and killed 13,000 people triggering internal human displacement and migrations (Naeraa & Jury, 1998; NRC, 2015).

The combination of additional data extracted from the international disaster database in Supplementary Annex 1 with metadata from Table 3 shows that 38 out of 47 countries experienced immediate displacement because of floods. Floods did not just cause a one-time displacement; in countries such as Niger, Somalia (Gu rains), and Sudan the resettlement centers were flooded again, leading to 'secondary displacement' to higher grounds (IDMC, 2020; IDMC & NRC, 2020). In some cases, flood and water-level rise did not cause immediate displacement but rather slow-onset adverse conditions, which are shown in gray in Figure 3 to stress the fact that they could occur either as extreme events or as slow-onset environmental drivers. The cascading connection of these migration drivers shows the severity and intensity scale of the events for people to stay in their habitual residence. The complex web of high precipitation-induced environmental impacts in Figure 3 resulted in internal displacement and migration in southern Africa, eastern Africa, and part of the Central African region (see Table 3) either as single drivers or in conjunction with others. The lack of well-documented, long-term hydro-climatological records of extreme events that have induced migration in the region points to an important gap in understanding the nexus between high precipitation and migration.

We then look at migrations induced by low rainfall and water scarcity (Figure 4). We found that dry spells and heatwave/extreme temperatures are associated with slow-emerging drivers of migrations within SSA. The crucial difference between Figures 3 and 4 is that each driver in Figure 3 causes migration on their own and in some countries cumulatively but in Figure 4 the cumulation of the drivers can only cause long-term migration. SSA is known for its high dependence on rain-fed agriculture to feed a large portion of its population. Farmers in many countries have developed an adaption method in the form of circular migration to make sure that they have enough food to feed their families. When facing an extended dry season, they migrate to the nearest city with more job opportunities and work as laborers. When the rainy season approaches, they return to their farm to prepare the land and work in the growing season, as reported by sample community surveys in Burkina Faso (Soum, Oudalan Nahouri, and Bougouriba provinces), northwestern Ghana (Nadowli district), and Kenya (Samburu county) (Abdul-Korah, 2011; Henry et al., 2004; Ng'ang'a et al., 2016; Rademacher-Schulz et al., 2013; van der Geest, 2011). In these cases, only some family members migrate often temporarily without displacing the entire household in the form of rural–rural/rural–urban or north–south/south–north.

Nigeria, Tanzania, and Zambia are countries affected by heatwaves which were not direct drivers of displacement. Dry spells and extreme heat were associated with water scarcity in Mauritania, Rwanda, and Somalia, but they did not induce direct displacement. Instead, they contributed to the recurring drought event in Burkina Faso, Ethiopia, Ghana, Kenya, Mali, Mauritania, Nigeria, Rwanda, Somalia, Tanzania, Zambia, and Zimbabwe. These drought events displaced many people and trapped others in further food insecurity, leading to poverty and famine. Trapped communities are those people facing severe vulnerability to a dry climate, poverty, and food insecurity but do not have the resource to migrate to a better place (Black et al., 2013; Nawrotzki & DeWaard, 2018; Simatele & Simatele, 2015). Even pastoralist communities that are well adapted to extreme weather events are facing water scarcity and grazing land degradation and seeking a more permanent settlement option in the case of West Pokot, Kenya, and Somalia (Ng'ang'a et al., 2016; Tsui et al., 1991). The combination of both rapid extreme events (flood, heatwave) and slow-onset events (drought) caused a large people displacement in Zimbabwe, Nigeria, Ethiopia, and Burkina Faso (Bola et al., 2013; Dillon et al., 2011; Henry et al., 2004; IDMC, 2020; IDMC & NRC, 2020). The review of the literature (see Table 3) shows the recurrence of some extreme events for over 20 years.

Ethiopia had severe recurring droughts followed by accumulated environmental changes (see Figure 4) such as famine, ecological degradation, dryland expansion, famine, and locust invasion in 1960–1980, 1984–1994, 1985, 1994–2009 (Bilsborrow & DeLargy, 1990; Ezra, 2000; 2001; Ezra & Kiros, 2001; Gray & Mueller, 2012; IDMC, 2020; IDMC & NRC, 2020; Jacobsen & Wilkinson, 1993; Kane, 1995a; Rahmato, 1991). These events caused a displacement of almost 2 million people in total. In the last couple of years, the recurring drought was accompanied by floods and further displaced 367,000 people. The accumulated environmental changes over the 20 years that

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expanded the dryland and degraded the quality of the farmlands caused by high population growth followed by agricultural intensification could be the reason that exposed the communities to flood occurrence in 2019. Somalia also had arable land degradation and water scarcity in early 1970, which later developed into severe drought in 1973–1975 and led to food insecurity (Gebremedhin, 1991; IDMC, 2020; IDMC & NRC, 2020; Molvær, 1991; Tsui et al., 1991; Westing, 1994). The unexpected tropical cyclone in 2018 caused heavy rainfall in the Arabian desert also created the perfect environment for locust breeding; the wind of yet another cyclone in 2019 facilitated the migration of locusts to East Africa exacerbating food insecurity (IDMC & NRC, 2020; Salih et al., 2020; WMO & FAO, 2016).

Besides other underlying non-environmental reasons in Somalia, the accumulated environmental changes led to slow-onset severe drought events developed over the years displacing 760,000 people. The neighboring Kenya and Tanzania also had accumulated and slow-onset environmental changes ranging from land scarcity, degradation, livestock diseases, and heatwave to drought resulting in the internal displacement of 90,420 people (Atuoye et al., 2020; Charnley, 1997; Maurel & Kubik, 2014; Mwakipesile, 1976; Ng'ang'a et al., 2016; Odgaard, 1986). In the last decade, Kenya experienced 28 major droughts and Samburu county is one of the few places that was affected by both heavy rainfall and dry spell robbing the chance of farming entirely. Most families in the county now depend on remittances from family members who migrated to the neighboring counties (Ng'ang'a et al., 2016).

