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Flood and Drought Displacement risk in Ethiopia, Somalia and Sudan

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Research paper

The HABITABLE project – Linking Climate Change, Habitability and Social Tipping Points: Scenarios for Climate Migration – aims at significantly advance our understanding of the current interlinkages between climate change impacts and migration and displacement patterns, and to better anticipate their future evolution.

Running for 4 years (2020-2024), HABITABLE brings together 21 partners: University of Liège, University of Vienna, Potsdam Institute for Climate Impact Research, University of Exeter, the IDMC, Lund University, Sapienza Università di Roma, adelphi, Université de Neuchâtel, Institut de Recherche pour le Développement, Council of Scientific and Industrial Research, UNESCO, University of Ghana, CARE France, University of Twente, Université Cheikh Anta Diop, Stockholm Environment Institute Asia, Raks Thai Foundation, Addis Ababa University, Institut National de la Statistique du Mali and Samuel Hall.

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Please visit www.habitableproject.org for more information about the project.

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Flood Displacement risk in Ethiopia, Somalia and Sudan

Abstract

This report highlights that floods have led to more than 185 million internal displacements, or forced movements within one's country, globally since 2008. Africa experienced around 29 million flood-induced displacements between 2008 and 2022, ranking as the second most affected region. Focusing on the Horn of Africa, particularly Sudan, Ethiopia and Somalia, this study introduces a novel flood displacement risk model. This model, developed under Work Package 3 of the HABITABLE project, aims to provide calibrated estimations of future movements, supporting the formulation of effective policies. The methodology incorporates a unique vulnerability assessment, considering factors often omitted in standard risk models, such as direct impacts on houses and livelihoods, and indirect impacts on critical facilities and services. The assessment uses a probabilistic approach, integrating climatic, hydrological and hydraulic modelling to estimate the impacts triggering displacement.

Using the latest technologies and a novel vulnerability assessment method, the study expresses displacement risk through average annual displacement (AAD) and probable maximum displacement. The results, evaluated under current and future climate conditions with optimistic and pessimistic scenarios, indicate a potential increase in AAD of two to four times compared with current conditions, and even higher risks for pessimistic scenarios, such as a ninefold increase for Sudan.

The outputs can inform national and subnational disaster risk reduction measures, helping identify areas prone to large-scale displacements. Decision-makers can use this information for risk-informed efforts to prevent and mitigate the impacts of displacement. The report concludes with recommendations for comprehensive policies and strategies to address flood-induced displacement risks and protect affected populations.

Keywords

Displacement Risk, Riverine Flood, Probable Maximum Displacement, Average Annual Displacement, Displacement Vulnerabilities

Introduction

Every year, floods, droughts, storms, earthquakes and other natural hazards force millions of people to leave their homes, a level of displacement greater than that associated with conflict and other forms of violence. Leaving home can be the first of many further disruptions to people's lives: they may be forced to move several times once they become displaced, and it can be weeks or even months before they are able to return home. Those who do return often face unsafe conditions and the prospect of being displaced again by the next disaster.

In 2023, the Internal Displacement Monitoring Center (IDMC) detected 26.4 million of movements due to consecutive disasters. And 1 out of 3 disaster displacements were triggered by floods, surpassing storms for the second time since 2016.[1]

Under the European Commission-funded project HABITABLE, IDMC brings its unique expertise as one of the world's definitive sources of data and analysis on internal displacement. Since its establishment in 1998 as part of the Norwegian Refugee Council, IDMC has offered a rigorous, independent and trusted service to the international community. Its work informs policy and operational decisions that improve the lives of the millions of people living in internal displacement or at risk of becoming displaced in the future. The objective of this report is to advance understandings of the current interlinkages between climate impacts and displacement patterns, and better anticipate their future evolution.

Under Work Package 3 of the HABITABLE project, we support the development of models to produce empirically calibrated estimations of future human mobility for flood hazards as the effects of climate change deepen in Ethiopia, Sudan and Somalia.

IDMC began a unique probabilistic modelling exercise for global disaster displacement in 2017, assessing the likelihood of such population movements in the future. It built on a risk analysis developed by the UN Office for Disaster Risk Reduction (UNDRR), based on the consideration of a wide range of hazard scenarios, their likelihood and their potential to cause housing damage (the latter serving as a proxy for displacement).[2] The model used a state-of-the-art probabilistic approach, similar to that applied by catastrophe modellers and the insurance industry over the past few decades. At the time, it covered only the physical aspect by looking at the extent of damage and destruction that hazards of different intensities were likely to cause.

Given that people's level of vulnerability and exposure to hazards does much to determine the severity of a hazard's impacts, however, it is important to assess how these aspects may change over space and time, and to unpack the economic, social and environmental factors that affect disaster risk.

To do so, IDMC has worked closely with partners to obtain improved data on risk exposure and rethink how to assess vulnerability in the displacement risk equation. Given that "riskscapes" evolve constantly, we need to understand population and socioeconomic patterns, and fluctuations in the frequency and intensity of hazards linked to climate change.

This report presents the future riverine flood displacement risk assessment at the national and subnational level for three countries in the Horn of Africa, through the application of a new methodology first applied in two small island developing states, Fiji and Vanuatu in the Pacific.[3] It provides a more comprehensive assessment of vulnerability in terms of disaster displacement risk, introducing socioeconomic drivers' key factors for displacement risk assessment.

It reveals the magnitude of displacement risk, and by comparing present climate conditions with various future scenarios, it shows how they are likely to differ. Like many countries in Africa, exposure to flood hazards in Ethiopia, Somalia and Sudan is driven by the growing concentration of people and assets in flood-prone areas.

For Work Package 3 of the HABITABLE project, we collaborated with the International Center for Environmental Monitoring (CIMA Research Foundation) on assessing flood displacement risk under two different climate scenarios (optimistic and pessimistic) in the medium and long term in Ethiopia, Somalia and Sudan.

UNICEF Ethiopia/2021/ Nahom Tesfaye
Nechye Aygaliye (45), a mother of 7 was among those displaced. She and her family were forced to leave their Chugar village and moved to Delerele where they were settled into a camp for the displaced, along with 12,000 other people, like her, displaced by the floods from villages dotted along the river and lake. Some 2,000 under-five children live in the camp.

Methods

Displacement risk concepts

Disaster risk and vulnerability

The UN Office for Disaster Risk Reduction (UNDRR) defines a disaster risk as "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity".[4] It is important to consider the social and economic background in which disaster risks occur and understand that people do not necessarily share the same perceptions of risk or underlying risk factors.

Vulnerability is defined as the conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of individuals, communities, assets or systems to the impacts of hazards.[5] The vulnerability of humans is influenced by a variety of economic, social, cultural, environmental, institutional, political and psychological aspects that mould the lives of individuals and the world around them. Factors including income, education and healthcare access play a role in determining individuals' vulnerability levels. Depending on these elements, vulnerability levels tend to vary across a community or a population. The higher the level of vulnerability, the greater the probability of being harmed by a disaster.

This vulnerability is not static; it changes over time. It comprises various dimensions, all of which must be considered when conducting a comprehensive evaluation.

Disaster displacement risk

The term disaster displacement refers to a situation in which people are forced to flee their homes or places of habitual residence because of a disaster or to avoid the impact of an impending natural hazard. Displacements generally occur when people are exposed to a natural hazard in situations where they are too vulnerable and lack the capacity to face the hazard's impacts.[6]

Like disaster risk, disaster displacement risk is linked to the nature and magnitude of a given hazard, and to people's exposure and vulnerability. Risk analysis reveals the likelihood of future disasters triggering displacement. Evaluating vulnerability levels proves valuable in understanding why severe events do not consistently yield proportionally severe consequences for populations and regions, whereas events of lesser severity can result in profound impacts. In other words, it clarifies why two hazards of similar intensity and duration could have different consequences in terms of damage, people affected and people displaced.

Understanding the parameters that influence vulnerability is essential to inform effective policies and strategies that prevent and manage disaster displacement risk, and so reduce the number of people forced to flee.

Until now, approaches to disaster displacement risk assessment have typically calculated vulnerability levels by using likely housing rendered uninhabitable as a proxy for displacement, as demonstrated in our 2017 report.[7] This involved assuming that if a disaster renders a residence uninhabitable, its occupants will encounter displacement, even if only temporarily. This approach allows for an estimation of the potential magnitude of future displacement.

The need for a broader approach

People's vulnerability is influenced by a combination of physical and societal elements. People who live in concrete buildings are likely to be less vulnerable to some types of hazards than those living in adobe huts, but their vulnerability also depends on a range of other factors that need to be assessed. They may have different sources of livelihood, income and social conditions, including access to basic services such as health and education.

Such elements, however, are not yet included in standard risk models even though they help to determine whether people flee or not.

Consider, for example, a flood that affects 2 hectares of land. Its impact will not be the same on all farmers. A subsistence farmer who only owns 5 hectares will suffer a significant loss of livelihood, while a large-scale farmer who owns a greater amount of land will be much more able to withstand the loss. People who depend on the primary sector (agriculture and livestock), particularly if it is for subsistence, are at higher risk of being displaced when a disaster strikes.

Disaster risk models need to analyse such socioeconomic factors if they are to inform more effective policies and strategies to reduce the number of people vulnerable to disaster impacts and the number at risk of displacement. Such policies and strategies would consider the geography and specific population groups and would include not only structural interventions – those intended to mitigate disaster impacts through physical construction – but also social and economic measures.

Being able to move implies having sufficient economic, logistical and social resources to do so. People without these resources are unlikely to be unable to flee and may become trapped in the affected area. Such groups may include extremely poor people, those with disabilities or illnesses and those living in isolated parts of a country.

Using a probabilistic risk assessment

The true benefits of a probabilistic risk assessment are frequently misconstrued because it is regarded as a complex and challenging method to implement and follow, with a communication hurdle when presenting outcomes. A probabilistic disaster displacement risk profile must be seen as a diagnostic tool, because it offers insights into potential hazard occurrences and their consequences.

Such profiles cover all possible risk scenarios in a certain geographical area. Both low-frequency, high-impact events and high-frequency, low-impact events are considered. Their probability of occurrence, all elements of the risk equation (risk = hazard X exposure X vulnerability), and their variability and uncertainty ranges are all included.

Events that have rarely been recorded but might occur more often under climate projections are thus also considered. This feature is particularly useful because climate change is increasing uncertainty about future hazard patterns. To be prepared, societies need to calculate the worst possible impact. Viewed through this lens, there is no valid alternative to a probabilistic analysis to address such uncertainty in a usable, quantitative way.

Displacement risk information, expressed in average annual displacement (AAD) and probable maximum displacement (PMD), is calculated at the subnational regions and aggregated at country level, allowing for a geographic and quantitative comparison within and between countries. These analyses and comparison exercises are an important step in risk awareness processes and key to pushing for risk reduction, adaptation and management mechanisms to be put in place.

The PMD curve illustrates the probability of a specific scenario leading to an estimated number of displacements. This likelihood is usually measured in terms of return period, which is often misunderstood. A return period is the average time interval in years that separates two consecutive events equal to or exceeding the given magnitude. The most common misconception is that an event with a 100-year return period will only occur once a century, when instead it means that it has an exceedance probability of 1 in 100, so events of the same or greater intensity happen once every 100 years on average. This does not preclude the possibility of several events with a 100-year return period happening within a century, or even the rare chance of consecutive events transpiring in consecutive years. Neither does it eliminate the possibility of an entire century passing without such an event occurring.

Applying different climate scenarios

To explore the potential impact of climate change on the forthcoming frequency and intensity of extreme events, along with their associated exceedance probabilities and return periods, our evaluation considers varying timescales:

- under current climate conditions, with disaster risk assessed using observed conditions from 1979 to 2016
- under long-term projected conditions from 2061 to 2100

To capture the spread of possible climate scenarios, we compared 15 models from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b), which provides bias-corrected Coupled Model Intercomparison Project Phase 6 (CMIP6) climate scenarios for pre-industrial, historical, SSP1-RCP2.6, SSP3-RCP7.0 and SSP5-RCP8.5 conditions, in terms of temperature and precipitation rise in 2016.[8] Temperature and precipitation trends proved to be highly correlated in the models considered, so we referred only to temperature trends to define representative scenarios, from which we selected two:

- optimistic: the scenario closest to the 20th percentile, corresponding to an average temperature rise of about 1°C by 2100
- pessimistic: the scenario closest to the 80th percentile, corresponding to an average temperature rise of more than 5°C by 2100

We did not consider changes in exposure and vulnerability between current and future climate conditions, although factors such as population growth and distribution (for example, the rapid urban sprawl that shrinks natural areas available to absorb floodwater) may greatly alter the future "riskscape".

Disaster displacement risk model

Our novel approach aims to address the deficiencies in existing displacement risk models and provide a more comprehensive assessment of vulnerability to the risk associated with sudden-onset hazards. Assessing displacement risk for slow-onset events, such as drought, would require a different approach. Under the same Work Package of the HABITABLE project, we also collaborated with the International Center for Environmental Monitoring (CIMA Research Foundation) to assess drought displacement risk in Ethiopia, Somalia and Sudan.

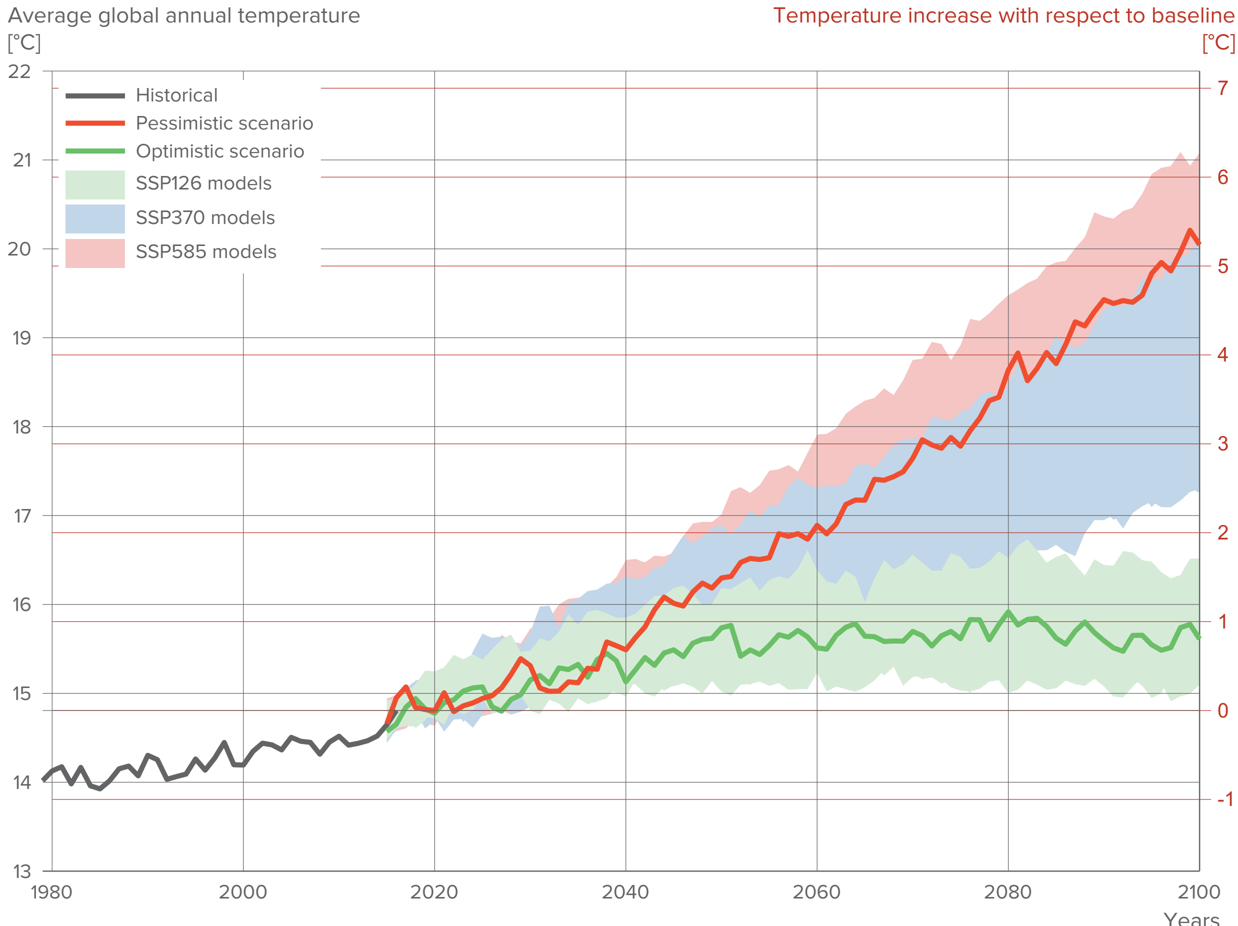


Figure 1: Model projections of future climate scenarios from ISIMIP3b.

This riverine flood displacement risk analysis aids understandings of exposure and some vulnerability dynamics.

The methodology considers different but intrinsically linked components, as follows, in assessing the impact of disasters that have already occurred.

