Earth's Future

COMMENTARY

10.1029/2020EF001958

Advancing the Evidence Base of Future Warming Impacts on Human Mobility in African Drylands

Lisa Thalheimer[1,2], David S. Williams[3], Kees van der Geest[4], and Friederike E. L. Otto[2]

[1]University of Oxford, Institute for New Economic Thinking, Oxford, UK, [2]University of Oxford, Environmental Change Institute, Oxford, UK, [3]Istanbul Policy Center, Sabancı University, Istanbul, Turkey, [4]United Nations University, Institute for Environment and Human Security, Bonn, Germany

Abstract A better understanding of climate change impacts and resulting human responses (climate-related human mobility) have been identified as a research priority by the climate science community. Here, we provide the basis for future research efforts by identifying knowledge gaps and consolidating published evidence in the IPCC 1.5 Special Report (SR15) with recent evidence from climate science and the literature on human mobility in African drylands, a region where migrants are particularly vulnerable to climate change. We first synthesize climatic changes and their projected impacts across the region to then contextualize the projected impacts with current knowledge regarding the effect of anthropogenic climate change on human mobility. We discuss these often indirect impact channels and argue that a systems approach is needed to address the interconnectedness of climate impacts and the cascading risks of adverse consequences for human mobility.

Plain Language Summary The Paris Agreement recognizes that climate change and extreme weather events alter human mobility patterns. Even under an optimistic scenario, an increase in global temperature of 1.5°C above pre-industrial levels is likely to increase the numbers of people vulnerable to climatic stress while limiting the capacity for effective climate change adaptation. Under a less optimistic scenario, the disruption is expected to be worse. Yet, the impacts of different warming scenarios, including observed warming, on human mobility remain insufficiently understood and discussed in policymaking. A synthesis of empirical evidence from the IPCC Special Report on Global Warming of 1.5°C and subsequently published literature on climate change effects in African drylands highlight implications of warming scenarios on human mobility in this region, where climatic change is a defining feature of local communities and predominantly agricultural economies. Adverse effects of climate change on African dryland communities may not necessarily cause mass migration but are likely to alter human mobility from more voluntary toward more forced displacement or entrapment. A systems approach can be used as a starting point to address the urgent challenges of climate-related human mobility.

Key Points:

- In African drylands, migration is already being altered by changes in climate with uncertain outcomes under a 1.5° warming
- Impacts in climate-sensitive sectors relying on migrants differ greatly, calling for an advancement of available evidence on regional scale
- A systems approach can address the urgent policy challenges regarding climate-induced human mobility

Correspondence to:

L. Thalheimer,
lisa.thalheimer@chch.ox.ac.uk

Citation:

Thalheimer, L., Williams, D. S., van der Geest, K., & Otto, F. E. L. (2021). Advancing the evidence base of future warming impacts on human mobility in African drylands. *Earth's Future*, *9*, e2020EF001958. https://doi.org/10.1029/2020EF001958

Received 30 DEC 2020
Accepted 16 SEP 2021

Author Contributions:

Conceptualization: Lisa Thalheimer, David S. Williams, Kees Geest
Formal analysis: Lisa Thalheimer, David S. Williams, Kees Geest, Friederike E. L. Otto
Methodology: Lisa Thalheimer, David S. Williams, Kees Geest
Project Administration: Lisa Thalheimer, David S. Williams
Resources: Kees Geest
Supervision: Lisa Thalheimer
Visualization: Lisa Thalheimer
Writing – original draft: Lisa Thalheimer, David S. Williams, Kees Geest
Writing – review & editing: Lisa Thalheimer, David S. Williams, Kees Geest, Friederike E. L. Otto

1. Introduction

Displacement, forced migration, and other forms of human mobility have long been recognized as a potential major impact of anthropogenic climate change. Therefore, limiting climate-related human mobility has been important in informing the goal of capping global warming at 1.5°C above pre-industrial levels in the Paris Agreement (Hoffmann et al., 2020; Task Force on Displacement, 2018; UNFCCC, 2015).

The importance of addressing climate-related human mobility has further been recognized in a range of legal and policy frameworks (Intergovernmental Authority on Development, 2020; International Organization for Migration, 2019; United Nations Office for Disaster Risk Reduction, 2015). The Task Force on Displacement, established under the Warsaw International Mechanism for Loss and Damage, aims to develop recommendations for integrated approaches to avert and minimize internal displacement from extreme weather events and slow-onset adverse effects of climate change (Oakes et al., 2019; Task Force on Displacement, 2018).

Climate change will impact a wide range of sectors (Dasgupta et al., 2014) which in turn could have profound implications for human mobility. The most significant sectors impacting climate-related human mobility are covered by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C (SR15). While more recent IPCC reports have been released, including the Special Report