Expanding the search from east to southern Africa showed us that the extended drought in Mozambique halved agricultural production and caused widespread food insecurity before the cyclone exacerbated the migration of people both permanently and temporarily (IDMC, 2015, 2020). In Zambia and Zimbabwe as well, the slow onset of severe drought in the late 1990s and early 2000 displaced more than 3 million people internally and externally to South Africa, respectively. From West SSA, the author found few temporal data on Mali, Mauritania, and Burkina Faso showing the development of accumulated environmental changes into slow-onset events (see Table 3: 1, 2, 26, 27, and 28) leading to displacement. These cases clearly demonstrate how soil erosion, deforestation, land degradation, desertification, water scarcity, and low rainfall/dry spell resulted in severe drought in these countries in 1960–1998, 1980–1990, and 2019.

3.2. QCA output

QCA is used to disentangle the complex causal conditions that lead to environmental migration from the collected datasets. It analyzed the combination of the direct environmental drivers whereas rapid/sudden events related to high-intensity downpours are grouped as one variable. These variables are (storm, cyclone,

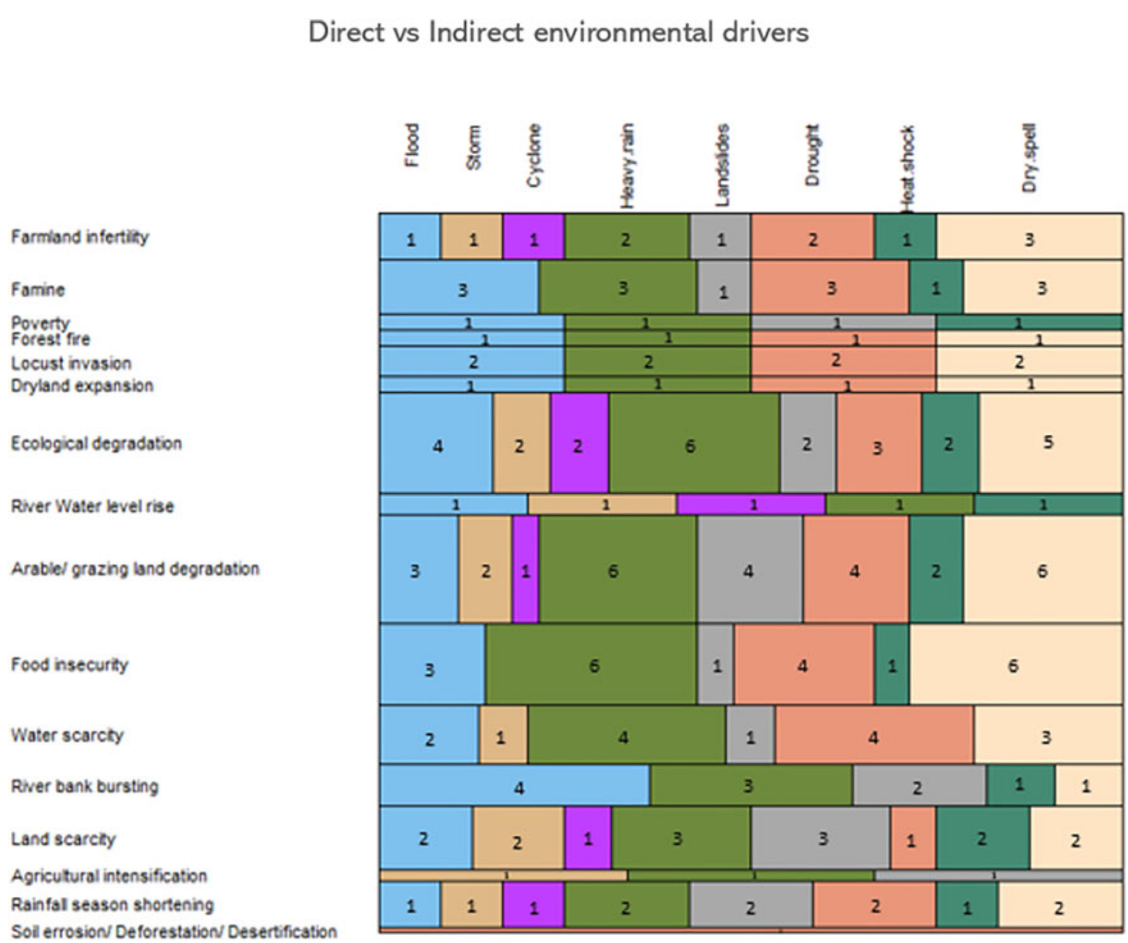

Figure 6. Mosaic plot of direct (*X*-axis) vs indirect drivers (*Y*-axis) of environmental change.