Direct impact on houses

This component is included in conventional models for disaster displacement risk. It takes into consideration the number of homes rendered uninhabitable because of a disaster. Many models, however, treat it in a simplified way, often using a threshold on the hazard intensity parameter, which means they do not differentiate between the different vulnerabilities to hazards

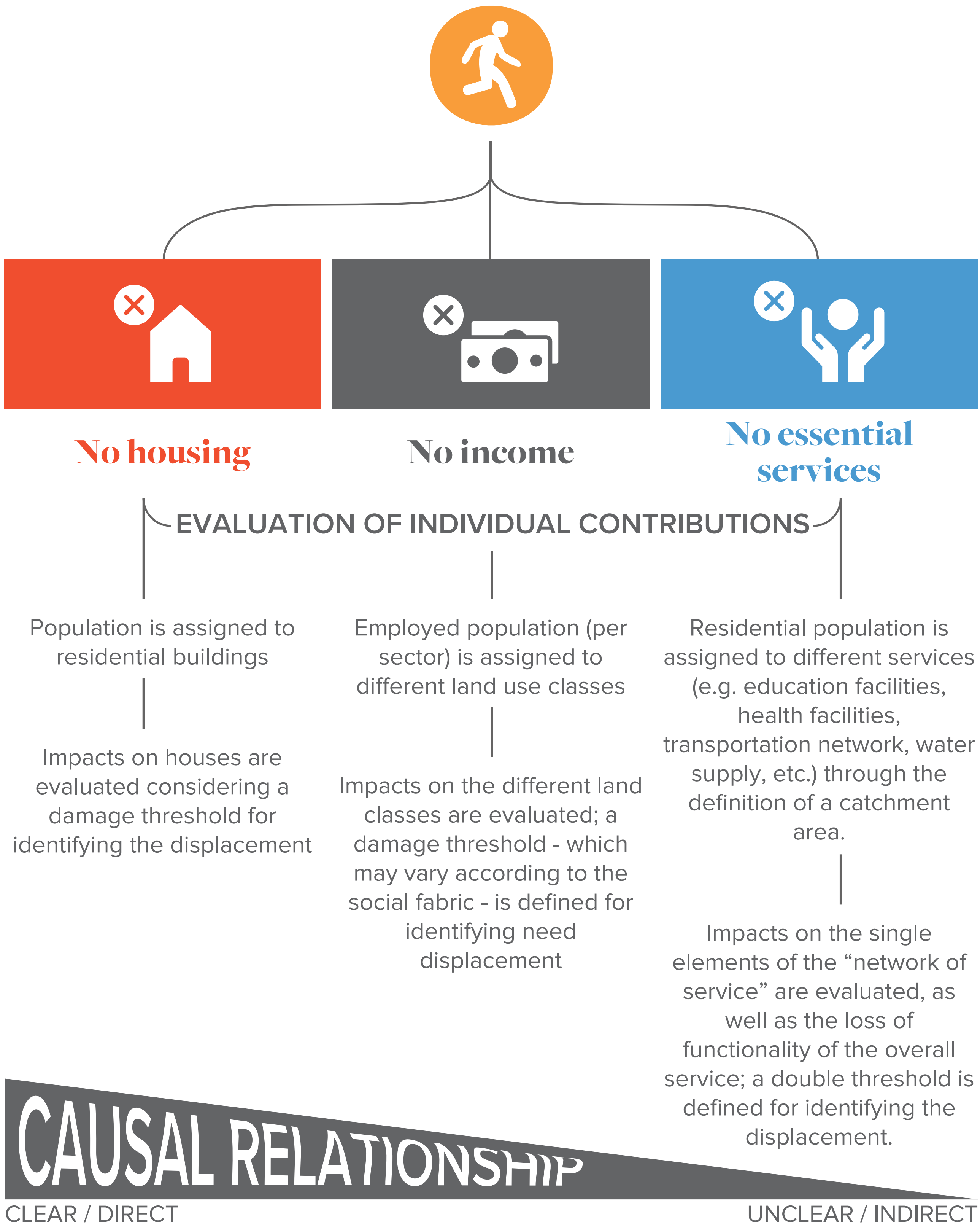


Figure 2: Identification of the main components with the potential to trigger disaster displacement.

associated with different house types. The new methodology employs a complete physical vulnerability model to compute the impact on housing.

Despite efforts to improve security and promote peacebuilding, conflict displacement continues to increase in many countries in Africa. The countries analysed in this project hosted more than 11 million internally displaced people (IDPs) as of 31 December 2022.[9] This creates a significant spread of sites and camps across the countries, which were considered as an additional element of housing in the analyses.

Direct impact on livelihoods

This element, which goes beyond traditional models, measures the direct impact of a disaster on people's livelihoods, namely damage to crops, herds, shops, industries and services. Accounting for these additional factors provides a more comprehensive understanding of disaster-related impacts that may influence people's decisions to move.

Indirect impact on critical facilities, services and livelihoods

Indirect consequences, like the extended absence of vital services, should also be considered. People's choices to remain in place or relocate are also dependent on their access to necessary resources like food, clean water, education and health facilities. Therefore, the potential indirect damage to critical facilities, public infrastructure and services must be considered. This enhances the thoroughness of the estimation of disaster displacement risk because, with these losses, the vulnerability of the person and consequently the likelihood of displacement may increase.

Taken together, these elements provide a more accurate estimate of the number of people who may be displaced by the direct and indirect impacts of future sudden-onset disasters, such as floods.

Incorporating analysis of these elements into disaster displacement risk assessments generates improved risk information. This, in turn, informs policymaking and the development of effective, localised and tailored strategies to reduce people's and communities' vulnerability to disaster impacts and to address the protection needs of those compelled to move out of harm's way.

To evaluate flood risk specifically, it is necessary to adapt the classical approach to evaluate the three main components, namely hazard, exposure and "physical" vulnerability.

Different procedures and methodologies to determine risk are used worldwide through a variety of models and approaches. Their common aim is to understand the probability of different magnitudes of flood characteristics, such as depth, horizontal extent, velocity and duration, occurring over an extended period.

Estimates can be computed for present and projected climate conditions, considering various emission scenarios. This involves conducting analysis of meteorological, geological, hydrological, hydraulic and topographical attributes of watersheds, channels and floodplains to generate comprehensive hazard maps. Consequently, this methodology facilitates the prediction of water depths for specific locations or individual infrastructure elements, across a range of return periods.

The damage assessment is converted into "loss" metrics through the computation of the expected AAD, averaged over many years, and the PMD, a curve showing possible displacement with a certain probability range.

From vulnerability to vulnerabilities

While our new methodology follows a relatively standard approach to impact assessment, it introduces innovative and unconventional components designed to tackle the vulnerability aspect. The interpretation of the term vulnerability strongly relies on its context. For instance, in terms of economic losses within a probabilistic flood risk assessment, vulnerability usually pertains to the potential physical impact of the flood on structures and infrastructure. In contrast, our novel approach views vulnerability as a multifaceted factor encompassing people's susceptibility to displacement.

This perspective necessitates the consideration of numerous additional factors, and specific physical vulnerability plays an important role in each of them. Integrating these factors results in a more comprehensive understanding of vulnerability to displacement, where potential

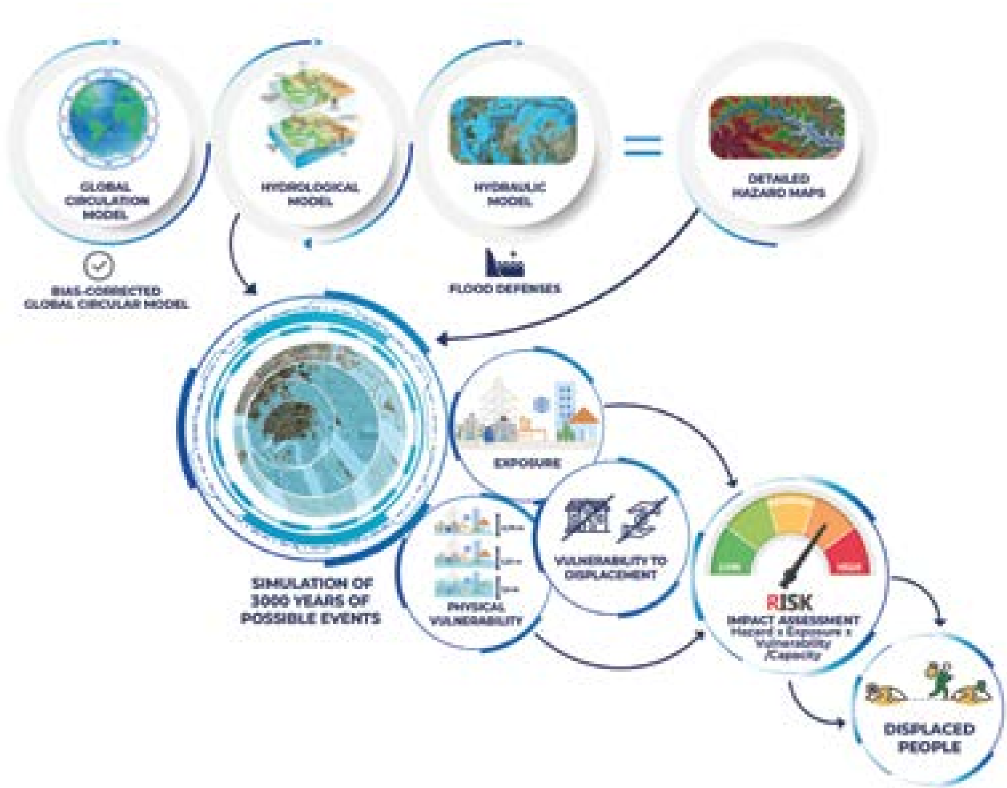


Figure 3: Representation of the overall process adopted for developing the assessment of flood displacement risk.

interactions among the different elements need to be factored in.

The scale of displacement in an area depends on the probability of people being displaced because their homes have been rendered uninhabitable, plus the probability of them being displaced because of livelihood loss, minus the probability of them having lost both their home and livelihood.

This concept can be expressed in the following equation:

Total number of displaced people

Number of displaced due to loss of livelihoods

$$d_{tot} = d_h + d_l - d_h \cap d_l$$

Number of displaced due to loss of their house

In this equation, d_{tot} is the total number of people displaced, dh is the number displaced because of housing loss and dl is the number displaced because of livelihood loss.

The probability of people losing both their home and livelihood can be expressed as: the probability of people being displaced because their home has been made uninhabitable conditioned to the fact that they have been displaced because of livelihood loss, which transforms the previous equation as follows:

The probability of people being displaced

Probability of having lost both house and livelihood

$$d_{tot} = d_h + d_l\,(1 - P[d_h \mid d_l])$$

because of livelihood loss is subdivided between those who depend on agriculture, pastoralism, services or industry.

The conditional probabilities are estimated separately for each sector, based on the number of people who depend on that specific livelihood and the fraction of people being simultaneously exposed in the workplace and at home.

The number of people who may lose access to basic services, such as health and education, is a factor that heightens vulnerability and is also quantified. As a first approximation, this additional information is provided separately and not integrated into the displacement risk computation. Integration has been deferred because there is insufficient data available to calibrate this element.

v

Exposure and vulnerability model

Exposure layers are a fundamental component in risk modelling. These layers provide spatial information about the distribution and characteristics of assets, populations and infrastructure in a specific area. Vulnerability is also a pivotal concept in risk modelling, playing a central role in understanding the potential consequences of hazardous events. It refers to the susceptibility of individuals, communities, infrastructure and ecosystems to damage or adverse impacts resulting from various hazards.

To evaluate the different components of the model, a spatial representation of the population, subdivided by the various sectors, is required. More specifically:

- To calculate the number of people displaced because of house damage, a spatial raster data set depicting the distribution of the residential population, expressed as the number of people per cell, is needed.
- To calculate the number of people displaced because of livelihood loss, a spatial raster distribution of employees in each sector, such as agriculture, service and industry, is needed.
- To calculate the number of people more likely to be displaced because of a lack of basic services, a spatial raster distribution of each service and the people related to them is needed.

These population distributions should be characterised by physical vulnerability, against which we assess the flood impact, as explained in the following.

The first two distributions, assets and livelihoods, are used directly to derive dh and dl, while the third is used as an aggravating element that increases the likelihood of people being displaced.

With all three, whenever we determine that an asset (a home, workplace or service point) is affected by an event, we can derive the number of people affected and identify them as susceptible to displacement.

To identify the residential distributions and the distribution of people dependent on different livelihoods in Ethiopia, Sudan and Somalia, we integrated and processed data from a number of different sources, such as: national statistical databases; available exposure models; global data sets on population distribution, settlement identification and land use/land cover; and sector-specific data sets.

National statistical database

The primary statistical data source considered was the Census, which provides an official count of population, dwellings and households. For the countries analysed, official Census data from the past few years was not available, but the following documents, found on the portal Humanitarian Data Exchange, provided some statistical information on population and gender:[10]

- Population Estimation Survey for Somalia in October 2013–March 2014, promoted by the United Nations Population Fund (UNFPA), which only had the population estimate at Admin level 1.[11] UNFPA investigated replacement or projection of this data set in 2021
- Subnational Population Statistics for Ethiopia administrative level 0–3 sex and age disaggregated projected 2022 population statistics, promoted by UNFPA
- Subnational Population Statistics for Sudan administrative level 0–1 sex and age disaggregated projected 2022 population statistics, promoted by UNFPA

The International Labour Organization (ILO) database ILOSTAT was also consulted and used for specific figures.[12] This database encompasses a comprehensive range of information related to the labour market, including data on employment by economic sector, hourly wages, weekly working hours, unemployment rates and strikes. The ILO data collection includes data derived from National Labour Force Surveys, which can differ from the ILO-modelled estimates. The ILOSTAT entry page provides access to country-specific or subject-specific statistics, along with information on concepts and definitions.

Exposure models

An existing exposure database has been adopted and analysed to extract essential information for defining the specific requirements in the modelling exercise within the study. Derived from the Global Infrastructure Risk Model and Resilience Index (GIRI) project led by Coalition for Disaster Resilient Infrastructure, it has been refined and developed by the United Nations Environment Programme's (UNEP's) Global Resource Information Database (GRID-Geneva), funded by the Internal Displacement Monitoring Centre (IDMC).[13]

The Global Exposure Socio-Economic and Building Layer (GESEBL) is an update of the of the existing Global Risk Model developed for the UN in 2013 for the Global Assessment Report.[14] This is a global data set on exposure that combines population data with country-specific building typology, usage and value in urban and rural settings. The data set uses the number of individuals, categorised by socioeconomic class, residing in a specific construction style in a defined geographic area as a foundation for distributing the exposed economic value of the building stock.[15]

Recent advances in data acquisition methods related to building footprints, Earth observation using satellite imagery and the appearance of alternative data sources have boosted the potential for and development of novel techniques to model and quantify exposed assets and people at a more granular level. All the data (socioeconomic, building type and capital stock) is provided through the uniform geographical unit of a reference grid at 1x1 kilometres at the equator. The resolution of 1x1 kilometres needs to be improved to properly match the increased resolution for the hazard proposed in this study (90 metres).

Additional global datasets

To improve the spatial representation of the GESEBL in coherence with the hazard, a downscaling procedure was performed using ancillary data, such as global data sets on population distribution, which have a good level of accuracy. In the procedure this map became the built-up mask of reference. These global layers are also essential for obtaining missed information on the characterisation of exposure and vulnerability through identifying urban and rural land.

Population

For the global data sets on population distribution, several products are available. In this project, two products were considered:

- the Global Human Settlement (GHS) population grid (R2023), epoch: 2020, resolution: 100 metres, for Ethiopia[16]
- the WorldPop product (100-metre resolution) for Somalia and Sudan, called in the following WorldPop[17]

The choice of these layers has followed statistical and visual comparisons, to define the best dataset that could represent reality. In particular, statistical representation is adopted for describing and displaying the data, highlighting anomalies and obtainable differences between the two layers.

The choice of these layers followed statistical and visual comparisons to define the best data set that could represent reality. Statistical representation was adopted for describing and displaying the data, highlighting anomalies and obtainable differences between the two layers.

Anomalies were located through a specific comparison conducted between the two layers and optical satellite images. In the geographic information system (GIS) environment, from the data sets, statistics at different Admin levels (1 and 2) were performed, as seen in figure 4. These graphs compare the values derived from the data sets (Sum of WorldPop 2020 and Sum of GHS-Pop2020) with those found in other sources, such as United Nations projection and Census data.

In the figure, "counts" represent the sum of population at Admin level 1, while "errors" illustrate the relative errors of the two layers with the UN projection. In this example, there is a substantial difference between the two data sets only for Addis Ababa area. In this region, the two layers and the optical satellite image have been compared in terms of spatial distribution, as in figure 5, and values of each pixel. In this case, GHS (red) seems to be more up to date, mapping a part of the urbanised area that WorldPop does not capture. Since checks like this have been carried out in several places in the region and GHS has always seemed more consistent with

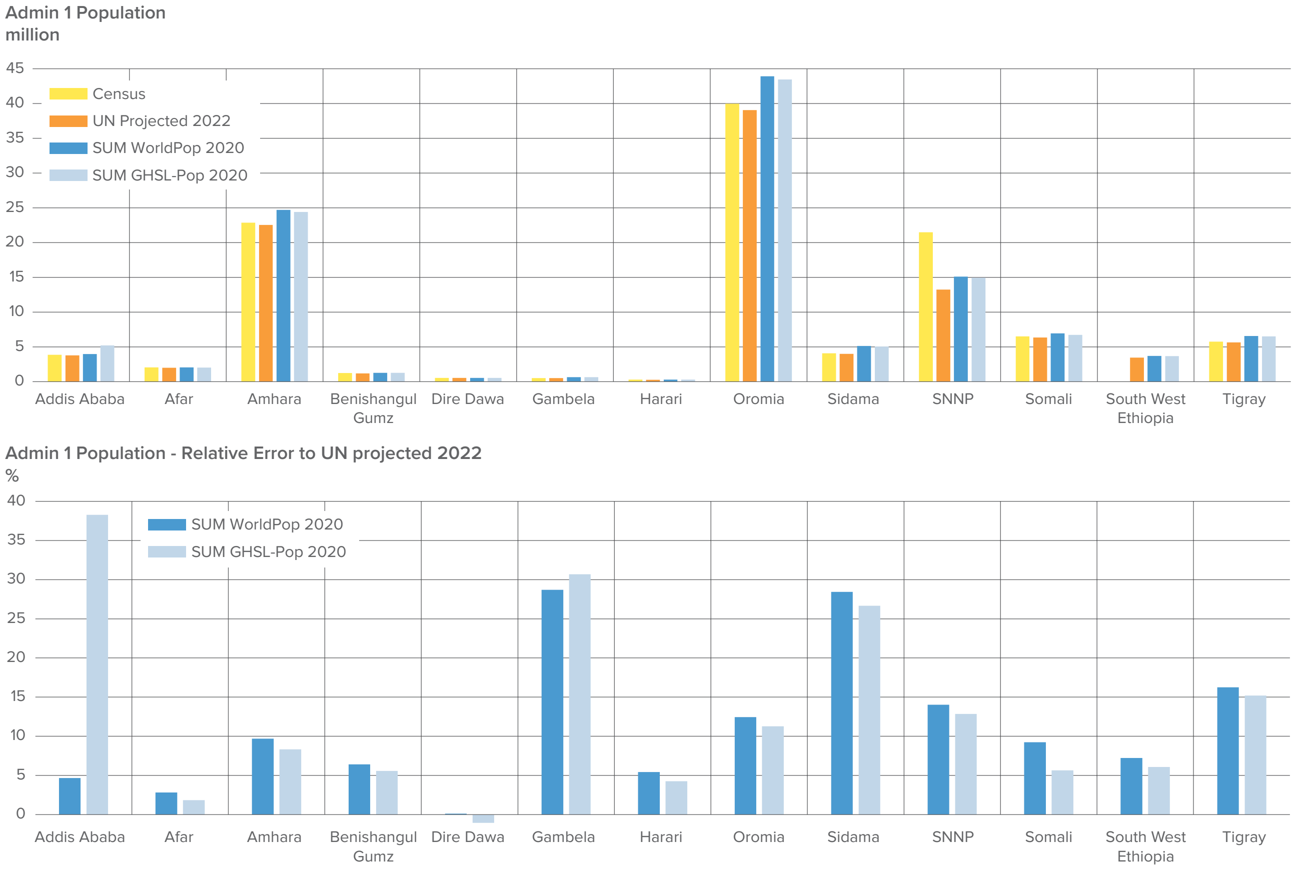


Figure 4: Statistical distribution on population in Ethiopia, according to different sources.