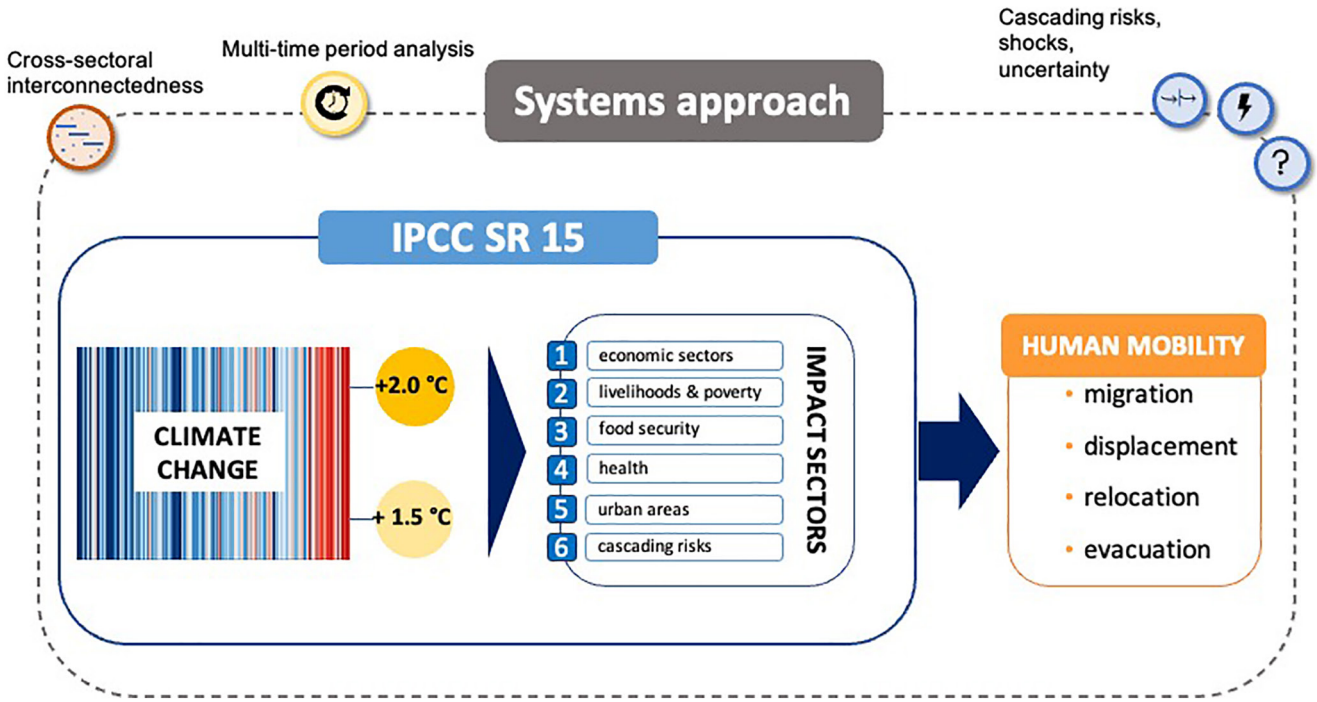

Figure 1. Schematic illustration of the interactions between climate change effects in the six climate change impact sectors and different types of human mobility in a systems approach framework.

on the Oceans and Cryosphere in a Changing Climate and the Special Report on Climate Change and Land (IPCC, 2019a, 2019b), SR15 was commissioned specifically with decision-makers and policy planners in mind. The report scientifically assesses the implications of pursuing efforts to implement the Paris Agreement by outlining sector-specific transitions and policy actions (Tokarska et al., 2019), as well as the expected societal impacts in six climate change impact sectors (Figure 1).

Human mobility in the form of migration provides a coping mechanism when facing extreme weather events and anomalous seasons (Geest & Warner, 2014; Harrington & Otto, 2018; A. D. King et al., 2018). However, without concrete climate and development action, situations of entrapment can become more prevalent globally (Adger et al., 2015; Ayeb-Karlsson et al., 2015). This is particularly relevant in regions where vulnerability and exposure are already high and even small changes in hazards amplify consequences on populations in situ (Harrington & Otto, 2018).

Here, we focus on one of the largest regions where such conditions apply. Home to over 38% of the Earth's population (Burrell et al., 2020; Huang et al., 2017), dryland communities are disproportionately affected and vulnerable to the impacts of climate change. Dryland regions are projected to experience a 3.2°C–4°C warming under a 2°C global warming scenario by 2050 (IPCC, 2018). This is particularly crucial for African dryland regions, where regional climate models further project increases in frequency and intensity of heatwaves, droughts, and floods, and adaptation is additionally hindered by high uncertainties and poor data availability (Harrington & Otto, 2020; Wartenburger et al., 2017). Therefore, we seek to answer: What is the current understanding of the implications for human mobility in African drylands under future warming?

In this study, we provide a comprehensive discussion of the impact channels through which future warming affects human mobility (climate-related human mobility). This Commentary aims to contribute to the ongoing, global effort toward a better understanding of climate-related human mobility (Boas et al., 2019) and to offer a directly usable approach for policy-makers. To this aim, we propose a systems approach to address the interconnectedness of climate impacts and cascading risks of future warming on human mobility in African drylands. Doing so, however, requires a thorough understanding of the systemic characteristics outlined in Figure 1 (ie., cascading risks, shocks, uncertainty, cross-sectoral interconnectedness, and the analysis of multiple time periods), and vulnerabilities of climate-related human mobility and the climate

system. Our systems approach recognizes dynamics and sectoral linkages (six impact sectors in Figure 1), which often-times align more closely with the realities of the complexities of climate-related human mobility. Conceptually, such an approach has been applied to a diverse range of fields such as food systems (Gaupp, 2020; Nicholson et al., 2020), but has been less used in the analysis of climate-related human mobility issues.

2. Climate-Related Human Mobility

Many weather and climate-related events have become more frequent and intense leading to widespread and disastrous impacts for populations globally (Hoegh-Guldberg et al., 2019). In extreme cases, populations have migrated away from locations frequently impacted by extreme weather events (Gray & Mueller, 2012) or are projected to move toward coastlines affected by sea-level rise (Bell et al., 2021). At the same time, human mobility decisions are often multi-causal and rarely due to extreme weather events alone. Climate change may influence human mobility both directly and indirectly through various channels ranging from economic, demographic, social, political, and environmental factors (Black et al., 2011). These factors ultimately lead to a decision between staying or going—and where to migrate to if needed. In this context, there are several climatic factors and cascading risks that can enhance and reduce human mobility, or even entrap populations (Cattaneo et al., 2019; Hoffmann et al., 2020).

In the existing literature, climate-related human mobility is often portrayed as a key impact of anthropogenic climate change (e.g., Biermann & Boas, 2008; Myers, 2002; Rigaud et al., 2018). Despite the increasing abundance of qualitative evidence (e.g., Groth et al., 2020; Wiederkehr et al., 2018) on how and where populations migrate due to the impacts of environmental change, surprisingly little research has linked such evidence to anthropogenic climate change (Borderon et al., 2019; Cattaneo et al., 2019); quantitatively or qualitatively. In East Africa, the confidence on attributable links regarding the climate change-human mobility nexus is low with evidence from climate science being in many cases underrepresented (Thalheimer et al., 2021). As the impacts of anthropogenic climate change are projected to fall disproportionately upon African countries (Harrington & Otto, 2020; Hoegh-Guldberg et al., 2019), this study focuses on climate-related human mobility in African drylands. To do so, an understanding of climate change effects, including evidence from extreme event attribution, and cascading risks in this region is needed.

In recent years, several meta-analyses have been published that study the multiple links between environmental change and human mobility nexus in Africa (e.g., Wiederkehr et al., 2018; Borderon et al., 2018). The reviewed case studies in these studies are mostly situated in Sub-Saharan African drylands. Climate change and extreme weather events play a central role in these studies and are found to drive different types of mobility, including temporary and longer-term migration over short and long distances. For example, Wiederkehr et al. (2018) find that 23% of 9,700 rural African households that were interviewed in 63 empirical studies, respond to environmental stressors with some form of migration. A review of African case studies by Borderon et al. (2019) shows how complicated it is to draw universal conclusions on the migration-environment nexus. However, based on their review, they do conclude that climate change will not generate mass migration from Africa to Europe and other continents. An important reason for this is that the people who are most affected by climate change in Africa do not have the financial resources and social networks that are needed to migrate intercontinentally. The picture is quite different for migration and displacement *within* countries, which is projected to increase sharply under more extreme climate change (Rigaud et al., 2018).