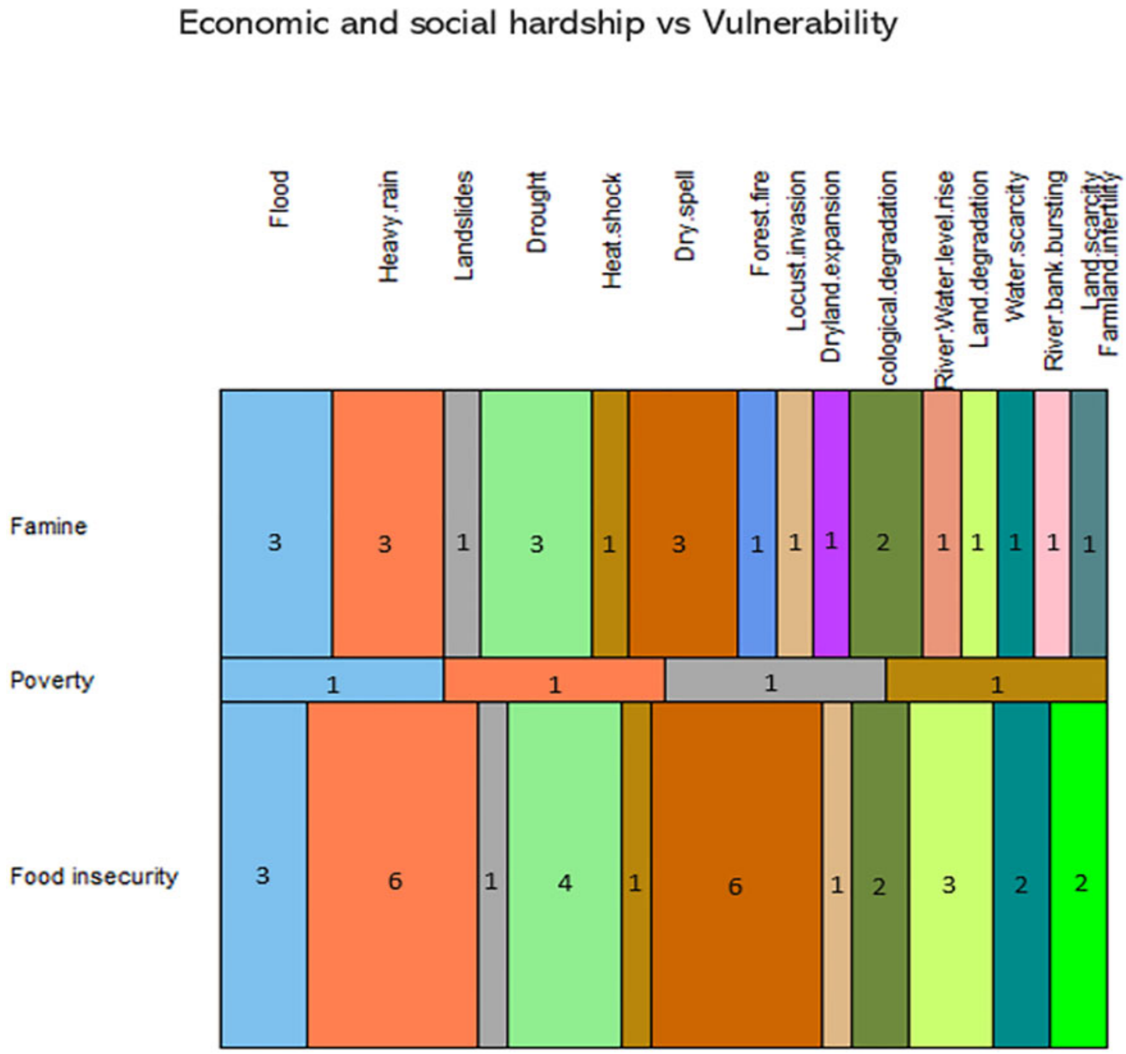

Figure 7. Mosaic plot of economic and social hardship (*Y*-axis) vs vulnerability to environmental change (*X*-axis).

heavy rain), flood, landslides, heat shock, drought, and dry spells. From reviewing 87 case studies on environmental migration, we found that the direct drivers shown in Figure 5 have 98 cases with evidence of direct displacement immediately or through a certain length of time, therefore, the QCA output shown below focused on the following cases: flood (20), storm (8), cyclone (10), heavy rain (23), drought (13), landslides (9), heat shock (4), and dry spell (11). The indirect drivers (Figure 6, *y*-axis) have also contributed to the displacement of more people in SSA but not exclusively. One or more of these drivers accompanied the direct drivers creating widespread vulnerability and exacerbating the effect of direct drivers. In total, we had 51 cases from the secondary drivers, that is, famine (4), poverty (1), forest fire (1), locust invasion (2), dryland expansion (1), ecological degradation (6), river water-level rise (1), arable/grazing land degradation (7), food insecurity (7), water scarcity (5), river-bank bursting (4), land scarcity (3), agricultural intensification (1), farmland infertility (3), rainfall season shortening (2), soil erosion (1), desertification (1), and deforestation (1).

Environmental migration decisions and drivers can only be explained by the interaction of several factors (conjunctural causation) (Foresight, 2011). The mosaic graph constructed from the QCA truth table demonstrates five distinct combinations between the various environmental change driver categories, we have encountered so far. The push from these environmental changes varies in the degree, scale, and intensity of the event. About 54% of the cases covered in this article focus on displaced people from rural communities relying on farming and pastoralism. Figure 6 shows the connection between 28 cases of arable/grazing land degradation and 21 cases of food insecurity as a result of direct migration drivers, respectively. Our finding further shows that 26 cases of ecological degradation and 16 cases of land scarcity were principal contributors to the displacement of communities dependent on agricultural production. The summary of direct and indirect drivers highlights that the agricultural community (farmers and pastoralists) dependent on seasonal rainfall is the most vulnerable and exposed to displacement as a result of environmental change extremes. Naturally, being vulnerable and exposed to recurrent environmental extreme events pushes people to change their place of residence, but the adaptive capacity in terms of economic and social status becomes the deciding factor.

Figure 7 displays the economic and social hardship faced by communities in terms of famine, poverty, and food insecurity as a push factor for out-migration. These hardship conditions were caused or worsened by climate change or extreme environmental

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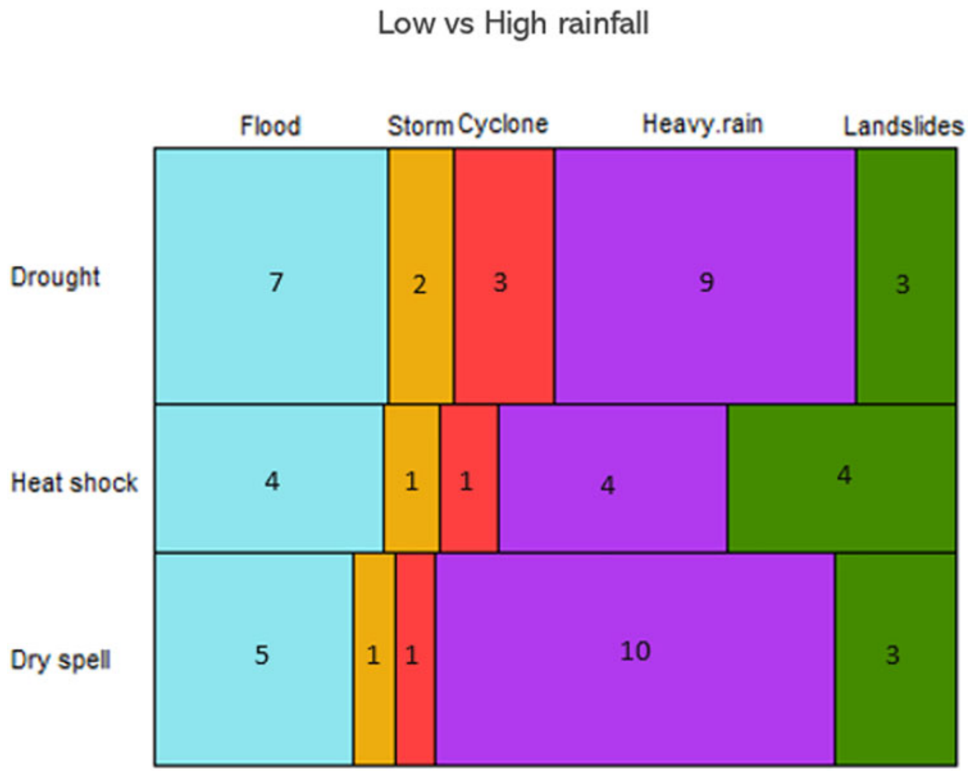

Figure 8. Mosaic plot of the relationship between low- and high-rainfall events.