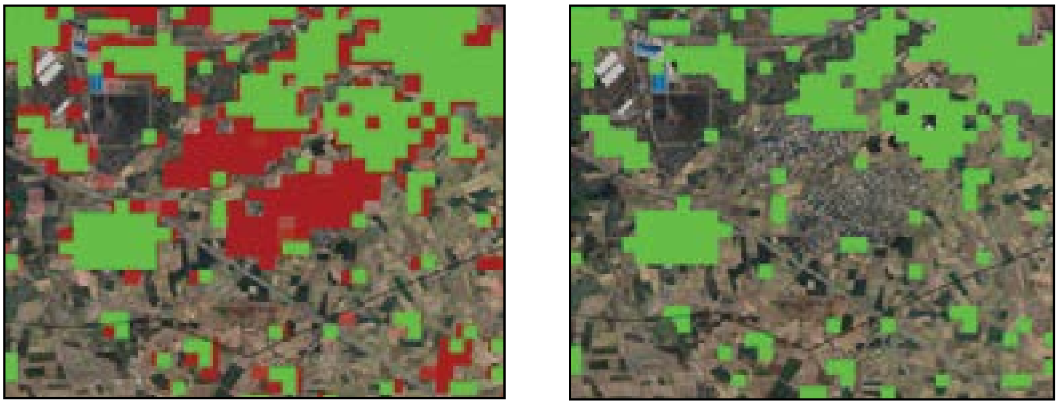


Figure 5: Comparison of GHS (red), WorldPop (green) and satellite images in the Addis Ababa Region.

urban development, it has been chosen as a reference layer.

Land cover and employment by economic activitiy

In terms of global products, as well as the land use/ land cover map, we employed the Joint Research Centre's (JRC's): Anomaly hot Spots of Agricultural Production (ASAP), to determine the cropland and grassland area; and GHS-SMOD R2022A settlement layers, application of the Degree of Urbanisation methodology (stage I) to GHS-POP R2022A and GHS-BUILT-S R2022A, multitemporal (1975-2030), to identify the rural and urban areas.[18, 19]

Statistical information pertinent to this study was extracted from these primary sources and is presented in Table 1. The table shows, for each country, the employment-to-population ratio and the employment rate by economic activity (agricultural, industrial and service sectors).

The values of employment-to-population ratio and the employment rate by industrial and service sectors derive from our GESEBL at a resolution of 1 kilometre, and they are in line with source as ILO. The agriculture data is not available in the GESEBL data set, so the employment rate by agricultural sector derive from ILO data. While the employment rate by cropland and grassland was determined by a ratio of area in the land cover map of reference, JRC's ASAP.[202122]

	SUDAN	ETHIOPIA	SOMALIA
Employment (2019)	1.04E+07 (24%)	2.81E+07 (26%)	8.21E+05 (5%)
Agriculture	45% Crop – 67% Graz – 33%	64% Crop – 71% Graz – 29%	27% Crop – 38% Graz – 62%
Industry	2,920,000 (15%)	7,930,000 (10%)	103,000 (9%)
Services	7,430,000 (40%)	20,200,000 (26%)	718,000 (64%)

Table 1: Statistical data on employment rate.

Sector-specific national dataset

By the end of 2022, Sudan, Ethiopia and Somalia were home to 12.2 million IDPs.[23] These countries are exposed to a mix of conflict and meteorological shocks every year, which not only trigger movements but also lead to protracted displacement situations.

While the situation of IDPs can be highly volatile, this study aims to investigate how disasters impact both informal and formal settlements of IDPs. This exploration is motivated by two primary factors.

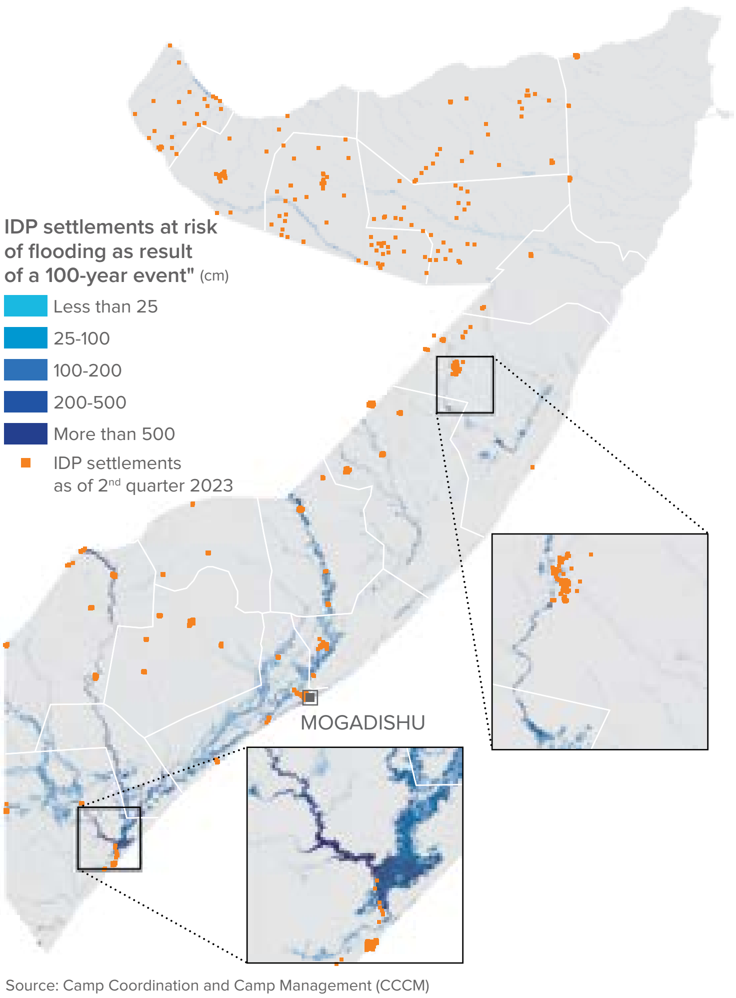


Figure 6: Somalia, locations of camps of IDP overlaid with a flooding of an 100 year return period event.

Firstly, many settlements are situated in or near flood-prone areas. Secondly, IDPs' ability to move elsewhere may be restricted by ongoing violence, among other reasons. More critically, some IDPs reside in inadequate shelters or tents, leaving them especially vulnerable to extreme weather conditions.

Sudan and Somalia were assessed to understand how settlements of IDPs are exposed to floods. Conscious that the situation of IDPs is dynamic in these two countries, we decided to take a snapshot of the location of IDPs and estimate the percentage of settlements exposed to severe flooding.

Identification and location of the different settlements of IDPs in Sudan and Somalia was put together using two data sets:

- Sudan: IOM-DTM Weekly Displacement Snapshot (3) 8 September 2023, referencing more than 800 points. A large majority were georeferenced as neighbourhoods and villages (informal settlements), with only 15 official camps (formal settlements). Before the military takeover in April 2023, more than 100 camps were georeferenced.[24]
- Somalia: Camp Coordination and Camp Management (CCCM) list of sites of IDPs for the second quarter 2023, referencing more than thousands of points.[25]

The limitations inherent in this analysis must be acknowledged. Given the dynamic nature of the situation and the limitation of input data sets, the findings of our analysis in Sudan and Somalia are subject to significant uncertainty. For instance, information on the location of camps was only available as a point-based layer (instead of area-based), which may lead to a potential underestimation of displacements.

Vulnerability component

The study is based on a physical vulnerability analysis. Physical damage (as a percentage) is directly derived from vulnerability curves, which relate the hazard intensity to the expected damage. In the displacement risk evaluation procedure, concerning the home and workplace for services and industries, we adopted a specific damage threshold, or loss, that could cause displacement (see figure 8). This threshold is a percentage value of building damage that means the place can no longer be used. It has been calibrated using empirical data from the IDMC Global Internal Displacement Database, as illustrated in figure 7. It shows a histogram with the values of displacement in terms of AAD for the different countries considered in the analyses, representing the empirical data from the IDMC Global Internal Displacement Database on the events: floods, riverine floods and with or without flash floods. The period for the selection of the events was from 2008 to 2016, consistent with the assessments made on flooding, where the historical discharge series used to create the scenarios ranged from 1979 to 2016.

Overestimation may be caused by the resolution of the simulation in Sudan. The area along the Nile is the most critical area in Sudan. It is where most of the population are concentrated and where people are used to living with and managing flood conditions. Buildings built on a higher terrain and local flood protections are not considered at a 90-metre resolution, and this may lead to overestimation. Furthermore, the empirical data from IDMC was recorded for Sudan in a single event per year, encompassing the entire rainy season. This methodology prevents the disaggregation of displacement occurrences based on specific locations, hindering a more granular analysis.

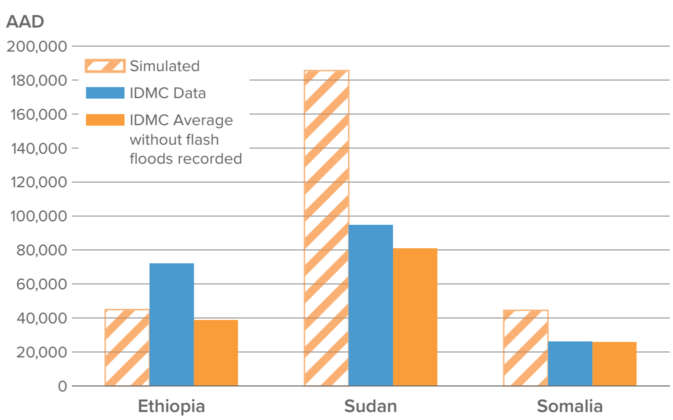


Figure 7: Simulated AAD for the countries compared with empirical data in the IDMC database.

This comparison of simulated values, computed by the application of our methodology and the recorded values, exhibits a good agreement, allowing us to validate the proposed procedure and calibrate the threshold on the damage curves. A mean value among the countries is represented in figure 8.

The matching between the curve and the element is done according to different characteristics, depending on the vulnerability library. In this study, the Comprehensive Approach to Probabilistic Risk Assessment (CAPRA) physical vulnerability functions for the built-up area were adopted.[26] They are region-specific vulnerability functions, defined for different construction materials (mud, concrete, masonry and wood, as in figure 8) and for different numbers of stories. The building typology in our GESEBL are associated to the CAPRA vulnerability library.

Furthermore, in the methodology proposed, the camps of IDPs have been associated to a high-vulnerability construction type, because of their provisional nature.

In agriculture, the vulnerability function is a binary parameter: "flooded" or "not flooded". It categorises a field as flooded if it cannot support agriculture and pastoralism for farmers, leading to displacement. This classification is based on a water depth of 50 centimetres.

Residential population

The residential population from the GESEBL corresponds to the sum of people in each of the four income classes established by the World Bank (World Bank's annual World Development Report [WDR]).[27] They are distributed in the different building typologies present in the country. The ratio of the population associated to a single building typology is evaluated, and this value is downloaded to the built-up mask of reference (GHS and WorldPop). Figure 9 shows the population spatial distribution (at raster level) for each country and the values summed at Admin 1.[28]

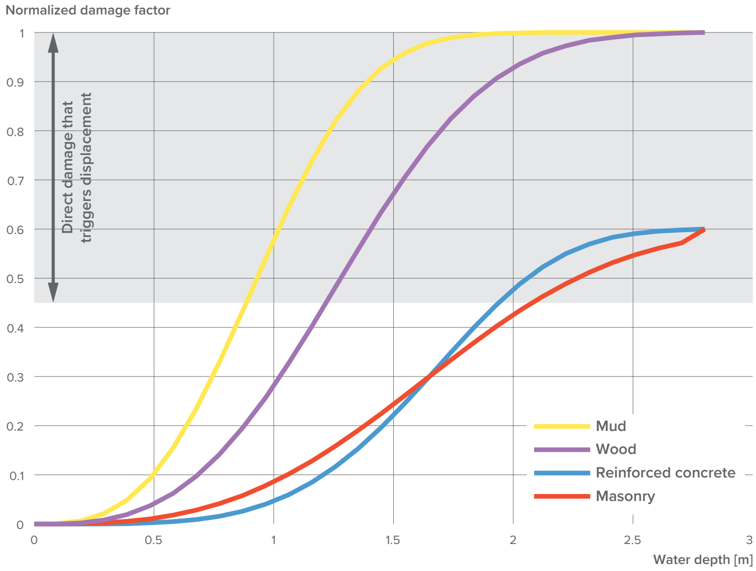


Figure 8: CAPRA vulnerability curves for some building typologies and a mean threshold on the damage ratio that causes displacement.

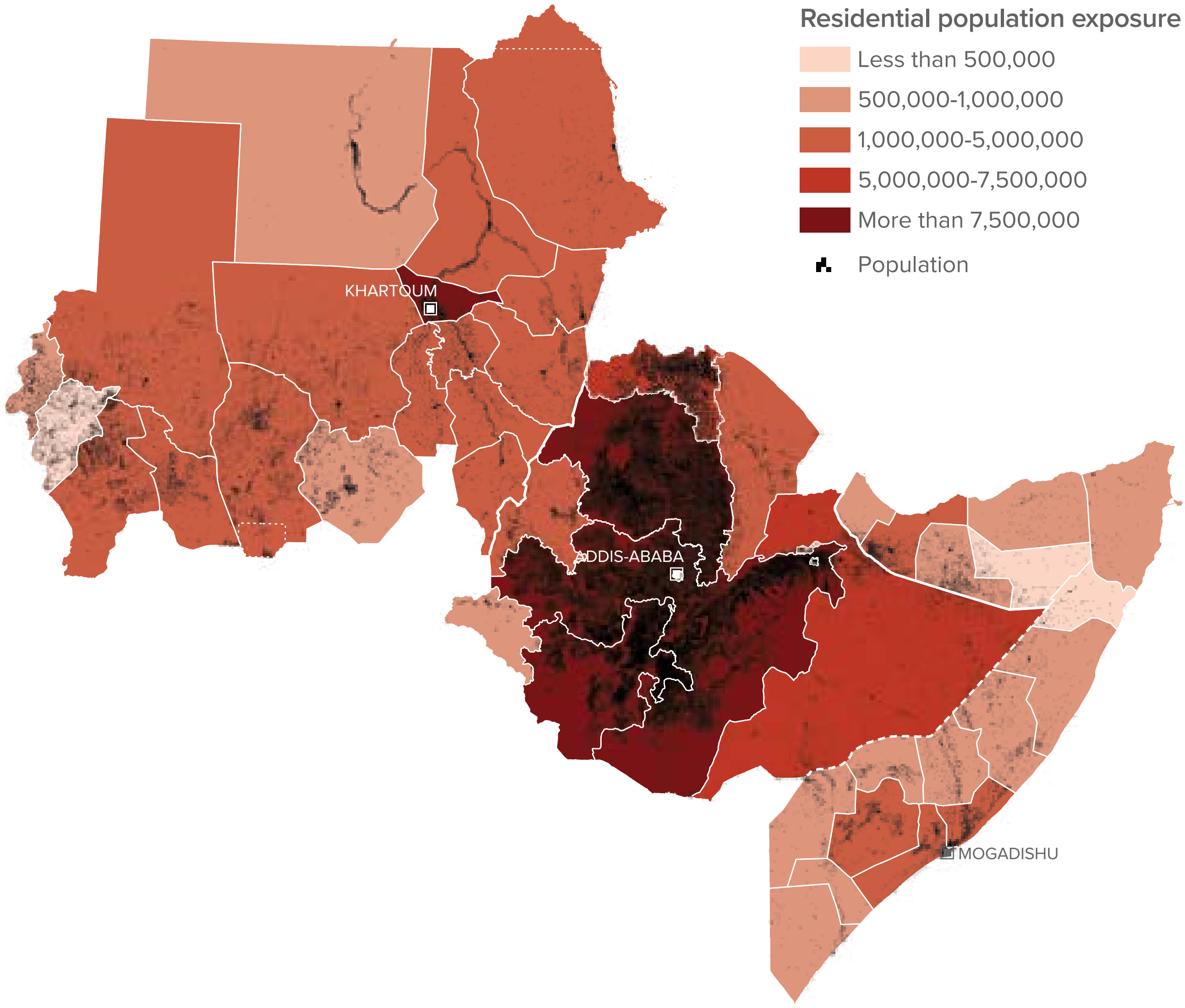


Figure 9: Residential population distribution at the reference administrative level for the three countries.

Population from different sourced in MLN	SUDAN	ETHIOPIA	SOMALIA
Estimated	41.76	171.31	16.55
UN 2021	45.66	120.28	17.07

Table 2: Population data from different sources.

Population by livelihood

We used different layers to determine the distribution of people depending on different livelihoods.

The non-residents population in the GESEBL include workers in industry and service sectors, students, represented by the sum of people included in the labour and education sectors. From this data, the workers in the service and industrial sectors have been defined, through the downscaling procedure on the raster reference layer.

For the agricultural sector, we determined the number of workers according to the areas of cropland and grassland based on the ASAP data set.

We derived the number of workers per sector from percentage values in table 1.