3. Mapping Climate Change Effects on African Drylands

SR15 lists projected climatic changes in a variety of climatological areas. We adopt the report's regional structure for Western, Southern, and Eastern Africa in which drylands are the predominant land zone (Cervigni & Morris, 2016), and summarize projected climatic changes (Table 1). The table updates findings from SR15 with recently published literature. The focus is on precipitation extremes and temperature extremes as they comprise the predominant natural hazards in African drylands.

Table 1
Summary of Regional Projected Climatic Changes and Their Effects in African Drylands (Including Confidence Levels)

	African drylands regions		
	Western Africa	**Southern Africa**	**Eastern Africa**
Precipitation and related extremes		**SR15**	
	Overall decrease in mean rainfall, stress in water availability (SR15, p. 197) (*medium confidence*).	Overall decrease annually, increased water stress while less water available (SR15, p. 197, 213) (*medium confidence*);	Increase in heavy precipitation events especially over Somalia and river flooding (SR15, p. 197, 201) (*low - medium confidence*);
		Increase in heavy precipitation events (*low confidence*), while region as a whole will experience precipitation decrease (SR15, p. 197, 204) (*high confidence*).	Increase in number of consecutive dry days (SR15, p. 199) (*high confidence*).
		Post-SR15	
	Observed increase in heavy precipitation events (Barry et al., 2018) which is likely to increase in frequency and intensity by 2100 (Akinsanola & Zhou, 2019; Dosio et al., 2019).	Drying is likely to increase (Dosio et al., 2019; Maúre et al., 2018), especially under Regional Climate Models (RCM) (Ahmadalipour et al., 2019) and recent droughts have been attributed to climate change (Herring et al., 2019; Nangombe et al., 2020; Otto et al., 2018).	Insufficient evidence from recent projections of rainfall over East Africa (Finney et al., 2020) to draw confident conclusions.
	Attribution studies on late onset of rain and heavy rain do not find a significant change (Gaetani et al., 2020; Lawal et al., 2019; Parker et al., 2017).		Several attribution studies suggest no significant attributable link to climate change in observed drying trends (Herring et al., 2019; Kew et al., 2019; Otto et al., 2018; Uhe et al., 2018).
Temperature and related extremes		**SR15**	
	Increase in heatwaves and number of hot nights (SR15, p. 259, 261). *Low confidence*.	Rise in extreme temperature causing more frequent heatwaves and aridity, especially at +2°C (SR15, p. 177, 178, 190, 200, 261). *High confidence*.	No findings for East Africa specified.
		Post-SR15	
	Throughout Sub-Saharan Africa: Exposure to dangerous heat projected to increase (Rohat et al., 2019).		
	Observed frequencies of warm extremes are likely to increase.	Increases in frequency of warm days and decrease in cold days.	East Africa is a hotspot of increasing trends in heatwaves (Perkins-Kirkpatrick & Lewis, 2020).
			Lack of research on compound heat and drought events (Raymond et al., 2020).

Note. We distinguish between effects listed in SR15 and new research published since.

In a warmer world, drylands are expanding globally (IPCC, 2018) while high population growth in drylands exposes more people to climate hazards (Koutroulis, 2019). Despite sparse literature, the current evidence concerning African dryland regions suggests that heat extremes will become more frequent in the region (Perkins-Kirkpatrick & Lewis, 2020; Rohat et al., 2019). For dry and wet extremes, the influence of climate change is less clear and varies across the continent, with a significant signal only in observed, attributed, and projected drying in Southern Africa, and an increase in heavy precipitation in Western Africa. In East Africa, increases in temperature have been found to be linked to anthropogenic climate change, while current rainfall deficits and subsequent droughts do not show a strong anthropogenic climate signal. Uncertainties are significant though, as is vulnerability to natural climate variability (Kew et al., 2019).

4. Climate Change Impact Sectors and Their Relation to Human Mobility in African Drylands

There is growing evidence that climate change and extremes primarily affect human mobility indirectly (Black et al., 2011; Hoffmann et al., 2020; Romankiewicz et al., 2018). With a focus on interconnectedness of climate impacts and cascading risks, this section consolidates and expands on the evidence provided in SR15 with relevant implications for human mobility in African drylands.

We find that the effects from interacting and cascading risks could imperil migration as an adaptation or coping mechanism across the region. Cascading risks are spatially compounding risks that involve multiple interacting hazards in the same location. Cascading risks lead to increased exposure (Piontek et al., 2014). The amount of people exposed to cascading risks is projected to double from 1.5°C to 2°C warmer world, with almost the entire global population affected either directly or indirectly under a 3°C warming scenario; the exposure in African regions to cascading risks is amongst the highest (IPCC, 2018). Poor communities affected by drought and water stress, as well as political instability and growing conflicts, could find themselves forced to move as a response to climate thresholds (Tol, 2018; Xu et al., 2020). Cascading risks are a cross-cutting theme and particularly impactful on people living in poverty (IPCC, 2018), highlighting the urgent need for a systems approach as a bridging framework.

Accessibility, trade, and distribution of food crops and livestock form an interconnected variable between human mobility and climate change (Adams & Adger, 2013; Afifi et al., 2016). Drylands have already experienced lower agricultural productivity and recurring weather shocks (van der Geest & Warner, 2014; Stavi et al., 2021). Even a warming of +1.5°C accelerates adverse risks of reduced water and food availability (Betts et al., 2018; Cheung et al., 2016). Constraining warming levels to 1.5°C can substantially minimize risks in crop yield losses in West Africa (Schleussner et al., 2016). Dryland areas, where rainfall levels are already increasingly uncertain, are projected to become less suitable for agricultural production (Läderach et al., 2013; Sultan & Gaetani, 2016; Zommers et al., 2016).

Further, food insecurity is projected to disproportionately affect poor populations in African drylands (Byers et al., 2018; Puma et al., 2018; Thalheimer et al., 2019). Related increases in local, regional, and global food prices could put an additional 122 million people in extreme poverty by 2030 (Guldberg et al., 2018). Climate change could adversely impact the livelihood security of seasonal migrants and pastoralists (Fanzo et al., 2018; Rademacher-Schulz et al., 2014). In regions with increased risk of water stress, pastoralists and their livestock will have to alter mobility patterns in the search for water and livestock fodder (Boone et al., 2018).