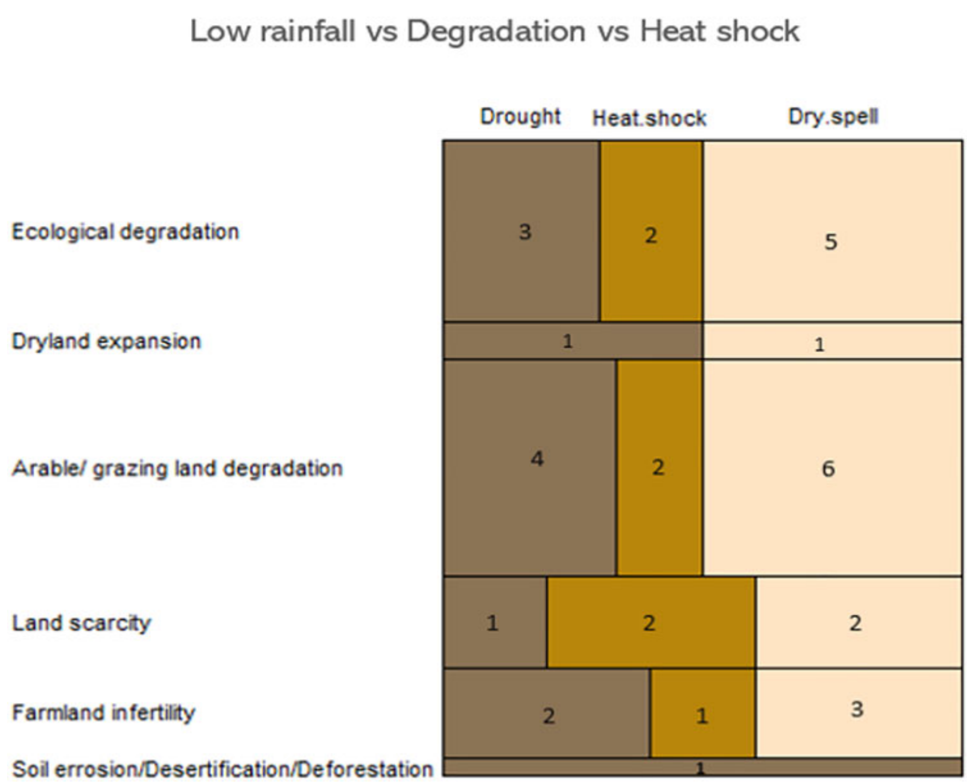

Figure 9. Mosaic plot of the relationship between low rainfall, degradation, and heat shock.

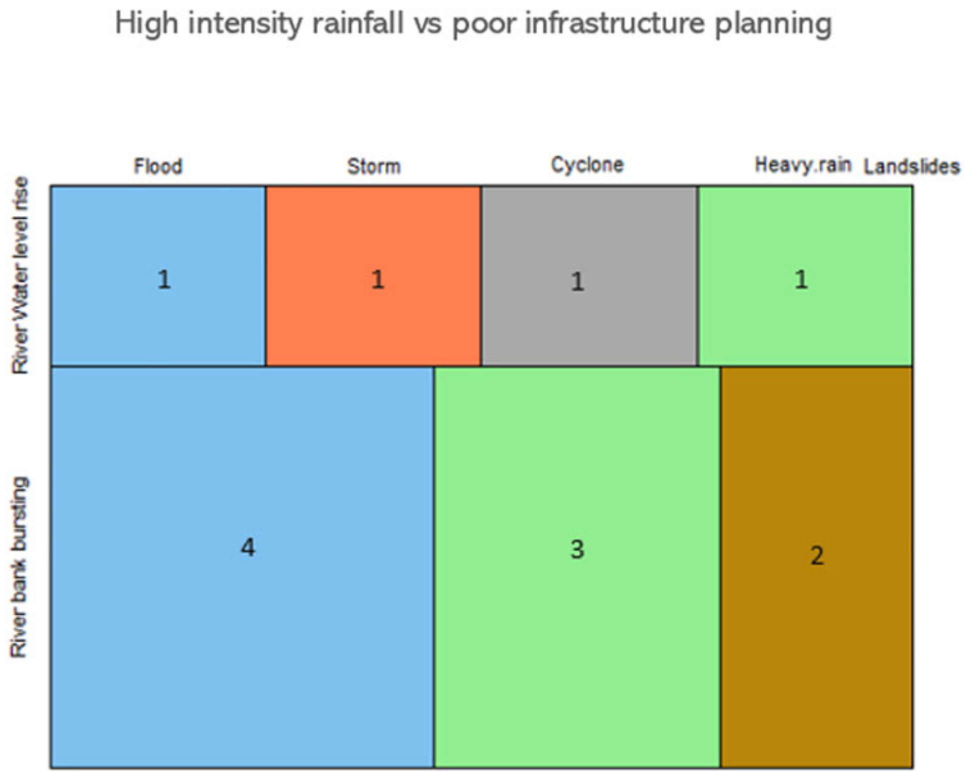

Figure 10. High rainfall vs poor infrastructure.

shocks. Conversely, individual or household vulnerability to environmental migration can be enhanced by famine, poverty, and food insecurity. While here we are unable to evaluate the synergy between these direct and indirect drivers of environmental migration, we investigate their co-occurrence (Figure 7). Once these drivers have set roots, the occurrence of extreme hydrological events causes an immediate displacement from their residence. This mosaic plot shows the role of non-environmental underlying drivers on environmental migration. Our meta-analysis found that Tanzania, Nigeria, Rwanda, Burkina Faso, and Somalia were the most vulnerable to environmental migration as a result of economic and social hardship (see Supplementary Annex 4: Africa map with all environmental drivers) (Figures 8 and 9).