Flood hazard assessment

Flood hazard assessment aims to systematically analyse the likelihood and magnitude of flood occurrences, considering factors such as topography, hydrology, climate patterns and land use. This multidisciplinary process incorporates geospatial data, hydrological modelling and historical flood records to generate accurate and comprehensive flood hazard maps, which serve as essential tools for promoting resilience and minimising the adverse effects of flooding events. To best predict possible flood scenarios, we used a chain of climate, hydrological and hydraulic models. We applied the "Continuum" hydrological model to all basins in Ethiopia, Sudan and Somalia, at a resolution of 4 kilometres, to obtain streamflow series for each pixel in current and projected climate conditions. We then input this information into a simplified hydro-morphological model, based on the Manning's

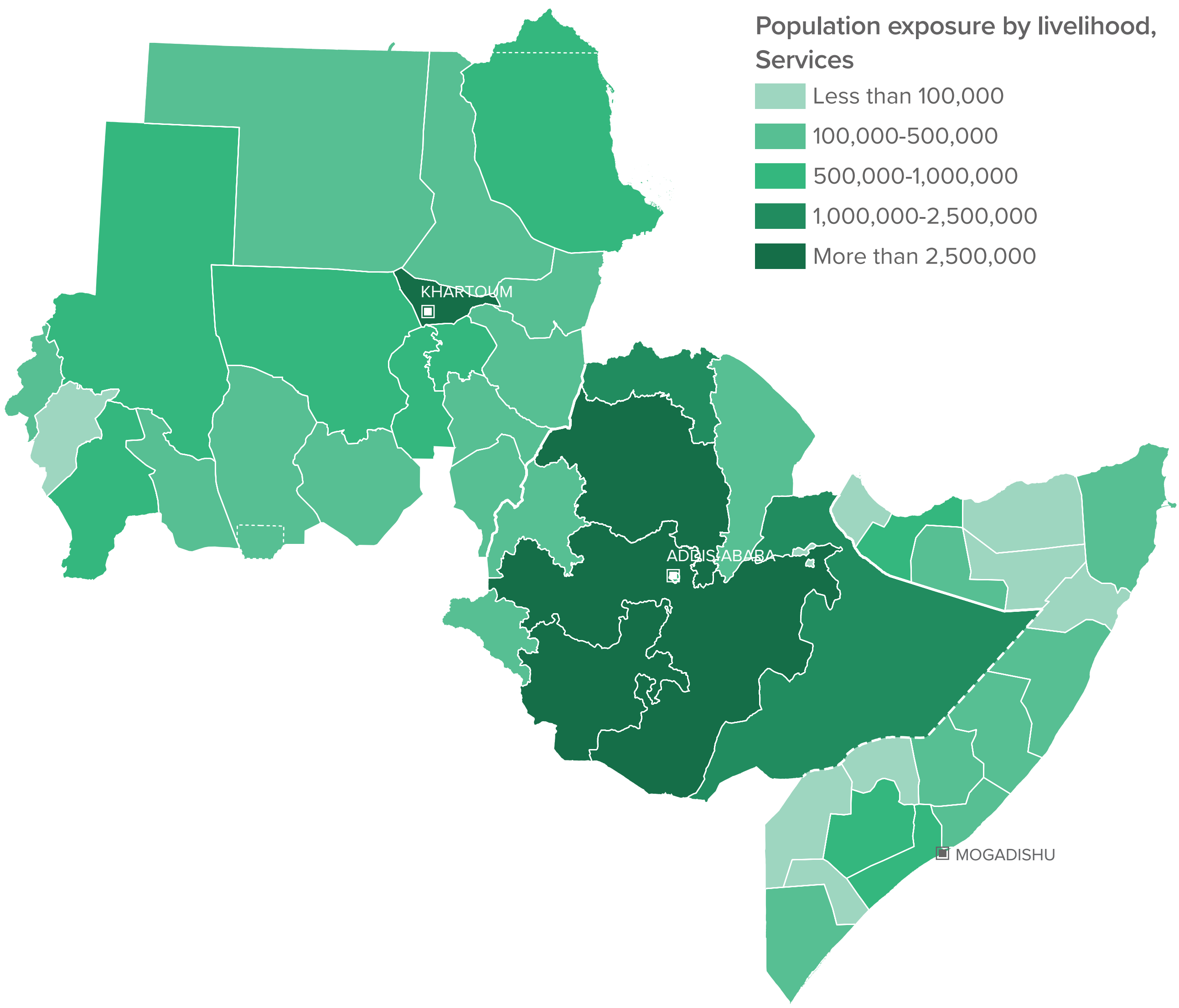


Figure 10: Population by livelihood, services

equation, to create hazard maps at a 90-metre resolution for different return periods. Return periods of T=2, T=5, T=10, T=50, T=100, T=200 and T=250 years in current and projected climate conditions were selected to represent the different frequencies and intensities of possible events in each basin.[29]

On this basis, we developed hazard maps for each country under current, optimistic and pessimistic projected climate conditions, with a long-term time horizon.

To assess risk in large domains, a set of mutually exclusive and collectively exhaustive possible hazard scenarios that may occur in the country (including the rarest and most catastrophic ones) was synthetically generated, keeping the historical spatial correlation of events.

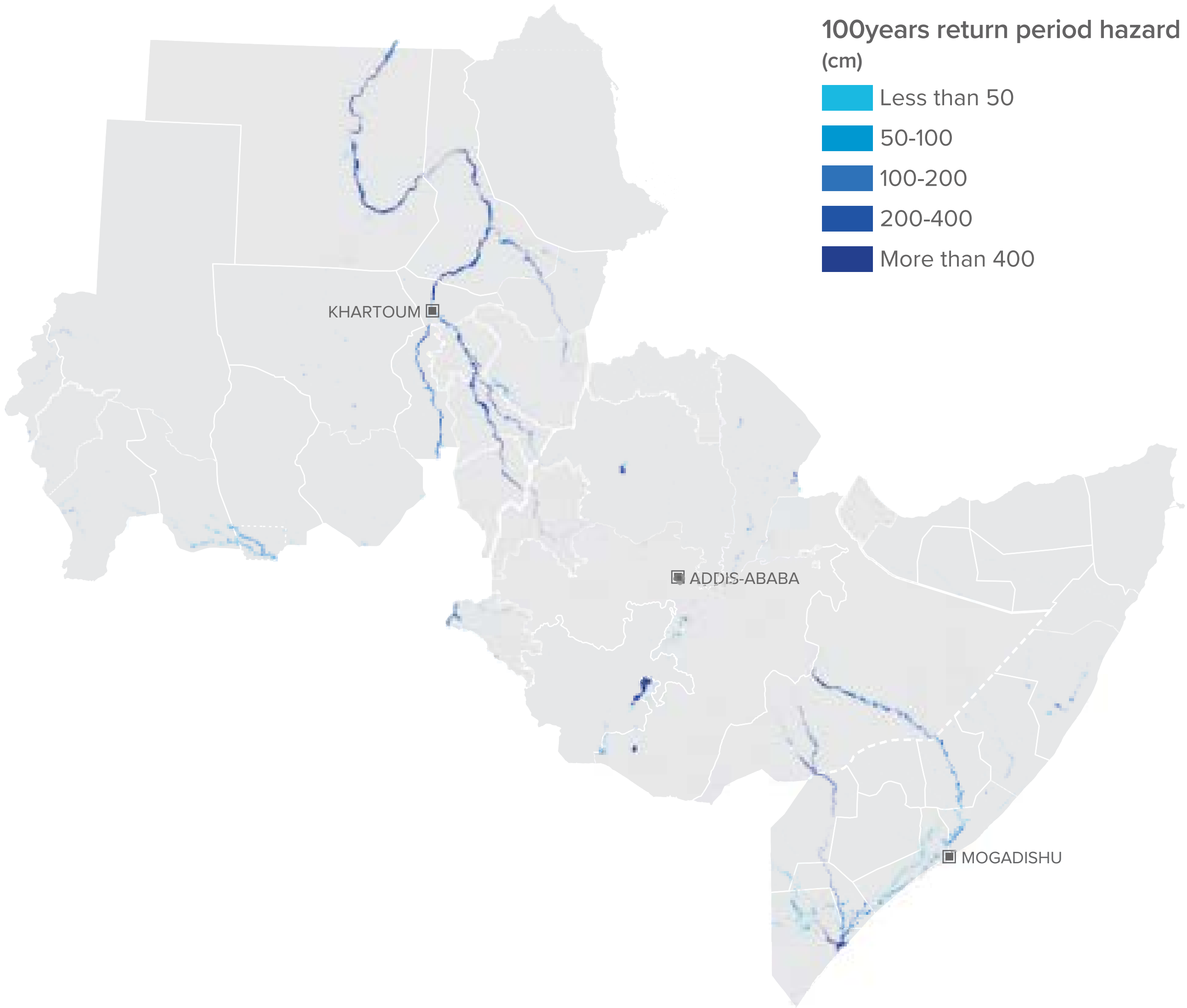


Figure 11: Hazard map of 100-year return period for the three countries.

Flood impact assessment

Presenting results from flood impact assessments conducted in Ethiopia, Somalia and Sudan, this section offers insights into the comprehensive evaluation of flood vulnerabilities. By analysing factors like topography, hydrological patterns, and assets and livelihoods exposed, these assessments provide a deeper understanding of the potential risks posed by flooding events. The outcomes contribute valuable information for informed decision-making, enabling effective disaster preparedness and mitigation strategies tailored to each country's unique situation.

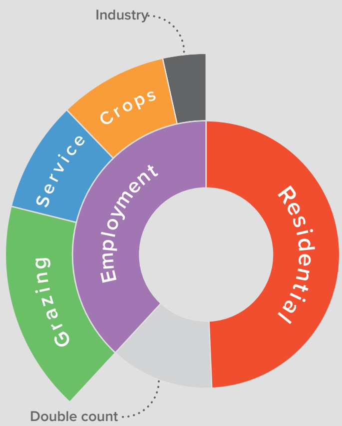
How did we do it?

Each scenario served as input for evaluating the impact on potentially displaced individuals. A value of water depth was assigned to each feature in the exposure model (residential buildings for residential population, industrial or service buildings for population working in these sectors, crop or grazing areas for the employees in agriculture, schools for the students, hospitals, and camps of internally displaced people [IDPs]).

Damage assessment was conducted by integrating the raster exposure model and Comprehensive Approach to Probabilistic Risk Assessment (CAPRA) curves, through the Rapid Analysis and Spatialisation Of Risk (RASOR) Platform libraries.[30] Elements in the built-up raster layer that exhibited damage beyond a specified threshold were considered unable to fulfil their functions (e.g. providing shelter, jobs or supporting crop fields), resulting in displacement.

The population associated with these damaged elements were deemed susceptible to displacement. Individuals who experienced both housing and livelihood loss in the same scenario were counted only once, to avoid duplication. The procedure to avoid potential double counting is based on the idea of associating workers to both their house and their workplace, to evaluate if both were in hazard-prone areas. As the assignment could not be performed for each single worker for computational issues, we adopted an aggregation based on a 5-kilometre regular grid. In each cell, we evaluated the number of employees for the considered working sectors and the corresponding percentage of employees located in hazard-prone areas (coming from the intersection between the spatial raster distribution of employees in each sector and the flood hazard map for T=1,000 years).

Box 1: The "risk" of double counting.



We present our results, incorporating our double counting procedure. The grey segment, labelled as "double count", signifies individuals who have experienced both housing and livelihood loss in the same scenario. Our intention is to visually depict the proportion of individuals affected by both displacement risks. When presenting numerical results, however, we only accounted once for people deemed to have lost their home and livelihood in the same scenario.

Residential capacity was considered at the same resolution as the exposure model, and at the beginning of the process, it was assumed to be equal to the residential population. An iterative procedure of assignment to residential areas was implemented, starting from the residential capacity within the cell itself. The residential capacity was updated within the procedure (reduced) whenever employees of a specific working sector were assigned. If not all the employees could be assigned within such a cell because the residential capacity was not sufficient for all the employees, the procedure searched for residual capacity in neighbouring areas, increasing the radius for the search step by step. The assignment stored the percentage of employees with a workplace in a hazard-prone area. The procedure was repeated until all workers were assigned to residential areas. At the end, a set of new products was available at the same resolution as the exposure model, each representing the percentage for a specific sector of employees living in the area and working in a hazard-prone area.

The number of potentially displaced people across various sectors was aggregated at the relevant administrative level. These impacts were then used to determine the average annual displacement (AAD) and probable maximum displaced (PMD) values.

We produced results for Ethiopia, Somalia and Sudan from Admin level 1 and aggregated these at national level.

Ethiopia

Ethiopia is a country known for its diverse and extensive river systems. Rivers are essential for various purposes, including agriculture, hydropower generation, transportation, and sustaining ecosystems and communities. Ethiopia's varied topography, ranging from highlands to lowlands, contributes to the diversity of its river systems and their significance to the country's development and environment. The main river basin is the Blue Nile, one of the two main tributaries of the Nile river, and it originates from Lake Tana in the Ethiopian Highlands. The Blue Nile contributes significantly to the overall flow of the Nile and is a critical water source for downstream countries.

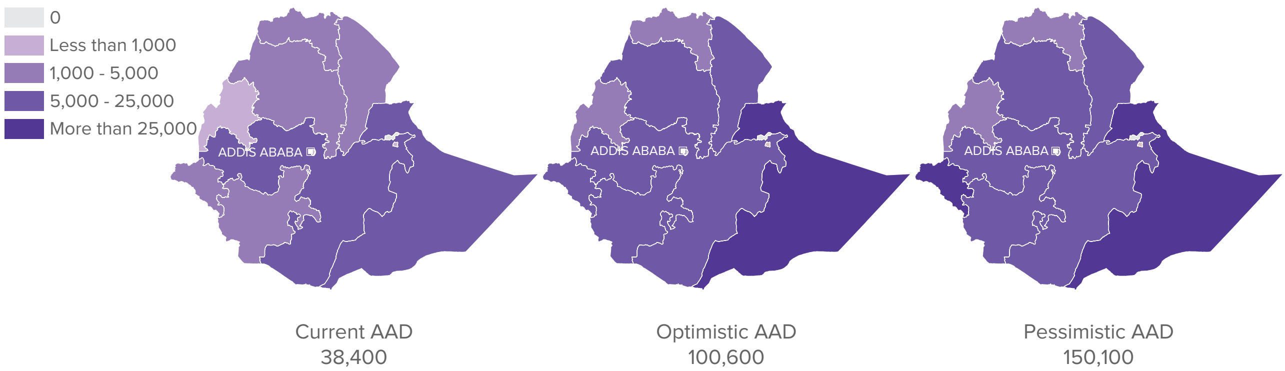
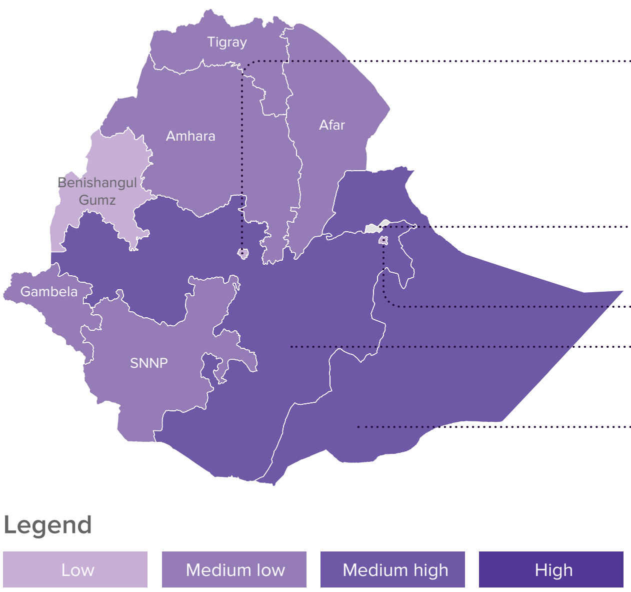


Figure 12: AAD in current climate conditions and in long-term projections under optimistic and pessimistic scenarios in Ethiopia. Results are aggregated at Admin level 1.



Region	AAD Current	% Male	% Female
Addis Ababa	50	47%	**53%**
Afar	1,500	**55%**	46%
Amhara	4,000	50%	50%
Benishangul Gumz	900	**51%**	49%
Dire Dawa	0	**51%**	50%
Gambela	2,000	**52%**	48%
Harari	10	50%	50%
Oromia	11,300	50%	50%
SNNP	4,800	49%	**51%**
Somali	17,900	**53%**	47%
Tigray	1,800	49%	**51%**

Figure 13: AAD disaggregated by sex.

The analysis of flood displacement risk at a country level shows an AAD value of around 38,500 people (considering the double counting effect), corresponding to about 0.02 per cent of the overall population. The results under different climate scenarios highlight a non-negligible influence of climate change. Both the optimistic (the scenario closest to the 20th percentile, corresponding to an average temperature rise of about 1°C by 2100) and the pessimistic (the scenario closest to the 80th percentile, corresponding to an average temperature rise of more than 5°C by 2100) scenarios increase AAD values, tripling and quadrupling the current conditions respectively. While climate change strongly influences the absolute numbers of potentially displaced people (a relevant number of Admin 1 considerably increases the expected level of displacement), their spatial pattern is comparable when considering results in current climate conditions alongside projected ones.

Knowledge of gender inequalities in internal displacement is limited, yet indispensable to propose tailored solutions for internally displaced men, women, boys and girls. Internal displacement generally amplifies pre-existing vulnerabilities and inequalities. As women across the world are, on average, economically, legally, politically and socially less empowered than men, internally displaced women are twice as disadvantaged. Figure 13 presents the disaggregation of AAD in current climate con.ditions at Admin level 1 by sex (male and female)

While the AAD expresses an average number of expected flood-induced displacements, it tends to hide potential outliers. For this reason, it is useful to compare the PMD curves for present and projected conditions (see figure 14), which show the number of potentially displaced people in connection with frequent (low return periods) or rare (high return periods) events.

In Ethiopia, displacements would increase significantly for higher return periods. For instance, observing the current climate conditions, the displacements triple from frequent events (e.g. T=5 years) to rare events (e.g. T=250 years). This trend is also confirmed when analysing the PMD associated to long-term projected climate conditions, for both optimistic and pessimistic scenarios. In this latter case, a 250-year event causes displacement ranging from 0.08 per cent to 15 per cent in the different Admin 1, according to the total population of each region.

The disaggregation of PMD at country level according to the source of displacement shows that in current climate conditions, almost 42 per cent of displacements are connected to loss of housing, while the majority, 58 per cent, are connected to loss of livelihoods. People working in the agricultural sector are the most affected.