According to the Lancet Countdown on Health and Climate Change, current warming has already resulted in "profound, immediate, and rapidly worsening health effects" (Watts et al., 2021). Climate change is likely to impact workers' health conditions and their ability to perform labor-intensive work outdoors. Climate change has already increased the exposure and vulnerability to climate-related stress and related health issues (Haines & Ebi, 2019). Heatwaves in particular have shown adverse effects on occupational health (Rey et al., 2007). Among vulnerable populations, climate change can reduce food security and labor productivity, which has adverse health outcomes, while the functioning of healthcare systems may be reduced in the event of weather extremes. Taken together, heatwaves and long-term climate change can limit the physical work capacity, leading to diminished agricultural productivity and causing undernutrition in drylands. Droughts contribute to biodiversity loss and ecosystem collapse, increasing the likelihood and occurrence of vector-borne diseases (Watts et al., 2017). A half-degree temperature increase to 2°C adversely impacts health conditions globally (Haines & Ebi, 2019). SR15 states with very high confidence that heat-related mortality and morbidity will be higher under 2°C than under 1.5°C.

While there is some evidence of climate-related health impacts influencing human mobility decisions, the extent to which out-migration will increase remains uncertain and needs further empirical research (McMichael, 2020; Schwerdtle et al., 2018). Initially, negative impacts on human health may decrease the likelihood of migration due to reduced personal capacity for relocation. However, studies have demonstrated migrants willing to move into sites with increased exposure to natural hazards and potentially cascading risks for their health (McMichael, 2020) during stages of the migration journey (Schwerdtle et al., 2018, 2019). The combination of various vector-borne diseases, especially malaria, and climate-induced socio-economic

disruption is projected to have significant regional impacts such as increased outward migration (Piontek et al., 2014) to areas with less exposure to extreme weather events. Systemic shocks like the COVID-19 pandemic show that access to health care is limited during relocation processes which may undermine global health goals (Schwerdtle et al., 2019).

With an increasing number of people from rural dryland areas pursuing urban migration in the search for alternative occupation, there is a higher vulnerability to heatwaves and poor urban air quality exacerbated by climate change. Even under a 1.5°C of warming, the incidence of heatwaves is projected to increase, doubling the number of megacities affected by heat stress and exacerbating urban heat island effects. Under a 2°C warming scenario, a significant rise in heat stress-related mortality is projected, particularly for low-income countries in sub-Saharan Africa. Given the lack of reporting on current heat impacts, this provides particular challenges to adaptation (Harrington & Otto, 2020). Climate projections further indicate a decrease in the number of consecutive wet days, and an increase in consecutive dry days for sub-Saharan Africa. Despite large uncertainties in projections (J. King et al., 2020), if the amount of annual precipitation is to stay constant, it will increase the intensity of hydrological extremes in the form of floods, droughts, and water scarcity (IPCC, 2018).

In some cases, climate-related migration can lead to further risk accumulation in urban areas (Ayeb-Karlsson, 2020; Wilkinson, 2016). Increased rural-urban migration accelerates rapid urbanization, which is compounded by the inability of already overstretched cities and municipalities to provide affordable and safe housing (Williams et al., 2019). The resulting number of people residing in environmentally precarious areas rises, meaning they experience higher exposure to natural hazards. Most arriving migrants lack financial resources to relocate to areas with a significant level of access to basic services and less exposure to hazards (Adams & Kay, 2019; Williams et al., 2019). They are thus trapped in environmentally precarious areas in which the climatic risks under future warming scenarios are significantly more precarious (Adger et al., 2015; IPCC, 2018).

Despite limited research on the effects of a current and near-term warming, variabilities in rainfall and temperature extremes are associated with higher levels of internal migration in agriculture-dependent communities (Cai et al., 2016; Rigaud et al., 2018) highlighting wider economic implications for affected populations. In poorly endowed communities, climate change impacts can further amplify conflict over scarce resources (Serdeczny et al., 2017). In some cases, a warming up to 1.5°C (expected by 2030s, independent of scenarios) already significantly increases the risk of inter-group conflicts, which in turn can generate reinforced involuntary mobility (Hsiang et al., 2013).

We deduce that climate change effects adversely impact African dryland communities and are likely to alter human mobility in different ways. In some cases, climate change can lead to more population displacement, whereas in other cases it can lead to less human mobility for instance when people become trapped. Overall, climate change can shift more voluntary human mobility to more forced flows. There is consistent evidence on the relationship between climate change impacts on economic development and human mobility through economic losses in agriculture and food insecurity from droughts (Nawrotzki & Bakhtsiyarava, 2017), changes in temperature (Gray & Wise, 2016), and precipitation (Mastrorillo et al., 2016). Cascading risks and compound events interlink all sectors and therefore indicate the biggest impact on human mobility under future warming. In East Africa, the ongoing locust spread and survival due to climatic stresses and socio-economic activities is yet another example that shows the importance of such cascading risks (Salih et al., 2020).

5. Systems Approaches to Advance the Current Evidence

In this paper, we highlighted that climate change impacts on African drylands mobility are not just a result of potential disruptions of a single impact sector, rather showcasing shocks to multiple sectors, cascading or even compounding risks. Given the increasing relevance of cascading risks from connected and compound events (Raymond et al., 2020), it thus seems reasonable to propose a systems approach as a starting point to address future warming impacts on human mobility in research and policy.

A first option to effectively respond to sectoral climate change impacts is to take a system-wide approach (Ratter, 2013), which requires decision-makers, policy planners, and various sectors to undertake a coordinated and concerted effort. The advantage of this method is that a holistic understanding of the interface between climate change and human mobility can be gained. Resulting interlinked concepts, dynamic relationships, and feedback behavior can be useful for enhancing cooperation and guidance, and for identifying resilience-enhancing pathways. However, a systems approach deems a form of cooperation that is currently constrained by a lack of cross-sectoral integration and political instrumentalization prevalent across regions affected by climate change (Williams et al., 2019). Further limitations lie in the governance context; in much of dryland Africa, fragile states are prevalent and have high poverty levels. Conversely, a systems approach could also be a bridging framework to address interlinked challenges.