In several cases, migration occurred as a result of high-rainfall events (i.e. heavy rain and flood) happened in drylands or areas highly affected by drought and dry spells (39 cases, 67%). Heavy rainfall either destroyed the crop that has already suffered because of the extended period of no rain (Benin, Mali, Niger, and Nigeria) or ended up flooding the drylands (Ethiopia, Somalia, Tanzania, Zambia, Zimbabwe, and Botswana) leading to the displacement of people. The combination of low rainfall with extreme heat events and degradation of natural resources was highlighted in countries like Benin, Ghana, Niger, and Tanzania (Figure 3) with 33% of the total cases associated with arable and grazing land degradation.

The last mosaic plot (Figure 10) shows environmental migration cases related to poor infrastructure planning that led to torrential flooding from the overflowing of dams and reservoirs, bursting of riverbanks, and water-level rise in rivers. The combination of these drivers was highlighted in Chad, Nigeria, Central Africa Republic, Mozambique, Angola, and Zambia.

Figure 5 shows the optimal result ('parsimonious solution') obtained from the QCA on direct drivers. This paper only reports the parsimonious solution as it is considered the most robust and capable of reducing redundant variables (Baumgartner & Thiem, 2017; Groth et al., 2020). See Supplementary Annex 3 for more details.

The parsimonious solution from QCA disentangles the migration decision pathways as a result of extreme hydrological events and drought. This method further analyzed the complex and intermediate pathways that could or could not lead to environmental migration (see Supplementary Annex 4). These pathways include – but are not limited to – the combined incidence of 'flood', 'landslide', 'drought but not dry spell'. The results show the probable occurrence of displacement associated with floods in Central, East, and South Africa (20 cases, 62%) or landslides (9 cases, 28%) in East, West Africa, and Madagascar. The analysis further emphasizes that Mauritania and Eritrea are prone to drought-induced displacement (without dry spell) (5 cases, 15%) while Zambia is the only country showing the cumulative effect of flood, landslide, and drought on human displacement.

3.3. Statistical analysis

In addition to the above QCA and empirical analysis, we also measured the strength and direction of the linear relationship between variables or, in our case, the number of people displaced by each extreme event. The statistical correlation yields that there is no significant cross-correlation between multiple drivers. The detailed result of the correlation output from SPSS is provided in Supplementary Annex 5.

The correlation of multiple drivers as environmental migration inducers mainly depends on the selection of the destination. The

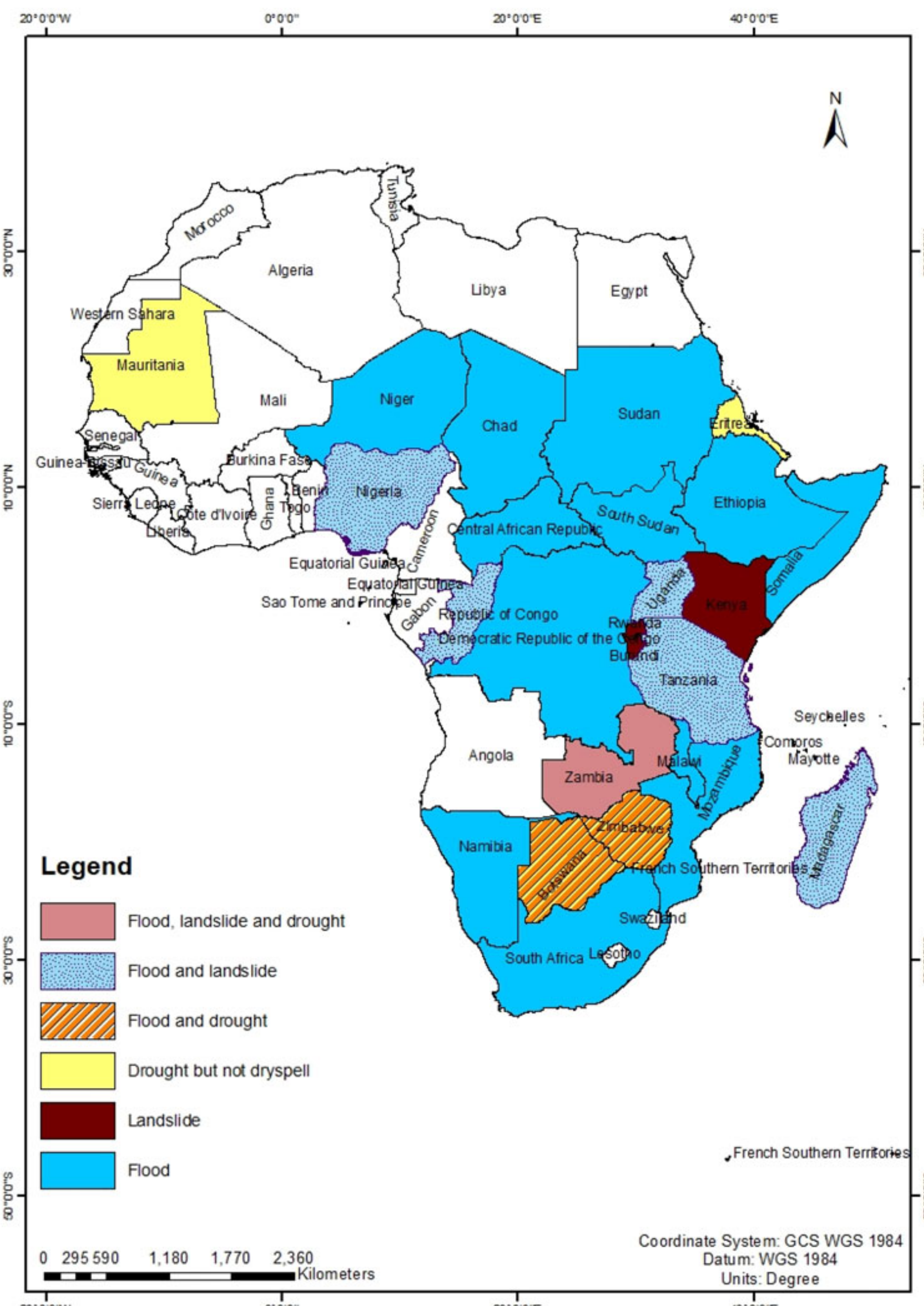

Figure 5. QCA parsimonious results.

destination of migrants is mainly governed by distance/access to better resources, climatic conditions, better income/job opportunities, and better living conditions/safety. The statistical analysis method does not consider this main governing factor. Figure 11 shows the environmental migrant population distribution from the case studies gathered. Each dot represents 4000 people, making Zimbabwe, Rwanda, Somalia, and Mozambique the top four countries with the highest environmental migrants in descending order (see Table 3). As previously mentioned, we also consulted the international disaster database (UCLouvain, 2020) from 2000 onward to complement the results generated from the review of 79 articles from the literature. Figure 12 shows the total environmental migration cases in SSA, see Supplementary Annex 2.