In long-term climate projections, the amount of displacements linked to loss of housing rises to more than 53 per cent. Regarding the disaggregation of PMD by origin of displacement, almost 80 per cent of displacements originated in rural areas. This decreases to 75 per cent in projected climate conditions.

Factors such as future population growth and changes in distribution (e.g. urbanisation), which might significantly change these estimates, are not considered in the modelled future scenarios.

Lack of services is likely not the main driver for displacement after a rapid-onset event. Nevertheless, the combined criticality of loss of housing, work or both alongside a general lack of services in the area can be a worsening factor.

In Ethiopia, there are about 23 million students (around 20 per cent of the total population). The areas characterised by high values of displacement linked to loss of housing service or loss of the possibility to work are also characterised by non-negligible disruption of the education

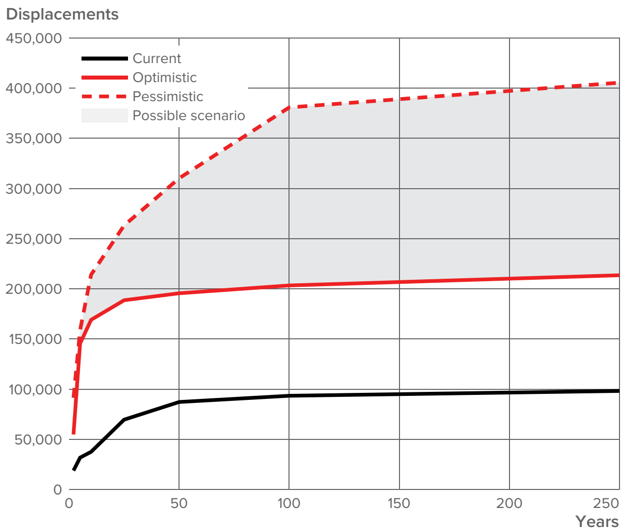


Figure 14: PMD curves for current climate conditions and long-term projections under both optimistic and pessimistic scenarios.

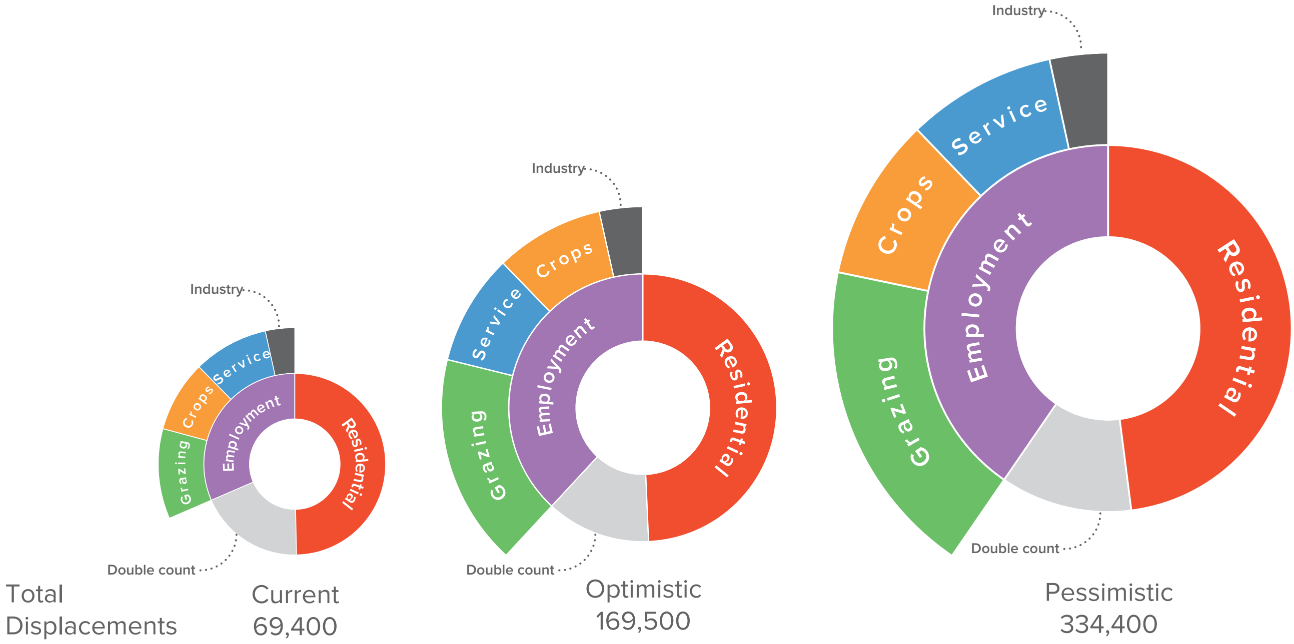


Figure 15 Displacements for a 100-year return period flood event (PMD at 100yrp) disaggregated by cause of displacement.

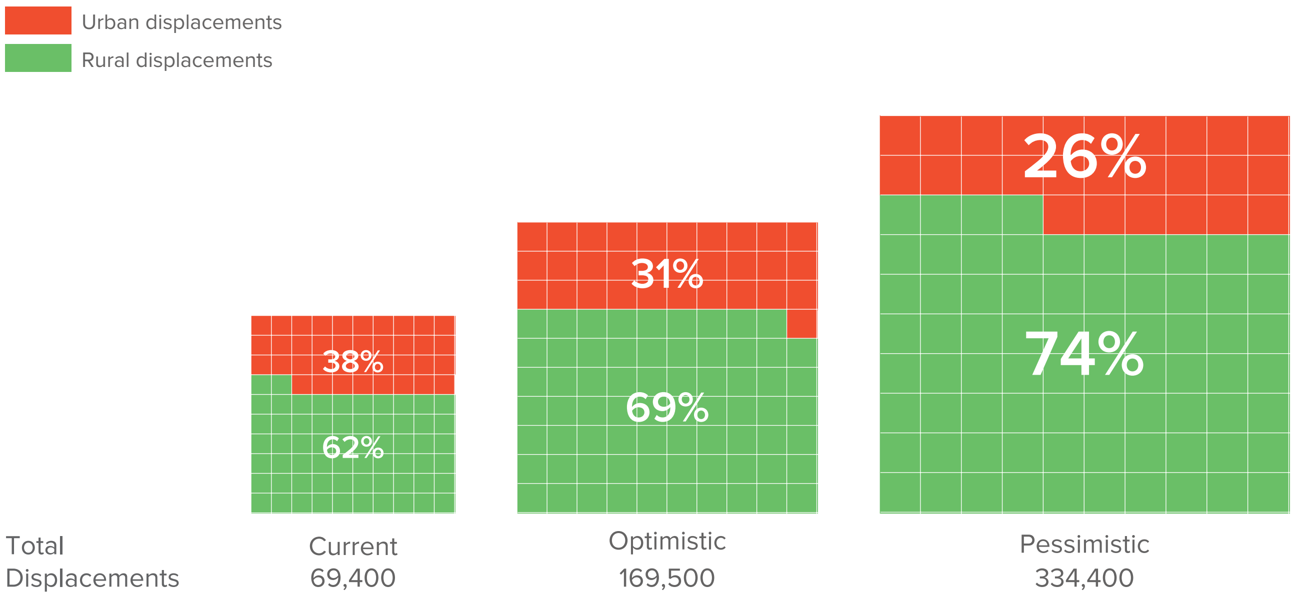


Figure 16: Origin of displacements for a 100-year flood event (PMD at 100yrp) at country level.

sector connected to flood events. This can be a worsening element that increases vulnerability, leading to a higher displacement propensity. About 16,750 students, accounting for around 0.008 per cent of the total student population, would need to relocate because of their inability to access severely damaged schools in the event of a 100-year return period event. The Somali region emerges as the most vulnerable to the risk of disrupted education services.

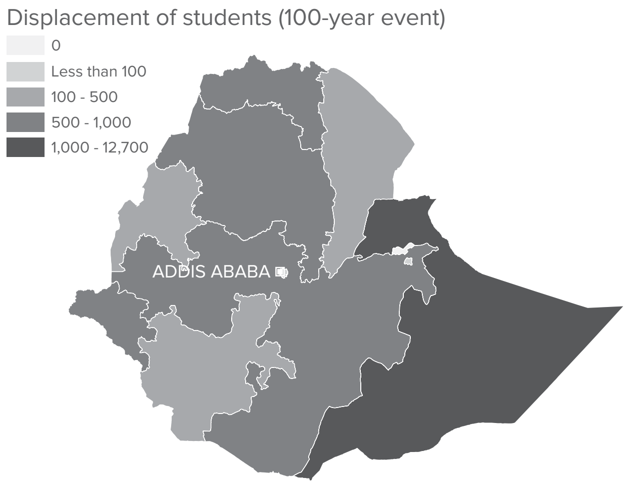


Figure 17: Number of students who would lose education services as a result of a 100-year flood event.

Sudan

Sudan is also home to several significant rivers that play crucial roles in its landscape, economy and the livelihoods of its population. The Nile is the lifeline of Sudan, with the Blue Nile and the White Nile converging in the capital city of Khartoum. Sudan is often referred to as the "breadbasket of the Arab world" because of its agricultural activities, supported by the Nile's waters. The river systems in Sudan have shaped its history, culture and development, making them integral to the nation's identity and progress.

The analysis of flood displacement risk at a country level shows an AAD value of nearly 170,000 people (considering the double counting effect), corresponding to about 0.3 per cent of the overall population. The results highlight climate change's strong influence. The optimistic and the pessimistic scenarios show AAD values 5 to 10 times higher than those in current conditions, respectively.

Climate change influences the absolute numbers of potentially displaced people (i.e. a relevant number of Admin 1 considerably increases the expected level of displacement), and their spatial pattern is coherent among the present and future conditions, but in the climate change projections the number of Admin 1 with relevant number of displaced grows.

Knowledge of gender inequalities in internal displacement is limited, yet indispensable to propose tailored solutions for internally displaced men, women, boys and girls. Internal displacement generally amplifies pre-existing vulnerabilities and inequalities. As women across the world are, on average, economically, legally, politically and socially less empowered than men, internally displaced women are twice as disadvantaged. Figure 19 presents the disaggregation of AAD in current climate conditions at Admin level 1 by sex (male and female).

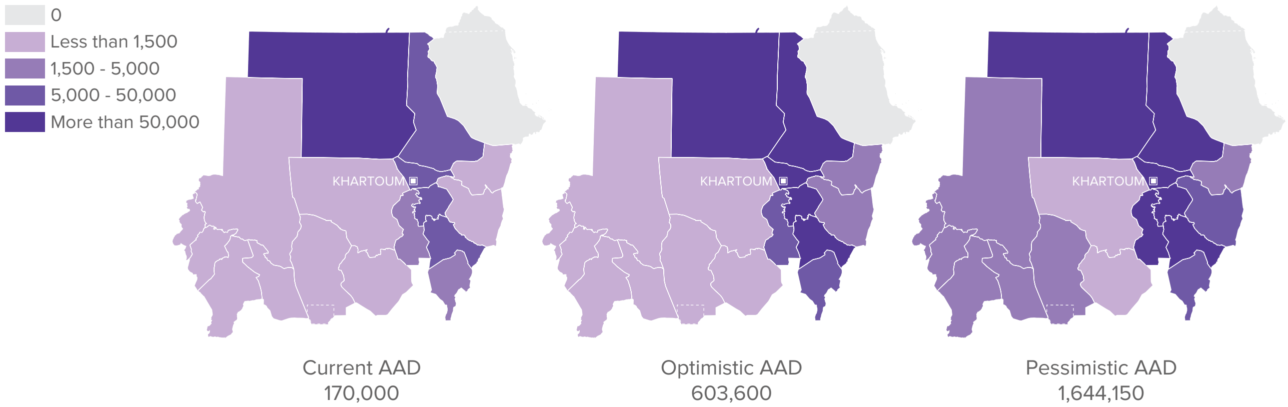
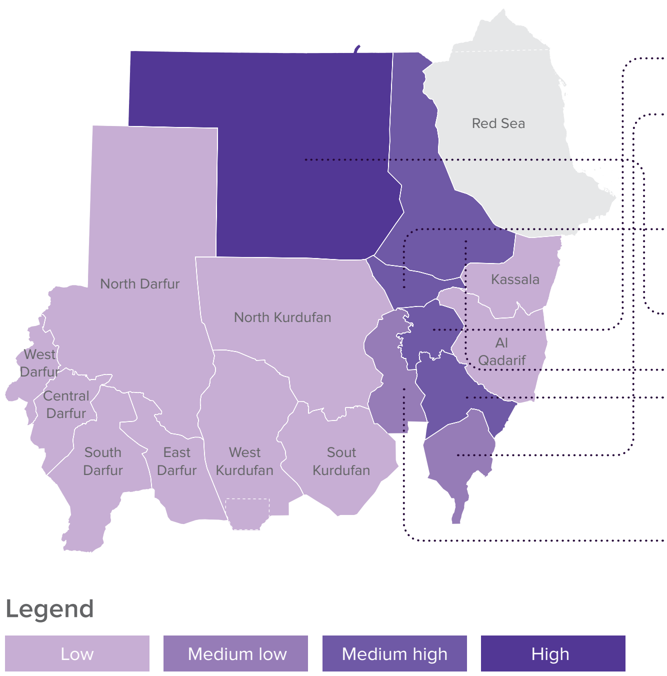


Figure 18: AAD in current climate conditions and in long-term projections under optimistic and pessimistic scenarios in Sudan. Results are aggregated at Admin level 1.



Region	AAD Current	% Male	% Female
Al Jazirah	19,800	52%	48%
Al Qadarif	630	50%	50%
Blue Nile	2,900	49%	51%
Central Darfur	60	51%	49%
East Darfur	20	48%	52%
Kassala	700	45%	55%
Khartoum	42,000	47%	53%
North Darfur	10	49%	51%
North Kurdufan	0	52%	48%
Northern	48,700	49%	51%
Red Sea	0	43%	57%
River Nile	33,200	49%	51%
Sennar	19,600	51%	49%
South Darfur	30	48%	52%
South Kurdufan	10	51%	49%
West Darfur	90	51%	49%
West Kurdufan	10	51%	49%
White Nile	1,900	51%	49%

Figure 19: AAD disaggregated by sex.

While the AAD expresses an average number of expected flood-induced displacements, it tends to hide potential outliers. For this reason, it is useful to compare the PMD curves for present and projected conditions (see figure 20), which show the number of potentially displaced people in connection with frequent (low return periods) or rare (high return periods) events.

Displacements in Sudan would increase significantly for higher return periods. For instance, observing the current climate conditions, the displacements may triple when comparing frequent (e.g. T=5 years) with rare (e.g. T=250 years) events. This trend is also confirmed when analysing the PMD associated to long-term projected climate conditions, for both optimistic and pessimistic scenarios. In this latter case, a 250-year event causes displacement ranging from 0.01 per cent to 25 per cent in the different Admin 1, according to the total population of each region.

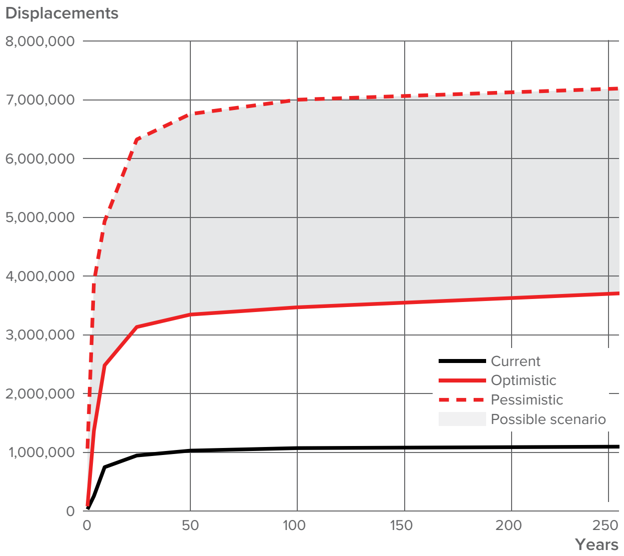


Figure 20: PMD curves for current climate conditions and long-term projections under both optimistic and pessimistic scenarios.

The disaggregation of PMD at country level according to the source of displacement shows that in current climate conditions, almost 60 per cent of displacements are connected to loss of housing. Among the remaining 40 per cent connected to loss of livelihoods, people working in the agricultural sector are the most affected. The same distribution is observed in long-term climate projections although, in this case, the amount of displacements linked to loss of livelihood decreases to around 15 per cent.

Regarding the disaggregation of PMD by origin of the displacement, almost 60 per cent of displacements originated in rural areas. This decreases significantly to 39 per cent in projected climate conditions.

Factors such as future population growth and changes in distribution (e.g. urbanisation), which might significantly change these estimates, are not considered in the modelled future scenarios.

Lack of services is likely not the main driver for displacement after a rapid-onset event. Nevertheless, the combined criticality of loss of housing, work or both alongside a general lack of services in the area could exacerbate the situation. The areas characterised by high

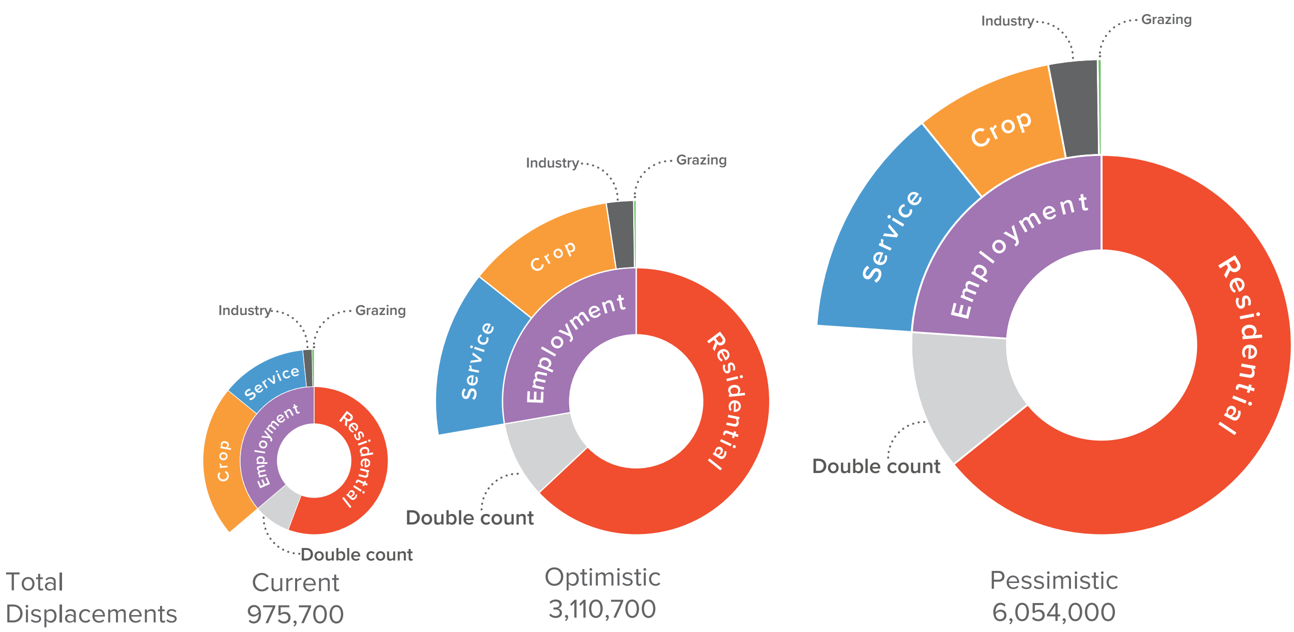


Figure 21: Displacements for a 100-year return period flood event (PMD at 100yrp) disaggregated by cause of diplacement.