Clearly, it is crucial to investigate and derive policy conclusions holistically, beginning with the interconnectedness of climate change, impact sectors, and human mobility. Climate change policies are likely to have significant impacts in economic, environmental, and social domains and on a wide range of stakeholders (Tol, 2018). It is therefore essential to take potential and unintended side-effects of the policy on other sectors into account. To exemplify, the livestock sector plays an important role across African drylands but global challenges make it difficult to navigate related policies and leverage positive impacts on the 17 sustainable development goals (Mehrabi et al., 2020). We have highlighted the importance of accounting for cascading risks, shocks, and uncertainties. Various policy alternatives and their trade-offs have to be accounted for. Cascading risks, and ways to deal with them, as well as risk criteria, have to be included from a systems dependency perspective. This is crucial for managing, analyzing, and governing those sectors that have global links such as food security (Gaupp, 2020). Management of risk also entails to capture uncertainty in the strength or in the direction of cross-sectoral interconnectedness. Short, medium, and long-term impacts of a policy need to be defined, for example, a trade-off between various types of proactive long-term (ex-ante) measures and reactive short term (ex-post) measures. Uncertain futures of climate change, including the possible occurrence of extreme weather events affecting human mobility versus life-spans of adaptation measures, have to be taken into consideration.

6. Outlook

We find ourselves at a crossroads. More research is needed on all aspects of the interface between human mobility and climate change, and the cascading risks associated with it. Evidence on the link between climate change and current extreme weather and slow-onset events as well as research on near-term changes at 1.5°C and 2°C warmings could provide ground-truthing of the above-described findings and be transformative in understanding human mobility if enhanced by a deeper understanding of the cross-sectoral interconnectedness of climate impacts that drive human mobility. From a research perspective, this requires global collaboration and truly transdisciplinary approaches that can inform policy aimed at preventing forced migration and facilitating safe and dignified human mobility in a changing climate.

Data Availability Statement

No additional data were used as part of this study.

Acknowledgments
The authors would like to acknowledge that the collaboration necessary for this study was funded by the EU COST Action "Drylands facing change: interdisciplinary research on climate change, food insecurity, and political instability" (Number CA16233). Funding was also provided by the Robertson Foundation (Grant no. 9907422). The authors further acknowledge the comments of two reviewers that helped to improve this commentary.

References

Adams, H., & Adger, W. N. (2013). The contribution of ecosystem services to place utility as a determinant of migration decision-making. *Environmental Research Letters*, *8*(1), 015006. https://doi.org/10.1088/1748-9326/8/1/015006

Adams, H., & Kay, S. (2019). Migration as a human affair: Integrating individual stress thresholds into quantitative models of climate migration. *Environmental Science & Policy*, *93*, 129–138. https://doi.org/10.1016/j.envsci.2018.10.015

Adger, W. N., Arnell, N. W., Black, R., Dercon, S., Geddes, A., & Thomas, D. S. G. (2015). Focus on environmental risks and migration: Causes and consequences. *Environmental Research Letters*, *10*(6), 060201. https://doi.org/10.1088/1748-9326/10/6/060201

Afifi, T., Milan, A., Etzold, B., Schraven, B., Rademacher-Schulz, C., Sakdapolrak, P., et al. (2016). Human mobility in response to rainfall variability: Opportunities for migration as a successful adaptation strategy in eight case studies. *Migration and Development*, *5*(2), 254–274. https://doi.org/10.1080/21632324.2015.1022974

Ahmadalipour, A., Moradkhani, H., Castelletti, A., & Magliocca, N. (2019). Future drought risk in Africa: Integrating vulnerability, climate change, and population growth. *The Science of the Total Environment*, *662*, 672–686. https://doi.org/10.1016/j.scitotenv.2019.01.278

Akinsanola, A. A., & Zhou, W. (2019). Ensemble-based CMIP5 simulations of West African summer monsoon rainfall: Current climate and future changes. *Theoretical and Applied Climatology*, *136*(3), 1021–1031. https://doi.org/10.1007/s00704-018-2516-3

Ayeb-Karlsson, S. (2020). "When we were children we had dreams, then we came to Dhaka to survive": Urban stories connecting loss of wellbeing, displacement and (im) mobility. *Climate and Development*, *13*, 1–359. https://doi.org/10.1080/17565529.2020.1777078

Ayeb-Karlsson, S., Tanner, T., van der Geest, K., Warner, K., Adams, H., Ahmedi, I., et al. (2015). *Livelihood resilience in a changing world—6 global policy recommendations for a more sustainable future*. Retrieved from https://collections.unu.edu/view/UNU:3339

Barry, A. A., Caesar, J., Tank, A. M. G. K., Aguilar, E., McSweeney, C., Cyrille, A. M., et al. (2018). West Africa climate extremes and climate change indices. *International Journal of Climatology*, *38*(S1), e921–e938. https://doi.org/10.1002/joc.5420

Bell, A. R., Wrathall, D. J., Mueller, V., Chen, J., Oppenheimer, M., Hauer, M., et al. (2021). Migration towards Bangladesh coastlines projected to increase with sea-level rise through 2100. *Environmental Research Letters*, *16*(2), 024045. https://doi.org/10.1088/1748-9326/abdc5b

Betts, R. A., Alfieri, L., Bradshaw, C., Caesar, J., Feyen, L., Friedlingstein, P., et al. (2018). Changes in climate extremes, fresh water availability and vulnerability to food insecurity projected at 1.5°C and 2°C global warming with a higher-resolution global climate model. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2119), 20160452. https://doi.org/10.1098/rsta.2016.0452

Biermann, F., & Boas, I. (2008). Protecting climate refugees. *The Case for a Global Protocol*, *50*(6), 11.

Black, R., Adger, W. N., Arnell, N. W., Dercon, S., Geddes, A., & Thomas, D. (2011). The effect of environmental change on human migration. *Global Environmental Change*, *21*, S3–S11. https://doi.org/10.1016/j.gloenvcha.2011.10.001

Boas, I., Farbotko, C., Adams, H., Sterly, H., Bush, S., van der Geest, K., et al. (2019). Climate migration myths. *Nature Climate Change*, *9*(12), 901–903. https://doi.org/10.1038/s41558-019-0633-3

Boone, R. B., Conant, R. T., Sircely, J., Thornton, P. K., & Herrero, M. (2018). Climate change impacts on selected global rangeland ecosystem services. *Global Change Biology*, *24*(3), 1382–1393. https://doi.org/10.1111/gcb.13995

Borderon, M., Sakdapolrak, P., Muttarak, R., Kebede, E., Pagogna, R., & Sporer, E. (2019). Migration influenced by environmental change in Africa: A systematic review of empirical evidence. *Demographic Research*, *41*, 491–544. https://doi.org/10.2307/26850658

Burrell, A. L., Evans, J. P., & De Kauwe, M. G. (2020). Anthropogenic climate change has driven over 5 million km^2 of drylands towards desertification. *Nature Communications*, *11*(1), 3853. https://doi.org/10.1038/s41467-020-17710-7

Byers, E., Gidden, M., Leclère, D., Balkovic, J., Burek, P., Ebi, K., et al. (2018). Global exposure and vulnerability to multi-sector development and climate change hotspots. *Environmental Research Letters*, *13*(5), 055012. https://doi.org/10.1088/1748-9326/aabf45