3.4. Conceptual framework analysis

We then propose a conceptual framework as a heuristic approach to structure the environmental drivers of migration with their underlying non-environmental factors into a systematic concept flow from evidence gathered in the literature. The literature review (Table 3) highlighted how environmental migrations are not the result of only environmental change drivers but of their complex inter-linkage with underlying non-environmental factors that

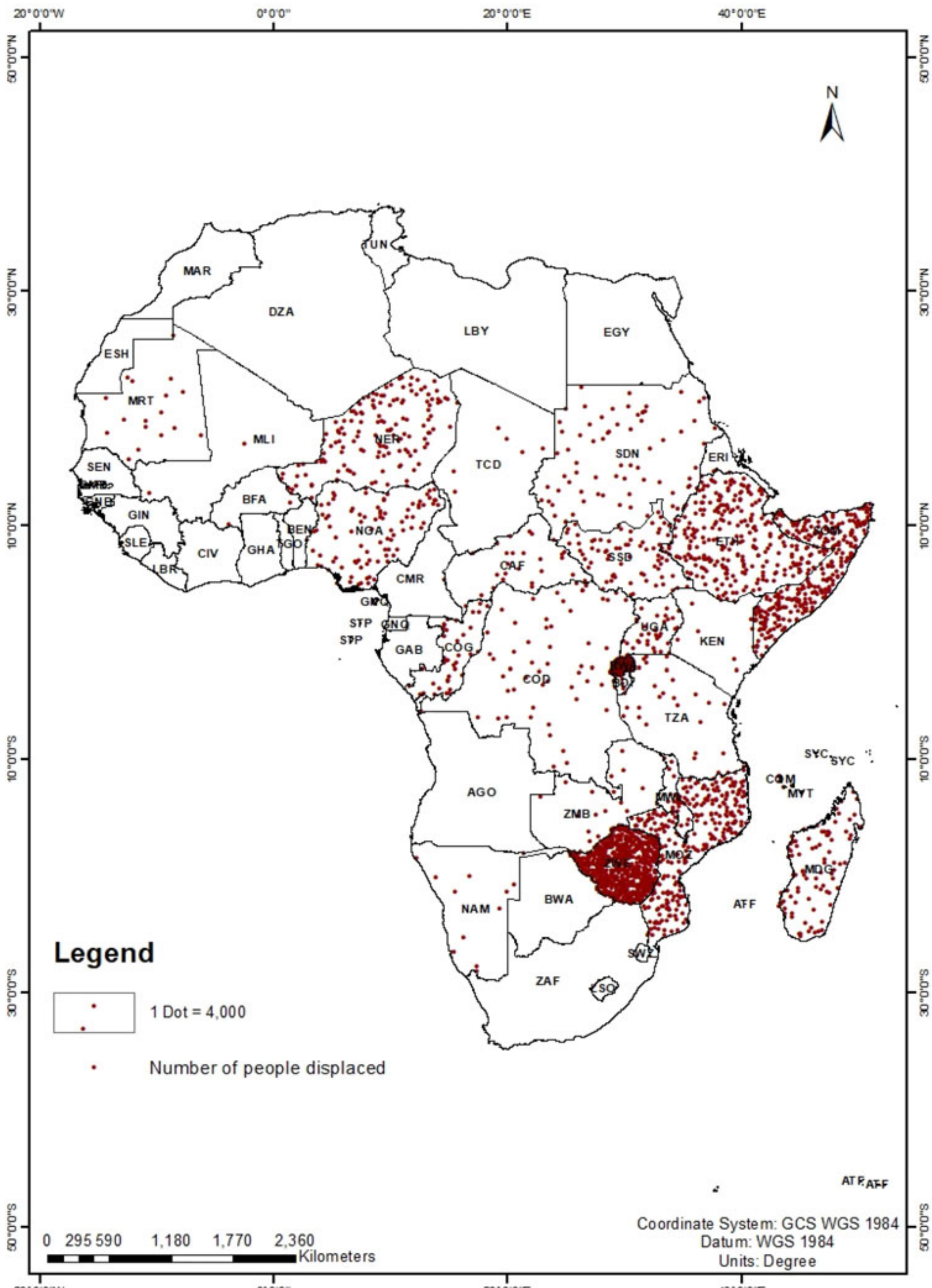

Figure 11. Environmental migrants' distribution per 32 countries.

enhance a population's vulnerability to environmental stressors. The following conceptual framework provides a clearer representation of the complex interrelationship of environmental migration drivers in SSA. The cumulative centripetal movement of drivers to the center (migration and displacement) is experienced when non-environmental factors existed for many years in each country. This centripetal movement of drivers is categorized into three main orbits based on their evolvement process.