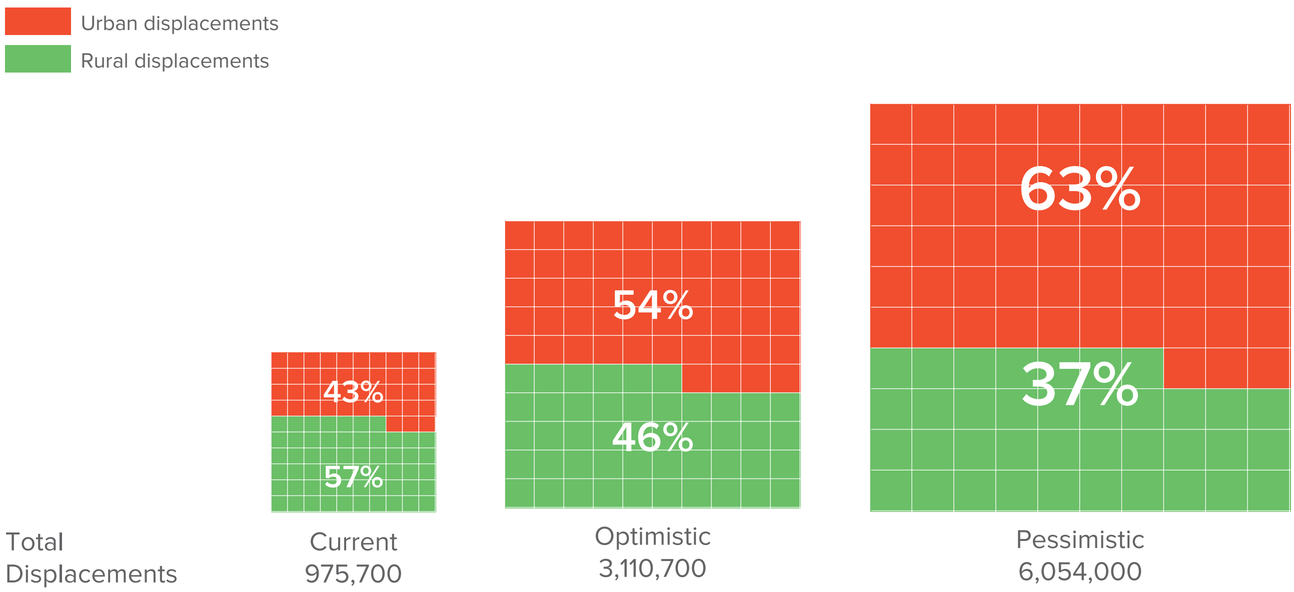


Figure 22: Origin of people's displacement for a 100-year flood event (PMD at 100yrp) at country level.

values of displacement linked to homes rendered uninhabitable or loss of the possibility to work are also characterised by non-negligible lack of access to the educational sector connected to flood events. This can contribute to an increase in vulnerability, ultimately resulting in a higher likelihood of displacement.

Around 50,000 (1.3 per cent) preschool and secondary students would need to relocate elsewhere because of their inability to access severely damaged schools, if the country suffered a 100-year event. All the regions crossed by the Nile and its tributaries, the Blue Nile and the White Nile, are the most vulnerable to the risk of disrupted education services, which can lead to displacement.

Figure 23: Number of students who would lose education services as result of a 100-year flood event.

Conflict and violence left around 3.6 million people living in internal displacement across the country as of the end of 2022. As political instability and unresolved intercommunal tensions persist, disaster risk reduction and resilience strategies have stalled, leaving IDPs particularly vulnerable to disasters, especially flooding.

Shifting displacement dynamics erupted in Sudan in 2023, from intercommunal violence to a nationwide conflict. The situation has had a significant impact on the millions of civilians who are fleeing their homes. All the IDPs in River Nile state, Northern state and White Nile state have arrived from Khartoum state and most of them are seeking shelter with relatives in the host community. A large majority of IDPs, since the military takeover in April 2023, are being hosted in informal settlements in neighbourhoods and villages. There are only 15 official camps (formal settlements).[31]

The overview of the situation in the summer of 2023 indicates that around 4 per cent of the sites accommodating more than 250 IDPs are susceptible to flooding in Sudan. While Gezira state, near Khartoum, has the highest number of sites exposed to flooding, the situation in the states Sennar, Kharthoum, River Nile and Northern, along the Nile river, is particularly serious.

If the country were to experience a 100-year event under the current climate scenario, around 18 per cent of the existing sites of IDPs in the Northern state would face severe damage. This percentage would increase to almost 60 per cent under optimistic scenarios and 76 per cent under pessimistic scenarios.

The situation in the River Nile region is even more concerning. Under the optimistic climate scenario, about 43 per cent of the existing sites would be severely damaged, and this number could escalate to 80 per cent under pessimistic scenarios. In the Khartoum region, near the capital, it is anticipated that about 15 per cent of the existing informal sites would experience severe damage under current climate conditions. This percentage could significantly increase to more than 60 per cent under both optimistic and pessimistic scenarios. In Sennar state, along the White Nile River, around 5 per cent of the existing sites are susceptible to severe damage, a figure that could rise to around 30 per cent under optimistic scenarios and exceed 55 per cent under pessimistic scenarios.

We may be potentially underestimating the actual impact because of the constraints of using points (coordinates) instead of camp areas in this analysis. Considering adequacy of shelter for refugees and displaced people, a minimum surface area of 45 square metres per person is recommended.[32]

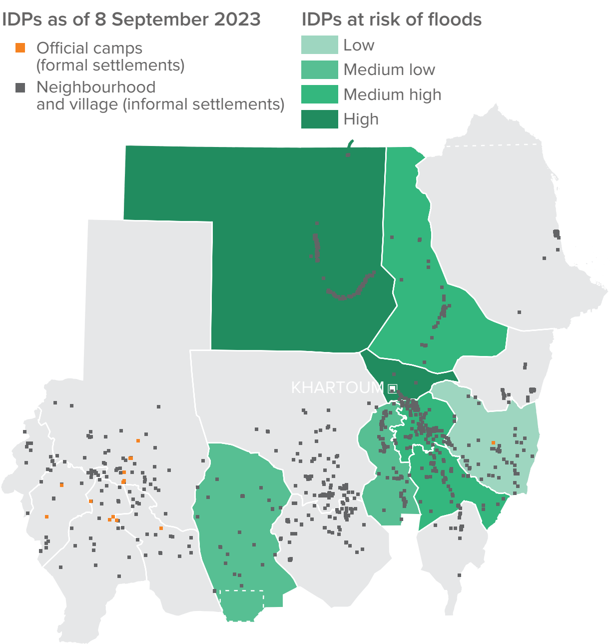


Figure 24: IDP settlements at risk of flooding as result of a 100-year event.

Somalia

Somalia, located in the Horn of Africa, has a relatively limited number of permanent rivers because of its arid and semi-arid climate. While Somalia's rivers might not be as extensive as those in some other regions, they still play a crucial role in providing water for irrigation, livestock and local communities. Because of the country's challenging environmental conditions, these water sources are essential for sustaining life and livelihoods, particularly during times of drought. The Juba and Shabelle rivers are some of the most significant rivers in Somalia. They originate in the Ethiopian Highlands and flow southward through Somalia before emptying into the Indian ocean. Both rivers are prone to seasonal flooding, which can be aggravated by the El Niño Southern Oscillation (ENSO). ENSO exerts various impacts on Somalia's climate variability, leading to increased rainfall and flooding during El Niño events, while causing droughts during La Niña years.

The analysis of flood displacement risk at country level shows an AAD value of around 43,400 people (considering the double counting effect), corresponding to about 0.26 per cent of the overall population. The results highlight a non-negligible influence of climate change. Both the long-term optimistic and pessimistic scenarios show AAD values that triple those in current conditions.

The present spatial risk pattern increases in projected conditions. The most affected administrative units will increase in projected conditions because of climate change, along with the absolute numbers of potentially displaced people in administrative units already affected in current conditions.

Knowledge of gender inequalities in internal displacement is limited, yet indispensable to propose tailored solutions for internally displaced men, women, boys and girls. Internal displacement generally amplifies pre-existing vulnerabilities and inequalities. As women across the world are, on average, economically, legally, politically and socially less empowered than men, internally displaced women are twice as disadvantaged. Figure 25 presents the disaggregation of AAD in current climate conditions at Admin level 1 by sex (male and female).

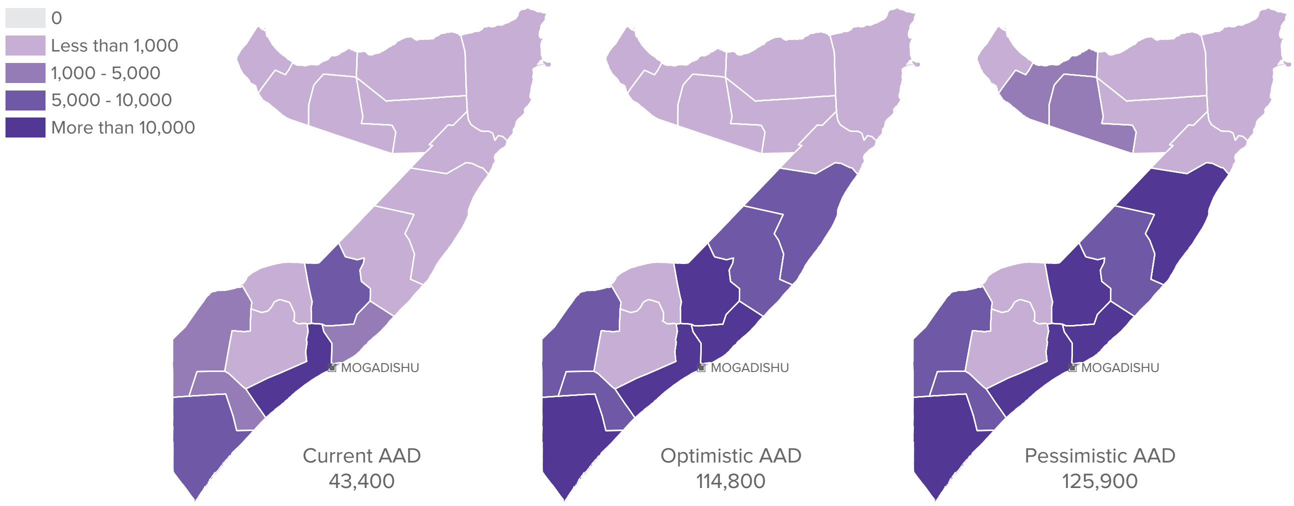
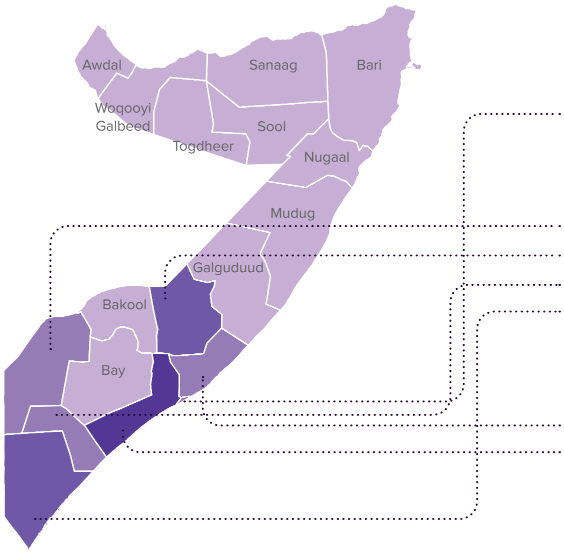


Figure 25: AAD in current climate conditions and in long-term projections under optimistic and pessimistic scenarios. Results are aggregated at admin level 1.



Region	AAD Current	% Male	% Female
Awdal	20	**51%**	49%
Bakool	20	48%	**52%**
Banaadir	1,300	49%	**51%**
Bari	30	49%	**51%**
Bay	10	**51%**	49%
Galguduud	80	**50%**	**50%**
Gedo	2,500	**51%**	49%
Hiiraan	5,060	**51%**	49%
Jubbada Dhexe	2,980	**51%**	49%
Jubbada Hoose	9,640	**51%**	49%
Mudug	120	**52%**	48%
Nugaal	10	**51%**	49%
Sanaag	10	**51%**	49%
Shabeellaha Dhexe	1,030	**50%**	50%
Shabeellaha Hoose	20,500	**50%**	50%
Sool	10	49%	51%
Togdheer	40	50%	**51%**
Woqooyi Galbeed	50	**52%**	48%

Legend

Low | Medium low | Medium high | High

Figure 26: AAD disaggregated by sex.

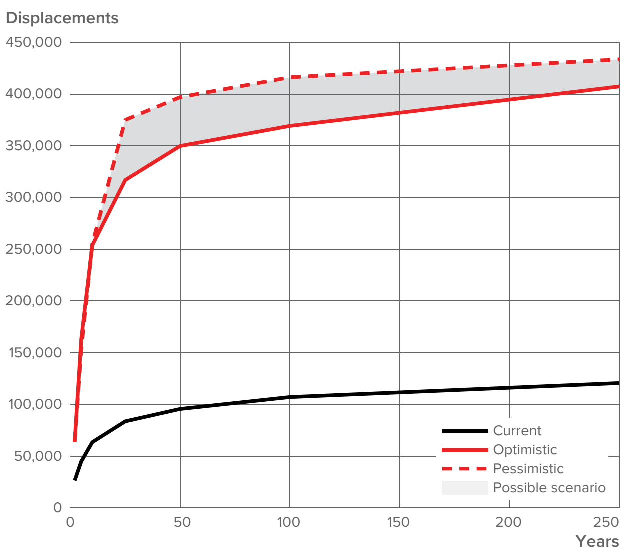


Figure 27: PMD curves for current climate conditions and long-term projections under both optimistic and pessimistic scenarios.

While the AAD expresses an average number of expected flood-induced displacements, it tends to hide potential outliers. For this reason, it is useful to compare the PMD curves for present and projected conditions (see figure 26), which show the number of potentially displaced people in connection with frequent (low return periods) or rare (high return periods) events.

Displacements would increase significantly for higher return periods. For instance, observing the current climate conditions, the displacements triple when comparing frequent (e.g. T=5 years) with rare (e.g. T=250 years) events. This is also confirmed when analysing the PMD associated to long-term projected climate conditions, for both optimistic and pessimistic scenarios. In the latter case, a 250-year event causes displacement

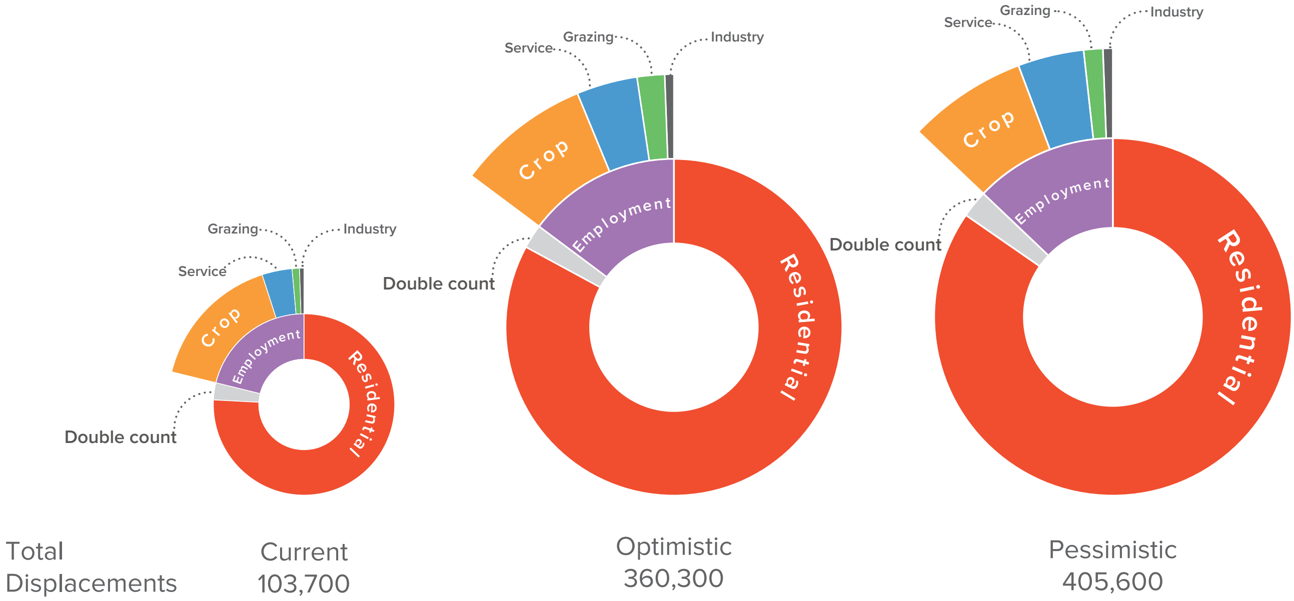


Figure 28: Displacements for a 100-year return period flood event (PMD at 100yrp) disaggregated by cause of diplacement.

ranging from 0.01 per cent to 7 per cent in the different Admin 1, according to the total population of each region.