Cai, R., Feng, S., Oppenheimer, M., & Pytlikova, M. (2016). Climate variability and international migration: The importance of the agricultural linkage. *Journal of Environmental Economics and Management*, *79*, 135–151. https://doi.org/10.1016/j.jeem.2016.06.005

Cattaneo, C., Beine, M., Fröhlich, C. J., Kniveton, D., Martinez-Zarzoso, I., Mastrorillo, M., et al. (2019). Human migration in the era of climate change. *Review of Environmental Economics and Policy*, *13*(2), 189–206. https://doi.org/10.1093/reep/rez008

Cervigni, R., & Morris, M. (2016). *Confronting drought in Africa's drylands: Opportunities for enhancing resilience*. The World Bank. https://doi.org/10.1596/978-1-4648-0817-3

Cheung, W. W. L., Reygondeau, G., & Frölicher, T. L. (2016). Large benefits to marine fisheries of meeting the 1.5°C global warming target. *Science*, *354*(6319), 1591–1594. https://doi.org/10.1126/science.aag2331

Dasgupta, P., Morton, J., Dodman, D., Karapinar, B., Meza, F., Rivera-Ferre, M. G., et al. (2014). Rural areas. In C. Field, & V. Barros (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability* (Vol. A, pp. 613–657). Cambridge University Press. Retrieved from https://gala.gre.ac.uk/id/eprint/14369/

Dosio, A., Jones, R. G., Jack, C., Lennard, C., Nikulin, G., & Hewitson, B. (2019). What can we know about future precipitation in Africa? Robustness, significance and added value of projections from a large ensemble of regional climate models. *Climate Dynamics*, *53*(9), 5833–5858. https://doi.org/10.1007/s00382-019-04900-3

Fanzo, J., Davis, C., McLaren, R., & Choufani, J. (2018). The effect of climate change across food systems: Implications for nutrition outcomes. *Global Food Security*, *18*, 12–19. https://doi.org/10.1016/j.gfs.2018.06.001

Finney, D. L., Marsham, J. H., Rowell, D. P., Kendon, E. J., Tucker, S. O., Stratton, R. A., & Jackson, L. S. (2020). Effects of explicit convection on future projections of mesoscale circulations, rainfall, and rainfall extremes over Eastern Africa. *Journal of Climate*, *33*(7), 2701–2718. https://doi.org/10.1175/JCLI-D-19-0328.1

Gaetani, M., Janicot, S., Vrac, M., Famien, A. M., & Sultan, B. (2020). Robust assessment of the time of emergence of precipitation change in West Africa. *Scientific Reports*, *10*(1), 7670. https://doi.org/10.1038/s41598-020-63782-2

Gaupp, F. (2020). Extreme events in a globalized food system. *One Earth*, *2*(6), 518–521. https://doi.org/10.1016/j.oneear.2020.06.001

Gray, C., & Mueller, V. (2012). Drought and population mobility in rural Ethiopia. *World Development*, *40*(1), 134–145. https://doi.org/10.1016/j.worlddev.2011.05.023

Gray, C., & Wise, E. (2016). Country-specific effects of climate variability on human migration. *Climatic Change*, *135*(3), 555–568. https://doi.org/10.1007/s10584-015-1592-y

Groth, J., Ide, T., Sakdapolrak, P., Kassa, E., & Hermans, K. (2020). Deciphering interwoven drivers of environment-related migration—A multisite case study from the Ethiopian highlands. *Global Environmental Change*, *63*, 102094. https://doi.org/10.1016/j.gloenvcha.2020.102094

Guldberg, O. H., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., & Zougmore, R. (2018). Chapter 3: Impacts of 1.5°C Global Warming on Natural and Human Systems. Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change.

Haines, A., & Ebi, K. (2019). The imperative for climate action to protect health. *New England Journal of Medicine*, *380*(3). https://doi.org/10.1056/nejmra1807873

Harrington, L. J., & Otto, F. E. L. (2018). Changing population dynamics and uneven temperature emergence combine to exacerbate regional exposure to heat extremes under 1.5°C and 2°C of warming. *Environmental Research Letters*, *13*(3), 034011. https://doi.org/10.1088/1748-9326/aaaa99

Harrington, L. J., & Otto, F. E. L. (2020). Reconciling theory with the reality of African heatwaves. *Nature Climate Change*, *10*(9), 796–798. https://doi.org/10.1038/s41558-020-0851-8

Herring, S. C., Christidis, N., Hoell, A., Hoerling, M. P., & Stott, P. A. (2019). *Explaining extreme events of 2017 form a climate perspective* (Vol. 11).

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bolaños, T. G., Bindi, M., Brown, S., et al. (2019). The human imperative of stabilizing global climate change at 1.5°C. *Science*, *365*(6459), eaaw6974. https://doi.org/10.1126/science.aaw6974

Hoffmann, R., Dimitrova, A., Muttarak, R., Crespo Cuaresma, J., & Peisker, J. (2020). A meta-analysis of country-level studies on environmental change and migration. *Nature Climate Change*, *10*, 904, 912. https://doi.org/10.1038/s41558-020-0898-6

Hsiang, S. M., Burke, M., & Miguel, E. (2013). Quantifying the influence of climate on human conflict. *Science*, *341*(6151), 1235367. https://doi.org/10.1126/science.1235367

Huang, J., Yu, H., Dai, A., Wei, Y., & Kang, L. (2017). Drylands face potential threat under 2°C global warming target. *Nature Climate Change*, *7*(6), 417–422. https://doi.org/10.1038/nclimate3275

Intergovernmental Authority on Development. (2020). *Protocol on free movement of persons*. Retrieved from https://disasterdisplacement.org/wp-content/uploads/2020/03/Communique-on-Endorsement-of-the-Protocol-of-Free-Movement-of-Persons.pdf

International Organization for Migration. (2019). *Global compact for migration*. International Organization for Migration. Retrieved from https://www.iom.int/global-compact-migration

IPCC. (2018). *Global warming of 1.5°C*. World Meteorological Organization. Retrieved from https://www.ipcc.ch/sr15/

IPCC. (2019a). *Special report on the ocean and cryosphere in a changing climate—Summary for policymakers*. Retrieved from https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/03_SROCC_SPM_FINAL.pdf

IPCC. (2019b). *Special report on climate change and land*. Retrieved from https://www.ipcc.ch/srccl/