The movement of people in search of a large quantity of untapped natural resources has existed for as long as history remembers. Nevertheless, what happens when these resources must be shared with more and more people? What about when other non-environmental factors prohibit the growing population from using these resources freely? Then communities would start to overexploit/deplete the resources available in their vicinity. The overuse of resources leads to degradation, exposing them to be severely impacted because of environmental changes over time. This theoretical framework of migration drivers has been translated for the 87 case studies of SSA as shown in Figure 13. Non-environmental underlying drivers such as poorly constructed infrastructures, limited economic development, high unemployment rate, lack of preparedness of local governments, unstable economic and political situation, some social and cultural norms (e.g. male role as a provider of the household, similar

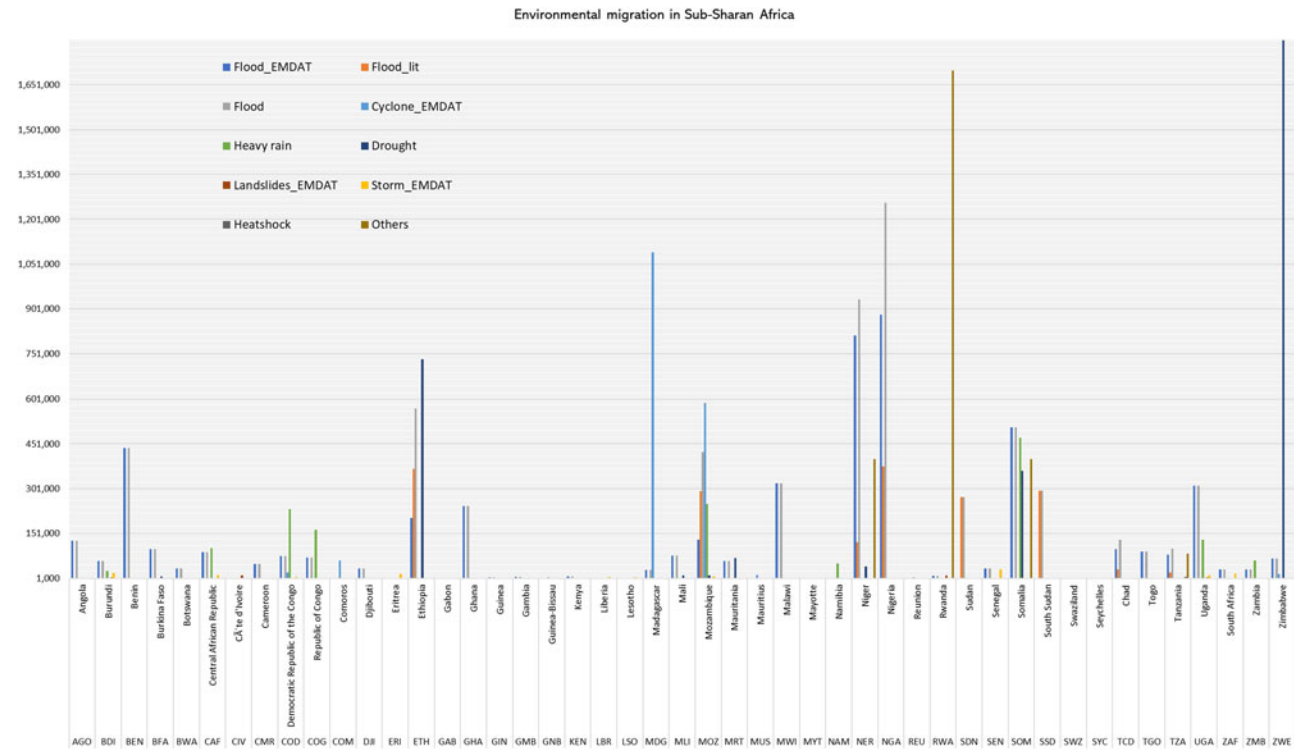

Figure 12. Total environmental migration in SSA (flood is read as the combination of flood from the EMDAT dataset and flood from literature. Other drivers without the extension EMDAT are collected from the literature).

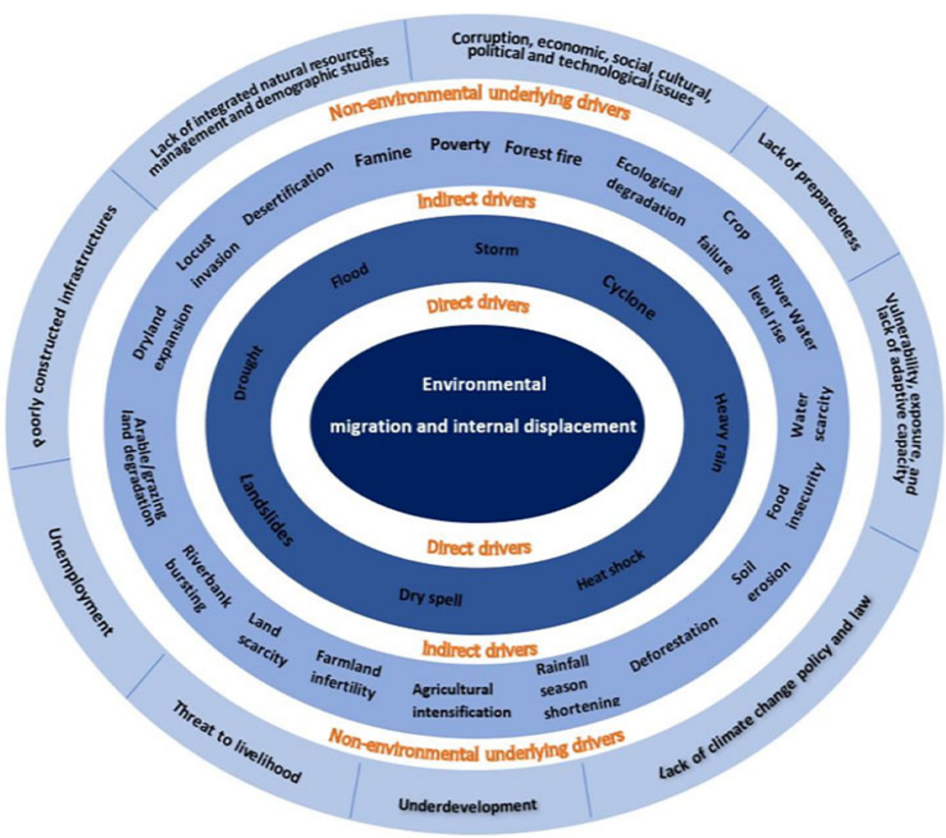

Figure 13. Conceptual framework of environmental migration drivers in SSA.
Note: The figure depicts the three categories of environmental migration and internal displacement drivers translated from the 87 case studies in concentric elliptical layers. The figure is read from the out most layer of underlying non-environmental drivers that create suitable conditions for the emergence of indirect drivers exposing communities to slow-onset environmental changes. These indirect drivers in turn create a more suitable condition for the rising of direct drivers characterized by accumulated and extreme events. For instance: poorly constructed infrastructure due to the community's lack of adaptive capacity (outer layer) creates susceptibility of riverbanks for bursting (second layer), thus intensifying the effect of flood and landslides (third layer), thereby causing internal displacement and environmental migration (centroid).