The disaggregation of PMD at country level by origin of displacement shows that in current climate conditions, almost 77 per cent of displacements are connected to housing rendered uninhabitable. Among the remaining 23 per cent connected to loss of livelihood, people working in the agricultural sector are the most affected. The same distribution is observed in long-term climate projections, although in this case, displacement linked to loss of livelihood decreases to around 14 per cent.

Regarding the disaggregation of PMD by origin of displacement, almost 69 per cent of displacements originated in rural areas. This decreases significantly to 59 per cent in projected climate conditions.

Factors such as future population growth and changes in distribution (e.g. urbanisation), which might significantly change these estimates, are not considered in the modelled future scenarios.

Lack of services is likely not the main driver for displacement after a rapid-onset event. Nevertheless, the combined criticality of loss of housing, work or both alongside a general lack of services in the area can be a worsening factor. The areas characterised by high values of displacement linked to loss of housing or loss of the possibility to work are also characterised by a non-negligible lack of access to education,

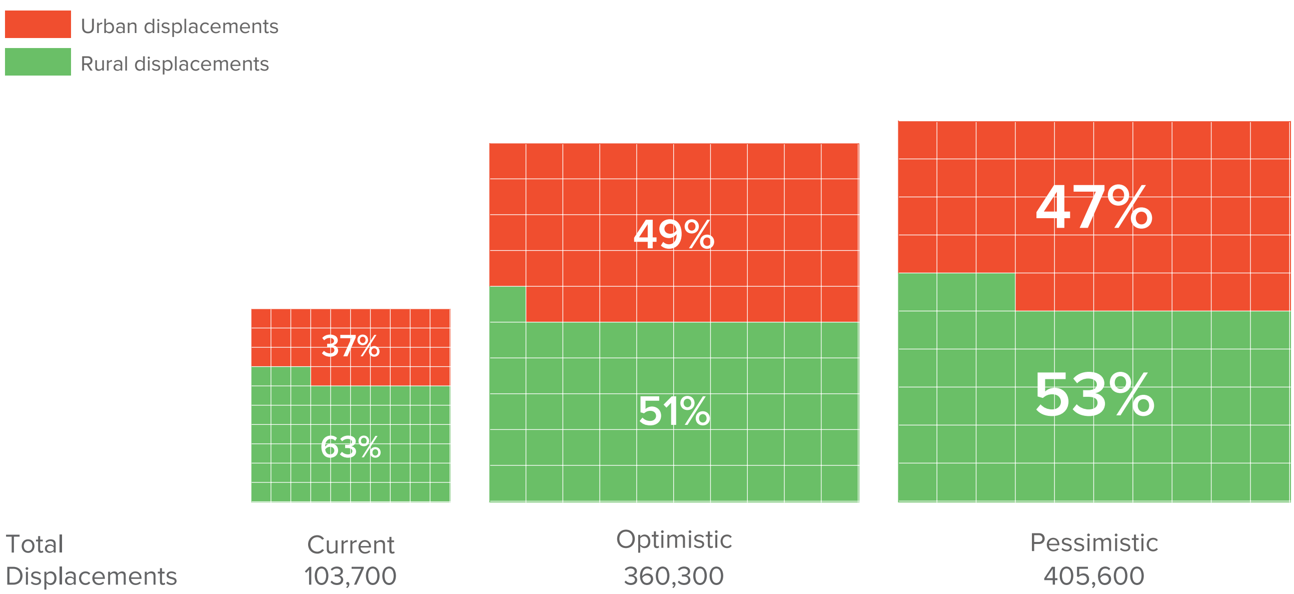


Figure 29: Origin of people's displacement for a 100-year flood event (PMD at 100yrp) at country level.

connected to flood events. This can be a worsening element which increases vulnerability, leading to a higher displacement propensity. Around 1,650 (0.05 per cent) students would need to relocate because of their inability to access severely damaged schools if the country suffered a 100-year event.

As of the end of 2022, nearly 3.9 million people were enduring displacement in Somalia. Over the past three decades, conflict and violence have remained the primary drivers of internal displacement in the region. Ongoing clashes between the military and non-state armed groups, notably al-Shabaab, persistently displace people from their homes. Many of these displaced individuals reside in temporary settlements, which can expose them to the added vulnerability of risk of flooding and the subsequent potential for secondary displacement.

The Camp Coordination and Camp Management (CCCM) – Somalia released an assessment of sites of IDPs in July 2023. At this time, about 4.3 million people were living in displacement situations and 2.2 million were hosted in camps managed by Somali Community Concern, the International Organisation for Migration (IOM), Acted, Danish Refugee Council, and 14 other internal and national organisations.[33] The assessment referenced more than 1,100 sites, which varied from hosting 60,000 people in the biggest site to 180 people in the smallest.

Although the Bay region contains the most sites exposed to flooding, Hiiraan and Mudug are the regions where sites could suffer the most. If the country suffered a 100-year event, under the optimistic climate scenario, about 5 per cent of the sites in Mudug would be severely damaged. This percentage will double under pessimistic scenarios. In Hiiraan, the situation is even more severe, with around 16 per cent of sites severely damaged under the optimistic climate scenario, and around 38 per cent under pessimistic scenarios.

We may potentially be underestimating the actual impact because of the constraints of using points (coordinates) instead of camp areas in this analysis. Considering adequacy of shelter for refugees and displaced people, a minimum surface area of 45 square metres per person is recommended.[34]

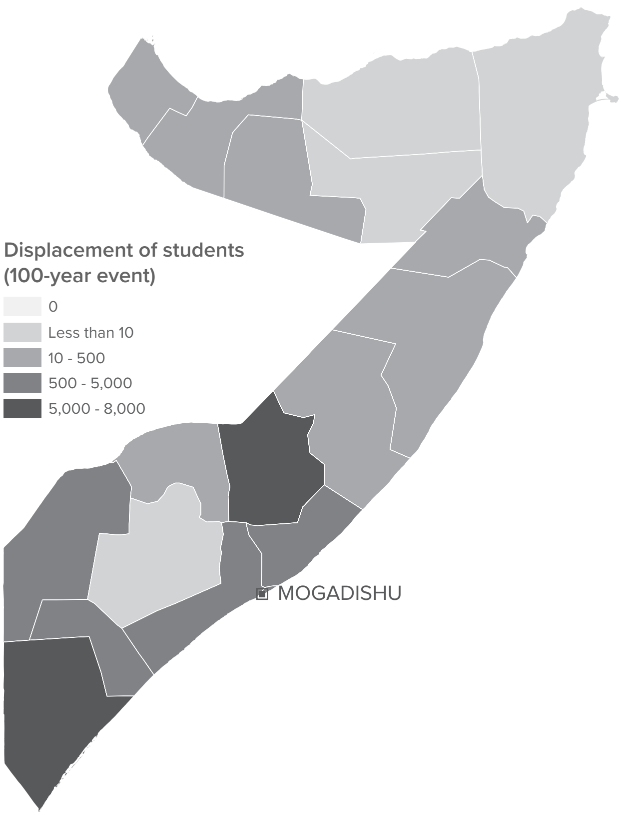


Figure 30: Number of students who would lose education services as result of a 100-year flood event.

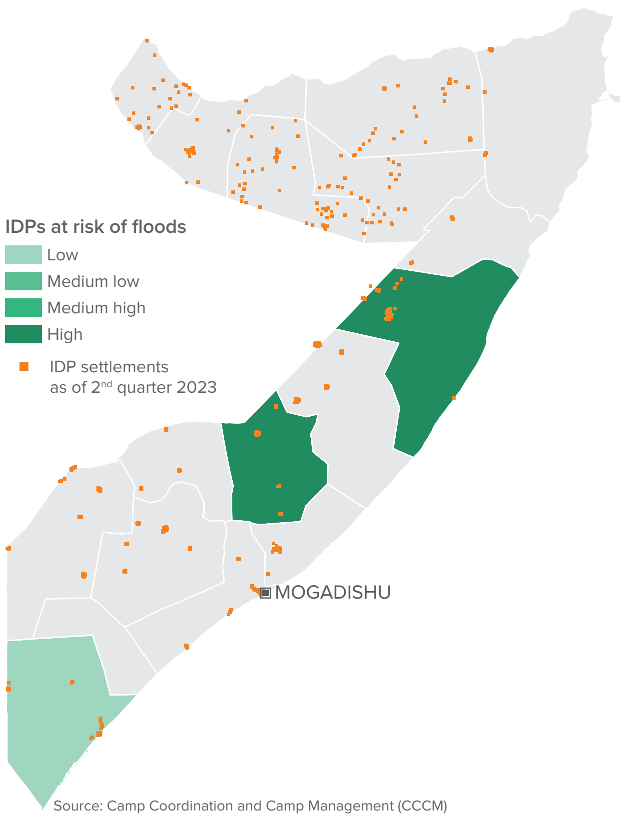


Figure 31: IDP settlements at risk of flooding as result of a 100-year event.

UN Photo/Tobin Jones
12 November 2013
Thousands displaced by floods and conflict near Jowhar, Somalia

Discussion and conclusion

Disaster displacement related to flood events is one of the most important humanitarian and development challenges we face in the 21st century. The Horn of Africa has experienced severe drought year after year, but now the region is also facing the threat of floods. Across Ethiopia, Sudan and Somalia, the rainy season and sporadic rains in certain areas have caused devastating floods, compounding the impacts of the drought and resulting in significant losses of livestock, livelihoods and homes.

This report creates and applies a flood displacement risk model that uses a novel method for vulnerability assessment. The methodology gauges the potential displacement of individuals as a result of riverine floods, taking into account the potential impact on homes and livelihoods. This includes a focus on potential loss of employment and, consequently, income.

We performed a fully probabilistic risk assessment based on a modelling chain that integrates climatic, hydrological and hydraulic modelling, to estimate impacts on physical assets and estimate displacement. The quantification of risk is expressed in terms of average annual displacement (AAD) and probable maximum displacement, computed under current climate conditions and long-term projections according to optimistic and pessimistic scenarios. The outputs of this methodology, which was first applied in two small islands of the Pacific, Fiji and Vanuatu, provide insightful information on the proportions of housing rendered uninhabitable and loss of livelihood, both of which can trigger displacements. We present outputs at Admin level 1 for Ethiopia, Sudan and Somalia, to highlight where the spatial risk pattern increases under projected conditions influenced by climate change, considering optimistic and pessimistic scenarios.

The results show that flood displacement risk may increase under these optimistic scenarios, with AAD two to four times higher than current conditions, depending on the country. Under pessimistic scenarios, the risk might increase by a factor of three for Somalia, four for Ethiopia and even nine for Sudan.

We also conducted an initial analysis of flood risks and their impact on formal and informal sites of internally displaced people (IDPs). Acknowledging that the situation of IDPs can be highly volatile and evolve from day to day, we aimed to emphasise that in certain areas, both formal and informal settlements are situated in flood-prone areas. This could further affect IDPs, leaving them with no choice but to move again as soon as a flood occurs.

The model's results can be used to inform national and subnational disaster risk reduction measures, identify areas where large numbers of people could be made homeless by floods, and calculate evacuation centre capacities and the amount of investment needed to support displaced people. In short, the results will allow decision-makers to make risk-informed efforts to prevent displacement happening in the first place and reduce its impact when it does occur. Through this report, we present some recommendations that can serve as a foundation for developing comprehensive policies and strategies to mitigate displacement risks associated with floods and protect the rights and wellbeing of affected populations.

We need to witness tangible steps in terms of:

- **Vulnerable Populations**

Identify and target vulnerable populations who are at higher risk of displacement. Develop tailored strategies to protect their rights and wellbeing.

- **Conflict and disaster linkages**

Recognise and address the potential linkages between conflict- and disaster-induced displacement, especially in areas where both risks are prevalent.

- **Community-based adaptation**

Support community-based adaptation initiatives that empower local communities to better prepare for and respond to floods.

- **Education and awareness**

Educate the public about flood risk, preparedness and evacuation plans. Promote awareness and community engagement.

- **Capacity building**

Build the capacity of local authorities, non-governmental organisations and communities to respond effectively to flood-related displacement and support recovery efforts.

- **Risk-informed land use planning**

Implement land use planning that considers flood risk at the most granular resolution possible. Avoid construction in high-risk areas and promote resilient infrastructure development. Please note that the current resolution of the model presented in this report is not suitable for informing land use and urban planning decisions.

- **Resilient infrastructure**

Invest in flood-resistant infrastructure and building standards to reduce displacement and damage to property.

- **Insurance and financial instruments**

Promote the use of flood insurance and other financial mechanisms to help individuals and communities recover from flood-related losses.

- **Resettlement**

Develop clear guidelines and policies for the planned and dignified resettlement of displaced populations when necessary.

- **Early warning systems**

Invest in and strengthen early warning systems to provide timely and accurate information to at-risk communities.[35] Ensure that these systems are accessible and understandable for vulnerable populations.

- **Social safety nets**

Establish or strengthen social safety nets to provide support to displaced individuals and families, including access to shelter, food and medical care.

- **Climate change mitigation**

Address the underlying causes of increased flood risk, including climate change. Advocate for and implement climate mitigation measures.

Continued investment in **data collection and research** will also improve the understanding of displacement (roots and causes), vulnerabilities and impacts. Regularly update displacement flood risk assessments.

Data availability, technological advances and growing international recognition of the scale and increasing risk of disaster displacement mean the time is right for more and better-coordinated action to build on good practices and address the challenge of designing effective displacement risk models.

Further efforts are required to effectively quantify future hazard risks, especially with the dynamic background of evolving "riskscapes". The effectiveness of our efforts will naturally improve with the availability of additional data to refine and calibrate our models. This necessitates a comprehensive understanding of population and socioeconomic patterns, along with fluctuations in the frequency and intensity of hazards associated with climate change. To achieve this, we must leverage open-access data, refine terrain models for greater accuracy and acquire more hydrometeorological data.

With support from the EU, this cutting-edge methodology lays a robust foundation for the creation of innovative approaches to assess displacement risk related to sudden hazards, spanning from the subnational to the global scale. The risk of disaster-induced displacement is a global reality, present in every country. Now is the opportune time to demonstrate our collective commitment to the principle of leaving no one behind, particularly those already enduring the challenges of protracted and repeated displacement.

Drought Displacement risk in Ethiopia, Somalia and Sudan

Abstract

The report highlights that drought has led to nearly five million global internal displacements since 2017, with Africa accounting for about 90 per cent of these over six years. Focused on the Horn of Africa (Sudan, Ethiopia and Somalia) and developed under Work Package 3 of the HABITABLE project, the model aims to estimate future internal displacements and support policy formulation. The methodology involves quantifying the link between drought hazard drivers and observed internal displacement, projecting changes under climate-induced variations. Modelling drought-driven displacement employs an impact-based approach with machine learning models, particularly decision trees. It establishes a quantitative relationship between observed impacts and drought hazards to understand system and sector vulnerability.

Using advanced technologies, the study assesses displacement risk using metrics such as average annual displacement and probable maximum displacement. The analysis reveals that while the risk of flood-induced displacement may significantly increase in certain areas, the impact of droughts may remain stable or even decrease in others, a phenomenon known as the East Africa Climate Paradox. For example, in Sudan, the risk of drought-induced displacement may slightly decrease under both optimistic and pessimistic scenarios. In Ethiopia, however, this risk may triple under optimistic scenarios and decrease by a factor of six under pessimistic scenarios. Somalia, meanwhile, demonstrates an increase in displacement risk under both scenarios, with a 50 per cent increase under the pessimistic one.

The outputs can inform national and subnational disaster risk reduction measures, helping identify geographical and socioeconomic landscapes prone to drought displacements.

Keywords

Displacement Risk, Drought, Probable Maximum Displacement, Average Annual Displacement, East Africa Climate Paradox

Introduction

Every year, floods, droughts, storms, earthquakes and other natural hazards force millions of people to leave their homes, a level of displacement greater than that associated with conflict and other forms of violence. Leaving home can be the first of many further disruptions to people's lives: they may be forced to move several times once they become displaced, and it can be weeks or even months before they are able to return home. Those who do return often face unsafe conditions and the prospect of being displaced again by the next disaster.

The Internal Displacement Monitoring Centre (IDMC) detected 36.6 million movements as a result of consecutive disasters in 2022. About 6 per cent, totalling 2.2 million disaster displacements, were triggered by drought. This represents the highest number ever recorded by IDMC since data was first published on this specific phenomenon in 2017.

More intense or frequent severe weather hazards, along with gradual changes in the climate and environment, already affect many people and their livelihoods. This trend is expected to worsen under future climate conditions, particularly in vulnerable regions of the world where livelihoods are already strained as a result of various climatic, political and social factors.[36]

Under the European Commission-funded project HABITABLE, IDMC brings its unique expertise as one of the world's definitive sources of data and analysis on internal displacement. Since its establishment in 1998 as part of the Norwegian Refugee Council, IDMC has offered a rigorous, independent and trusted service to the international community. Its work informs policy and operational decisions that improve the lives of the millions of people living in internal displacement or at risk of becoming displaced in the future. The objective of this report is to advance understandings of the current interlinkages between climate impacts and migration and displacement patterns, and better anticipate their future evolution.

Under Work Package 3 of the HABITABLE project, we support the development of models to produce empirically calibrated estimations of future human mobility caused by drought hazards as the effects of climate change deepen in Ethiopia, Sudan and Somalia. This report accompanies the one focusing on flood displacement risk in the same area. To assess drought displacement risk, we also collaborated with knowledgeable partners and explored new technologies, such as machine learning, to make progress in this emerging field of research.

Severe and prolonged droughts result in reduced soil moisture and drinking water reserves, causing crop and livestock loss. Such drought disasters are detrimental to regional economies because they produce income losses, threaten food security, and worsen conflicts and violence among communities. Severe droughts affect millions of people in the Horn of Africa drylands.

Internal displacement must be addressed in the context of drought risk, especially in regions like Somalia, Ethiopia and Sudan, which are prone to slow- and fast-onset hazards, with an increasing impact on human mobility in the region.[37]

This report presents a future drought displacement risk assessment at the national and subnational level for three countries in the Horn of Africa, through the application of a new methodology developed jointly by the International Center for Environmental Monitoring (CIMA Research Foundation, Italy) and the Vrije Universiteit Amsterdam. Tackling drought-related mobility, and particularly drought displacement, from a data-driven perspective is still at an early stage. More advanced methodologies have only been applied in this area in the past decade.[38]

For Work Package 3 of the HABITABLE project, we reveal the magnitude of displacement risk by comparing present climate conditions with various future scenarios, highlighting the potential disparities. Given the diverse geographical and socioeconomic landscapes of Ethiopia, Somalia and Sudan, it is crucial to recognize how exposure to drought hazards may vary and affect different regions in these countries.