Kew, S. F., Philip, S. Y., Hauser, M., Hobbins, M., Wanders, N., van Oldenborgh, G. J., et al. (2019). Impact of precipitation and increasing temperatures on drought in eastern Africa. *Earth System Dynamics Discussions*, 1–29. https://doi.org/10.5194/esd-2019-20

King, A. D., Donat, M. G., Lewis, S. C., Henley, B. J., Mitchell, D. M., Stott, P. A., et al. (2018). Reduced heat exposure by limiting global warming to 1.5°C. *Nature Climate Change*, *8*(7), 549–551. https://doi.org/10.1038/s41558-018-0191-0

King, J., Washington, R., & Engelstaedter, S. (2020). Representation of the Indian Ocean Walker circulation in climate models and links to Kenyan rainfall. *International Journal of Climatology*, *41*(S1). https://doi.org/10.1002/joc.6714

Koutroulis, A. G. (2019). Dryland changes under different levels of global warming. *The Science of the Total Environment*, *655*, 482–511. https://doi.org/10.1016/j.scitotenv.2018.11.215

Läderach, P., Martinez-Valle, A., Schroth, G., & Castro, N. (2013). Predicting the future climatic suitability for cocoa farming of the world's leading producer countries, Ghana and Côte d'Ivoire. *Climatic Change*, *119*(3), 841–854. https://doi.org/10.1007/s10584-013-0774-8

Lawal, K. A., Abiodun, B. J., Stone, D. A., Olaniyan, E., & Wehner, M. F. (2019). Capability of CAM5.1 in simulating maximum air temperature patterns over West Africa during boreal spring. *Modeling Earth Systems and Environment*, *5*(4), 1815–1838. https://doi.org/10.1007/s40808-019-00639-2

Mastrorillo, M., Licker, R., Bohra-Mishra, P., Fagiolo, G., Estes, D. L., & Oppenheimer, M. (2016). The influence of climate variability on internal migration flows in South Africa. *Global Environmental Change*, *39*, 155–169. https://doi.org/10.1016/j.gloenvcha.2016.04.014

Maúre, G., Pinto, I., Ndebele-Murisa, M., Muthige, M., Lennard, C., Nikulin, G., et al. (2018). The southern African climate under 1.5°C and 2°C of global warming as simulated by CORDEX regional climate models. *Environmental Research Letters*, *13*(6), 065002. https://doi.org/10.1088/1748-9326/aab190

McMichael, C. (2020). Human mobility, climate change, and health: Unpacking the connections. *The Lancet Planetary Health*, *4*(6), e217–e218. https://doi.org/10.1016/S2542-5196(20)30125-X

Mehrabi, Z., Gill, M., van Wijk, M., Herrero, M., & Ramankutty, N. (2020). Livestock policy for sustainable development. *Nature Food*, *1*(3), 160–165. https://doi.org/10.1038/s43016-020-0042-9

Myers, N. (2002). Environmental refugees: A growing phenomenon of the 21st century. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *357*(1420), 609–613. https://doi.org/10.1098/rstb.2001.0953

Nangombe, S., Zhou, T., Zhang, L., & Zhang, W. (2020). Attribution of the 2018 October–December drought over South Southern Africa. *Bulletin of the American Meteorological Society*, *101*(1), S135–S140. https://doi.org/10.1175/BAMS-D-19-0179.1

Nawrotzki, R. J., & Bakhtsiyarava, M. (2017). International climate migration: Evidence for the climate inhibitor mechanism and the agricultural pathway. *Population, Space and Place*, *23*(4), e2033. https://doi.org/10.1002/psp.2033

Nicholson, C. F., Kopainsky, B., Stephens, E. C., Parsons, D., Jones, A. D., Garrett, J., & Phillips, E. L. (2020). Conceptual frameworks linking agriculture and food security. *Nature Food*, *1*(9), 541–551. https://doi.org/10.1038/s43016-020-00142-3

Oakes, R., Banerjee, S., & Warner, K. (2019). *Human mobility and adaptation to environmental change* (pp. 253–269). International Organization for Migration. https://doi.org/10.18356/2a8d511f-en

Otto, F. E. L., Philip, S., Kew, S., Li, S., King, A., & Cullen, H. (2018). Attributing high-impact extreme events across timescales—A case study of four different types of events. *Climatic Change*, *149*(3), 399–412. https://doi.org/10.1007/s10584-018-2258-3

Parker, H. R., Lott, F. C., Cornforth, R. J., Mitchell, D. M., Sparrow, S., & Wallom, D. (2017). A comparison of model ensembles for attributing 2012 West African rainfall. *Environmental Research Letters*, *12*(1), 014019. https://doi.org/10.1088/1748-9326/aa5386

Perkins-Kirkpatrick, S. E., & Lewis, S. C. (2020). Increasing trends in regional heatwaves. *Nature Communications*, *11*(1), 3357. https://doi.org/10.1038/s41467-020-16970-7

Piontek, F., Müller, C., Pugh, T. A. M., Clark, D. B., Deryng, D., Elliott, J., et al. (2014). Multisectoral climate impact hotspots in a warming world. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(9), 3233–3238. https://doi.org/10.1073/pnas.1222471110

Puma, M. J., Chon, S. Y., Kakinuma, K., Kummu, M., Muttarak, R., Seager, R., & Wada, Y. (2018). A developing food crisis and potential refugee movements. *Nature Sustainability*, *1*(8), 380–382. https://doi.org/10.1038/s41893-018-0123-z

Rademacher-Schulz, C., Schraven, B., & Mahama, E. S. (2014). Time matters: Shifting seasonal migration in Northern Ghana in response to rainfall variability and food insecurity. *Climate and Development*, *6*(1), 46–52. https://doi.org/10.1080/17565529.2013.830955

Ratter, B. M. W. (2013). Surprise and uncertainty—Framing regional geohazards in the theory of complexity. *Humanities*, *2*(1), 1–19. https://doi.org/10.3390/h2010001

Raymond, C., Horton, R. M., Zscheischler, J., Martius, O., AghaKouchak, A., Balch, J., et al. (2020). Understanding and managing connected extreme events. *Nature Climate Change*, *10*, 611, 621. https://doi.org/10.1038/s41558-020-0790-4

Rey, G., Jougla, E., Fouillet, A., Pavillon, G., Bessemoulin, P., Frayssinet, P., et al. (2007). The impact of major heat waves on all-cause and cause-specific mortality in France from 1971 to 2003. *International Archives of Occupational and Environmental Health*, *80*(7), 615–626. https://doi.org/10.1007/s00420-007-0173-4

Rigaud, K. K., De Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., et al. (2018). *Groundswell: Preparing for internal climate migration*. World Bank.