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religion, and ethnicity; Davis et al., 2013; Rademacher-Schulz et al., 2013; van der Geest, 2011)), slow technological advancement, corruption, threats to livelihoods, lack of climate change policy, and law (Abdiker et al., 2019), lack of integrated natural resources management and demographic studies with no actionable impact left communities vulnerable and with little adaptive capacity to environmental changes in SSA.

From the early 1970s to 2000 population of SSA kept increasing along with the inequality in access to resources (Naudé, 2010). During this time SSA was strongly affected by natural disasters, particularly in Ethiopia (54 disaster occurrences), Tanzania (38), Kenya (28), Sudan (32), Madagascar (35), South Africa (56), Mozambique (46), and Nigeria (28) (Krishnamurthy, 2012; Naudé, 2010). These countries were found to be most susceptible to internal displacement. The outer 'orbit' of underlying non-environmental drivers (Figure 13) contributed to the emergence of accumulated environmental changes (indirect drivers) which over time became critical factors for direct migration drivers. Ecological degradation, arable/grazing land degradation, dry-land expansion, declining freshwater resources, desertification, soil infertility, land scarcity, loss of livestock, locust infestation, forest fire, malaria resurgence, and agricultural intensification fueled by high population growth are the indirect environmental/land-use drivers that enhanced the occurrence of more rapid/extreme events in the subsequent years. The direct drivers (Figure 13, innermost 'orbit') such as floods, storms, cyclones, heavy rain, heat shock, dry spell, landslides, and drought led to the human displacement and migration in SSA either alone or in combination with other environmental drivers. Thus, while direct and indirect environmental factors are important drivers of environmental migration in SSA, the underlying non-environmental factors are also expected to play a critical role in triggering internal displacement.

4. Conclusion

Environmental migrations have been a major focus of research on environmental change impacts. Indeed, empirical studies on environmental change drivers of migration have notably increased in the last few decades. To date, there is little agreement within the scientific community on the extent to which climate and environmental factors influence human mobility. Based on the secondary data collected from 32 countries, there are 149 cases in which various degrees of environmental changes contributed to migration in this paper.

This review quantified the effects of rapid, slow, and accumulated environmental changes on human mobility to better understand migration flows in SSA. The result from the theoretical analysis (Figure 13) and also the QCA reveals that the complex web of causal links are the main drivers of environmental migration in SSA while individual extreme or slow-onset events with high intensity and severity are very critical migration inducers. However, the existence of non-environmental underlying factors plays a significant role by exposing the population to cumulative environmental changes and hindering their resilience. The widely accepted notion that developing countries will endure the brunt of global environmental change in the not-too-distant future (Clement et al., 2021; Gahouma-Bekale, 2021) establishes the great importance of understanding these links (Carr, 2005). The long-term hydro-climatological records of extreme events that have induced migration in the region point to an important gap in understanding the nexus between high precipitation and migration. This paper fills the gap in knowledge by presenting well-documented evidence of environmental migration cases from more than two decades of records. It investigates the complex web of environmental drivers and how they lead to human displacement. The quantitative and qualitative analysis further evaluates the pattern and weight of each migration driver in SSA.

The review of the literature on African environmental migration encountered some limitations such as the substantial lack of holistic evidence, the scarcity of comprehensive temporal and spatial data to fully understand the extent of human displacement in-depth, the lack of information about the future of IDPs permanent or temporary destination or secondary displacement, and the scale of data collection limited to the scope of (often scattered) past research and data collected by first responders. Limitations associated with the use of these metadata can be seen in the results of the statistical analysis. In fact, the statistical analysis shows no significant cross-correlation between multiple drivers of migration in SSA, in complete disagreement with the evidence, gathered in the literature as well as the results of theoretical, and QCA. Statistical analysis can only provide accurate and reliable outcomes when based on well-documented, systematic, and relatively complete datasets (Groth et al., 2020; Ide et al., 2020). Therefore, with the currently available data compiled from the literature, the use of statistical correlation analysis may yield inaccurate results. 'This requires transparency, information, and data-sharing between the African States on migration, and an openness to engage with the full range of stakeholders that play a significant role in migration knowledge production' (Abdiker et al., 2019). Because about 85% of the African migration is an active cross-border movement within SSA there is a need for more data to document this phenomenon (Achieng et al., 2020). The adaptation and resilience of communities to cope with the scale of extreme and slow-onset environmental changes are quite limited. In fact, about 93% of the assessed countries had forced displacement as a coping mechanism to the environmental change drivers while the rest practiced short-term circular migration to increase their resilience. According to the IPCC estimates, the projected impacts and risks of frequent and intense extreme weather and climate events under 2°C and above climate warming (2021–2100) are expected to exacerbate and undermine food and water security by threatening water availability, food production, and access in SSA, likely leading to severe malnutrition and micro-nutrient deficiency (high confidence) (Pörtner et al., 2022; Trisos et al., 2022). Food insecurity, in turn, is likely to contribute to humanitarian crises in more vulnerable and exposed communities, thereby leading to human displacement. African migration studies have often focused on fluxes from Africa to Europe while cross-border migration within SSA has remained understudied despite the greater number of people it affects (85% of the total migrants) (Achieng et al., 2020). The evidence-gathering process of this meta-analysis suggests that intra-African migrations are not well captured by past studies. Fortunately, some of the migratory fluxes are recorded by local governments, international organizations, and humanitarian groups. Thus, gathering and analyzing such records can shed light on environmental drivers of human displacement within SSA. To advance the understanding of this complex regional phenomenon there is a need for a more holistic approach with research focusing on the entire SSA region instead of single countries. This review has shown that understanding the link between migration and extreme environmental changes mainly depends on disentangling multi-causality relations, including not only environmental factors but also the vulnerability of SSA people to poverty, famine, and water scarcity.

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Research transparency and reproducibility. This research is reproducible by following the methods in which we transparently explain how the data were gathered and analyzed.

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