Rohat, G., Flacke, J., Dosio, A., Dao, H., & van Maarseveen, M. (2019). Projections of human exposure to dangerous heat in African cities under multiple socioeconomic and climate scenarios. *Earth's Future*, *7*(5), 528–546. https://doi.org/10.1029/2018EF001020

Romankiewicz, C., van der Land, V., & van der Geest, K. (2018). Environmental change and migration: A review of West African case studies. In R. McLeman, & F. Gemenne (Eds.), *The Routledge handbook of environmental displacement and migration*. Routledge. Retrieved from https://eref.uni-bayreuth.de/37443/

Salih, A. A. M., Baraibar, M., Mwangi, K. K., & Artan, G. (2020). Climate change and locust outbreak in East Africa. *Nature Climate Change*, *10*(7), 584–585. https://doi.org/10.1038/s41558-020-0835-8

Schleussner, C.-F., Lissner, T. K., Fischer, E. M., Wohland, J., Perrette, M., Golly, A., et al. (2016). Differential climate impacts for policy-relevant limits to global warming: The case of 1.5°C and 2°C. *Earth System Dynamics*, *7*(2), 327–351. https://doi.org/10.5194/esd-7-327-2016

Schwerdtle, P., Bowen, K., & McMichael, C. (2018). The health impacts of climate-related migration. *BMC Medicine*, *16*(1), 1. https://doi.org/10.1186/s12916-017-0981-7

Schwerdtle, P., Bowen, K., McMichael, C., & Sauerborn, R. (2019). Human mobility and health in a warming world. *Journal of Travel Medicine*, *26*(1). https://doi.org/10.1093/jtm/tay160

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., et al. (2017). Climate change impacts in Sub-Saharan Africa: From physical changes to their social repercussions. *Regional Environmental Change*, *17*(6), 1585–1600. https://doi.org/10.1007/s10113-015-0910-2

Stavi, I., Roque de Pinho, J., Paschalidou, A. K., Adamo, S. B., Galvin, K., de Sherbinin, A., et al. (2021). Food security among dryland pastoralists and agropastoralists: The climate, land-use change, and population dynamics nexus. *The Anthropocene Review*. https://doi.org/10.1177/20530196211007512

Sultan, B., & Gaetani, M. (2016). Agriculture in West Africa in the twenty-first century: Climate change and impacts scenarios, and potential for adaptation. *Frontiers in Plant Science*, *7*. https://doi.org/10.3389/fpls.2016.01262

Task Force on Displacement. (2018). *Report of the task force on displacement*. Retrieved from https://environmentalmigration.iom.int/sites/default/files/2018_TFD_report_16_Sep_FINAL-unedited.pdf

Thalheimer, L., Ficko, A., Roque de Pinho, J., Hashimshony-Yaffe, N., Paschalidou, A., Savic, D., et al. (2019). *Policy brief: Food security in drylands under a changing climate*. Retrieved from https://collections.unu.edu/view/UNU:7469

Thalheimer, L., Otto, F., & Abele, S. (2021). Deciphering impacts and human responses to a changing climate in East Africa. *Frontiers in Climate*, https://doi.org/10.3389/fclim.2021.692114

Tokarska, K. B., Schleussner, C.-F., Rogelj, J., Stolpe, M. B., Matthews, H. D., Pfleiderer, P., & Gillett, N. P. (2019). Recommended temperature metrics for carbon budget estimates, model evaluation and climate policy. *Nature Geoscience*, *12*(12), 964–971. https://doi.org/10.1038/s41561-019-0493-5

Tol, R. S. J. (2018). The economic impacts of climate change. *Review of Environmental Economics and Policy*, *12*(1), 4–25. https://doi.org/10.1093/reep/rex027

Uhe, P., Philip, S., Kew, S. F., Shah, K., Kimutai, J., Mwangi, E., et al. (2018). Attributing drivers of the 2016 Kenyan drought. *International Journal of Climatology*, *38*(S1), e554–e568. https://doi.org/10.1002/joc.5389

UNFCCC. (2015). *Adoption of the Paris agreement*. Retrieved from https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

United Nations Office for Disaster Risk Reduction. (2015). *Sendai framework for disaster risk reduction 2015–2030*. Retrieved from https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

van der Geest, K., & Warner, K. (2014). Loss and damage from droughts and floods in rural Africa. In A. Akinyoade, W. Klaver, S. Soeters, & D. Foeken (Eds.), *Digging deeper: Inside Africa's agricultural, food and nutrition dynamics* (pp. 276–293). Brill. https://doi.org/10.1163/9789004282698_014

Wartenburger, R., Hirschi, M., Donat, M. G., Greve, P., Pitman, A. J., & Seneviratne, S. I. (2017). Changes in regional climate extremes as a function of global mean temperature: An interactive plotting framework. *Geoscientific Model Development*, *10*(9), 3609–3634. https://doi.org/10.5194/gmd-10-3609-2017

Watts, N., Adger, W. N., Ayeb-Karlsson, S., Bai, Y., Byass, P., Campbell-Lendrum, D., et al. (2017). The Lancet Countdown: Tracking progress on health and climate change. *The Lancet*, *389*(10074), 1151–1164. https://doi.org/10.1016/S0140-6736(16)32124-9

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Beagley, J., Belesova, K., et al. (2021). The 2020 report of The Lancet Countdown on health and climate change: Responding to converging crises. *The Lancet*, *397*(10269), 129–170. https://doi.org/10.1016/S0140-6736(20)32290-X

Wiederkehr, C., Beckmann, M., & Hermans, K. (2018). Environmental change, adaptation strategies and the relevance of migration in Sub-Saharan drylands. *Environmental Research Letters*, *13*(11), 113003. https://doi.org/10.1088/1748-9326/aae6de

Wilkinson, E. (2016). *Climate change, migration and the 2030 agenda for sustainable development*.

Williams, D. S., Máñez Costa, M., Sutherland, C., Celliers, L., & Scheffran, J. (2019). Vulnerability of informal settlements in the context of rapid urbanization and climate change. *Environment and Urbanization*, *31*(1), 157–176. https://doi.org/10.1177/0956247818819694

Xu, C., Kohler, T. A., Lenton, T. M., Svenning, J.-C., & Scheffer, M. (2020). Future of the human climate niche. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(21), 11350–11355. https://doi.org/10.1073/pnas.1910114117

Zommers, Z., van der Geest, K., De Sherbinin, A., Kienberger, S., Roberts, E., Harootunian, G., et al. (2016). *Loss and damage: The role of ecosystem services*. United Nations Environment Programme. Retrieved from https://collections.unu.edu/view/UNU:5614