Methods

Drought-induced displacement risk concepts

Disaster displacement risk and vulnerability

The term disaster displacement refers to a situation in which people are forced to flee their homes or places of habitual residence because of a disaster or to avoid the impact of an impending natural hazard. Forced displacements generally occur when people are exposed to a natural hazard in situations where they are too vulnerable and lack the capacity to face the hazard's impacts.[39]

The UN Office for Disaster Risk Reduction (UNDRR) defines a disaster risk as "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity".[40] It is important to consider the social and economic background in which disaster risks occur and understand that people do not necessarily share the same perceptions of risk or underlying risk factors.

Like disaster risk, disaster displacement risk is linked to the nature and magnitude of a given hazard, and to people's exposure and vulnerability. Risk analysis reveals the likelihood of future disasters triggering displacement. Evaluating vulnerability levels proves valuable in understanding why severe events do not consistently yield proportionally severe consequences for populations and regions, whereas events of lesser severity can result in profound impacts. In other words, it clarifies why two hazards of similar intensity and duration could have different consequences in terms of damage, people affected and people displaced.

Drought disaster risk and vulnerability

Drought disaster risk and vulnerability stem from the interplay of various factors. Vulnerability is defined as the conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of individuals, communities, assets or systems to the impacts of hazards.[41] The vulnerability of humans is influenced by a variety of economic, social, cultural, environmental, institutional, political and psychological aspects that mould the lives of individuals and the world around them. Factors including income, education and healthcare access play a role in determining individuals' vulnerability levels. Depending on these elements, vulnerability levels tend to vary across a community or a population. Vulnerability is not static. Rather, it changes over time, because it comprises several dimensions. The higher the level of vulnerability, the greater the probability of being harmed by a disaster.

Drought-induced displacement

Drought combines with socioeconomic and governance factors to set the stage for specific triggers of displacement. These triggers encompass loss of land, loss of livelihood and loss of access to essential resources such as food and water.

Soil degradation and rising temperatures may contribute to nutrient loss and erosion, devastating agricultural practices and severely affecting livestock and pastoralist activities. When such factors combine with drought, people's livelihoods can become irretrievable. Nomadic pastoralist and agro-pastoralist communities, for example, find themselves increasingly displaced from their traditional territories, relocating to nearby small towns and peri-urban areas. Although there is emerging evidence of these dynamics, it remains largely anecdotal and inadequately documented. The absence of comprehensive data makes drought modelling complex.

Sudan, Ethiopia and Somalia were home to 16.6 million internally displaced people (IDPs) at the end of 2023. These countries are exposed to a mix of conflicts and meteorological shocks every year, which not only trigger movements but also lead to protracted displacement situations.

The need for a broader risk assessment approach

Methods for assessing the risk of disaster-induced displacement have traditionally determined vulnerability levels by employing hazard thresholds as a substitute for displacement, as was done in our 2017 report.[42] This implies that if a disaster renders a residence uninhabitable, its occupants will encounter displacement, even if only temporarily. This approach allows for an estimation of the potential magnitude of future displacement. Evaluating drought-induced displacement risk, however, presents greater complexity than assessing sudden-onset hazards such as storms, floods or earthquakes. Despite this complexity, these detailed assessments must consider various human factors.

The direct and indirect impacts of drought pose significant challenges for populations that depend primarily on natural resources. The impacts can generate severe disruptions in people's livelihoods, food security, the economy and ecosystems[43]. Drought-induced displacement occurs when the direct or indirect impacts of drought push communities to critical thresholds and erode their traditional coping strategies (such as mobility), making livelihoods unsustainable or unviable. Drought and its impacts are among the most difficult hazards to monitor, more so than sudden-onset disaster events. Droughts are episodic (time-limited events), complex and multifaceted phenomena that result from intricate interactions between natural processes and human activities.

Drought-affected mobility is a multicausal and multidimensional phenomenon where no driver can be determined as the single reason for displacement. Its dynamics emerge, instead, from a combination of socioeconomic, political and environmental drivers that interact at different spatiotemporal scales in non-linear ways.[44] When does population displacement become forced and unusual? The distinction between voluntary and forced displacement is often difficult to discern.[45]

Drought crisis events also involve intrinsic complexities, such as the duration of the hazard, uncertain onset times, the influence of compound effects (e.g. land degradation over the years) and climate patterns (e.g. El Niño/Southern Oscillation). There is no single definition of drought. Researchers have defined several types, such as agricultural, hydrological, meteorological and socioeconomic droughts (see figure 1).

Figure 1: Different types of droughts [NOAA].

As the UNDRR states, the damage and costs caused by drought are usually underestimated because of extended and cascading impacts and are often not attributed to the drought because most impacts are indirect (UNDRR, 2021). Drought, for example, may trigger food and water security crises in regions where there is poor water and land management. Conflict over scarce resources may then arise, generating demographic pressures and exacerbating a drought's widespread impacts.[46] These processes are intertwined, affecting the social and ecological dimensions that may trigger displacement.

With increased data availability on the topic, IDMC compiled data for drought-associated displacement for the first time in 2017. An estimated 1.3 million movements were recorded, primarily in the Horn of Africa.

IDMC has identified drought displacements in 17 countries since 2017, resulting in 4.9 million internal displacements. Notably, almost 80 per cent of these displacements were recorded in Somalia and Ethiopia (although in the latter case with only a few data points). Unfortunately, no data was available for Sudan.

This discrepancy in reporting on drought-induced displacements can be attributed to several factors:

1. Not all drought events result in disasters or trigger displacements.
2. Because of the slow development and creeping nature of a drought's impacts, determining that it has been a trigger of displacement is challenging, as drought can be a direct or indirect trigger of internal displacement.
3. There is often a reactive approach to monitoring displacement events resulting from drought. For this reason, several countries do not engage in regular monitoring of it.
4. The magnitude of drought-induced displacement can often be small, involving only a few families, which makes it difficult to track and monitor accurately.

The existing data gap poses a challenge in assessing long-term impacts and developing robust models to evaluate short, medium and long-term displacement risks. The scarcity of data is a primary obstacle to the calibration of parameters in displacement drought modelling approaches. For the moment, however, only in situ measurements, such as the International Organization for Migration's Displacement Tracking Matrix (IOM-DTM) in Ethiopia, the UN Refugee Agency's (UNHCR's) Population Movement Tracker, and the Protection and Return Monitoring Network (PRMN) data in Somalia, are available as reliable data sources of drought internal displacement for modelling purposes.

Probabilistic risk assessment

In the past few decades, academics and operational actors have tried to understand and model drought as a trigger of displacement. Few projects or academic publications, however, have focused on the modelling of drought-induced internal displacement from a data-driven perspective.[47]

Recent advances in data acquisition methods related to displacement monitoring, Earth observation using satellite imagery and the appearance of alternative data sources have boosted the potential for and development of novel techniques to model and quantify the impacts of events and estimate levels of drought displacement.[48]

For this study, we combine probabilistic risk assessment from a data-driven perspective using machine learning (ML). It is important to regard a probabilistic disaster displacement risk profile as a diagnostic tool, because it offers insights into potential hazard occurrences and their likely consequences. Such profiles cover all possible risk scenarios in a certain geographical area, ranging from low-frequency, high-impact events to high-frequency, low-impact events.

Events that have rarely been recorded but might occur more often under climate projections are thus also considered. This feature is particularly useful because climate change is increasing uncertainty about future hazard patterns. To be prepared, societies need to calculate the worst possible impact. Viewed through this lens, there is no valid alternative to a probabilistic analysis to address such uncertainty in a usable, quantitative way.

Displacement risk information, expressed in average annual displacement (AAD) and probable maximum displacement (PMD), is calculated at the subnational regions and aggregated at country level, allowing for a geographic and quantitative comparison within and between countries. These analyses and comparison exercises are an important step in risk awareness processes and key to pushing for risk reduction, adaptation and management mechanisms to be put in place.

The AAD estimate shows the average amount of drought-induced displaced people on yearly basis. Most years, displacement numbers are low, but some years, because of drought conditions, displacement will be elevated. Thus, the AAD gives an indication of the overall size of the problem, averaged over time. The PMD curve illustrates the probability of a specific scenario leading to an estimated number of displacements. This likelihood is usually measured in terms of return period.

A return period is the average time interval in years that separates two consecutive events equal to or exceeding the given magnitude. This concept, however, is often misunderstood. The most common misconception is that an event with a 100-year return period will only occur once a century, when instead it means that it has an exceedance probability of 1 in 100, so events of the same or greater intensity happen once every 100 years on average. This does not rule out the occurrence of several events with a 100-year return period within a century, or the rare possibility of back-to-back events happening in consecutive years. Neither does it eliminate the possibility of an entire century passing without such an event occurring.

To assess drought displacement risk for this study quantitatively to estimate AAD and PMD, we have used a data-driven approach that correlates the number of displacements with hazard drivers, along with the probability risk assessment.

Drought displacement risk assessment

Our novel approach aims to address the deficiencies in existing displacement risk models (system dynamics, gravity model, logistic regression and timeseries forecasting models) and provide a more comprehensive assessment, by starting from impacts felt on the ground (displacement of people) and considering a wide range of hydrometeorological drought indicators to capture a variety of ways that drought impacts can develop in a region (see figure XX). This section describes, step by step, the model chain (see figure XX). It starts an assessment of drought hazard followed by vulnerabilities linked to ecological zones, evaluation of the people exposed to droughts and observed impacts on displacement. This is all brought together in an ML-based risk-impact assessment model, to evaluate the annual average and probable maximum drought-induced displacement.

Figure 2: Model chain to evaluate the drought-induced displacement risk.

Drought hazard assessment

A drought hazard assessment aims to systematically analyse the likelihood and magnitude of drought occurrences, considering different climate variables.

Drought indices are frequently used in drought assessments to characterise hazard conditions. Indices are proxies that indicate the abnormality of the water availability in the hydrological cycle: the atmosphere (meteorological drought indices), hydrological system (hydrological drought indices) and the soil (agricultural drought indices).

In this study, drought indices are computed based on:

- root-zone and surface soil moisture, potential evaporation from the Global Land Evaporation Amsterdam Model (GLEAM, 0.25-degree resolution, Martens et al., 2017; Miralles et al., 2011)
- precipitation from the Multi-Source Weighted-Ensemble Precipitation (MSWEP, 0.1-degree resolution, Beck et al., 2019)
- temperature from the Multi-Source Weather (MSWX 0.1-degree resolution, Beck et al., 2022)

These physical variables are used to calculate the following drought indices at various accumulation times (1, 2, 3, 6, 9, 12 and 24 months):

- SPI: standardised precipitation index (identifies rainfall deficits)
- SEI: standardised evaporation index (potential, atmospheric water demand)
- SPEI: standardised precipitation-evaporation index (effective rainfall)
- SETI: standardised precipitation/evaporation ratio index (aridity, water balance)
- SSMI: standardised soil moisture index (related to plant root moisture)
- SSFI: standardised surface moisture index (related to runoff, streamflow)
- STI: standardised temperature index (identifies heat waves)

All indices are calculated on a monthly temporal scale from 1980 to 2022 at Admin 2 level. The inclusion of 2022 is intended to maximise the overlap with the drought-induced internal displacement data.

As drought is a deviation from normal conditions, it is not straightforward to visualise drought indicators. An average of standardised drought hazard indices will not show any spatial variability. Nevertheless, mapping how often (monthly) indicators are below a certain threshold value illustrates how variable the hydrometeorological situation is, and thus gives a first indication of how often hydrometeorological drought conditions are expected to occur.

To investigate how climate change may alter the future frequency and intensity of extreme severe weather events, within exceedance probabilities and return periods, our assessment also considers different timescales:

- under current climate conditions, using observations from 1981 to 2022
- under long-term projected conditions from 2051 to 2092

To capture the spread of possible future climate scenarios, we compared 15 realisations of five models from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b), which provides bias-corrected Coupled Model Intercomparison Project Phase 6 (CMIP6) future climate scenarios for SSP1-RCP2.6, SSP3-RCP7.0 and SSP5-RCP8.5 conditions (besides pre-industrial and historical runs), in terms of temperature and precipitation rise in 2016. Temperature and precipitation trends proved to be highly correlated in the models considered, so we referred only to temperature trends to define representative scenarios. From the 15 realisations (three scenarios and five global climate models), we selected two:

- optimistic: the scenario closest to the 20th percentile, corresponding to an average temperature rise of about 1°C by 2100
- pessimistic: the scenario closest to the 80th percentile, corresponding to an average temperature rise of more than 5°C by 2100

The climate scenarios were used to force the fully distributed, process-based hydrological model called Continuum.[49, 50, 51]. The hydrological processes for all basins in Ethiopia, Sudan and Somalia were simulated at a 4-kilometre resolution, obtaining projected daily series of flow, evapotranspiration and soil moisture, for each pixel in current and projected climate conditions.

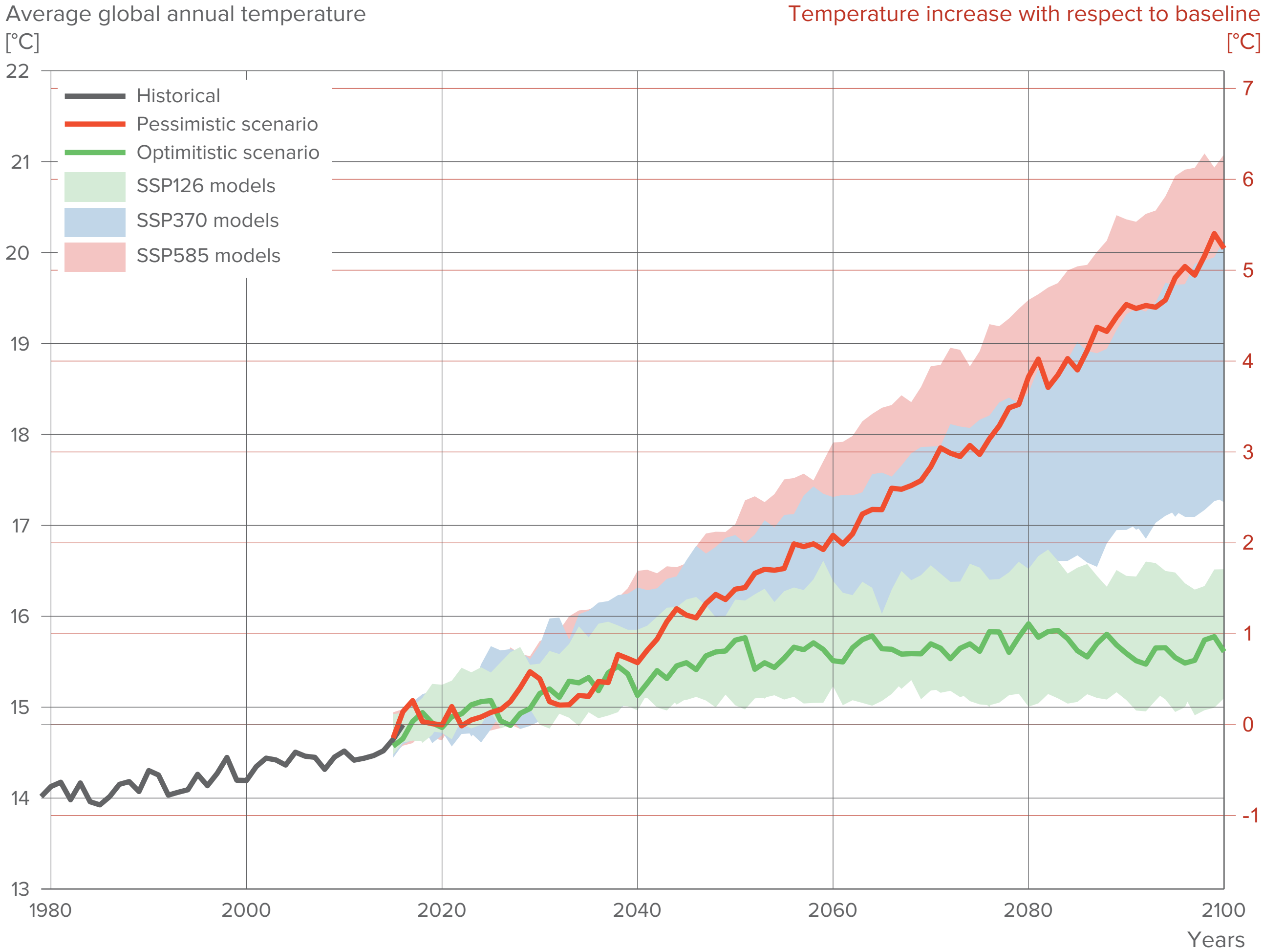


Figure 3: Model projections of future climate scenarios from ISIMIP3b.

We then employed the widely used "delta-change" approach,[52] which involves using the simulated projected change (anomalies) as a perturbation of observed data.[53]

In figures 4, severe drought hazard conditions is illustrated as the annual likelihood of having the considered drought index (either the standardised precipitation index, SPI, or the standardised precipitation-evaporation index, SPEI) 1.5 standard deviations below normal for three consecutive months. This does not say anything about the impacts felt but shows how much area is hit by severe droughts and at what frequency.

In figure 4, the drought hazard conditions are shown for Somalia, Ethiopia and Sudan under current, optimistic and pessimistic climate scenarios.

On each of the figures of the three countries, it is evident that climate change will affect precipitation in a "positive" way (more rain) and temperature in a "negative" way (more heat). Hence, SPI decreases in projected scenarios, while SPEI, with potential evaporation strongly linked to temperature, increases generally in the projected climate scenarios.

As a result of the high increases in temperature and thus atmospheric water demand, the likelihood of experiencing a "effective precipitation" deficit (i.e. atmospheric water supply [rain] minus atmospheric water demand [potential evaporation]) becomes almost 100 per cent in Somalia, larger part of Ethiopia and Sudan. This means that the effective precipitation conditions currently experienced as a severe drought will become "normal" under unmitigated anthropogenic climate change.

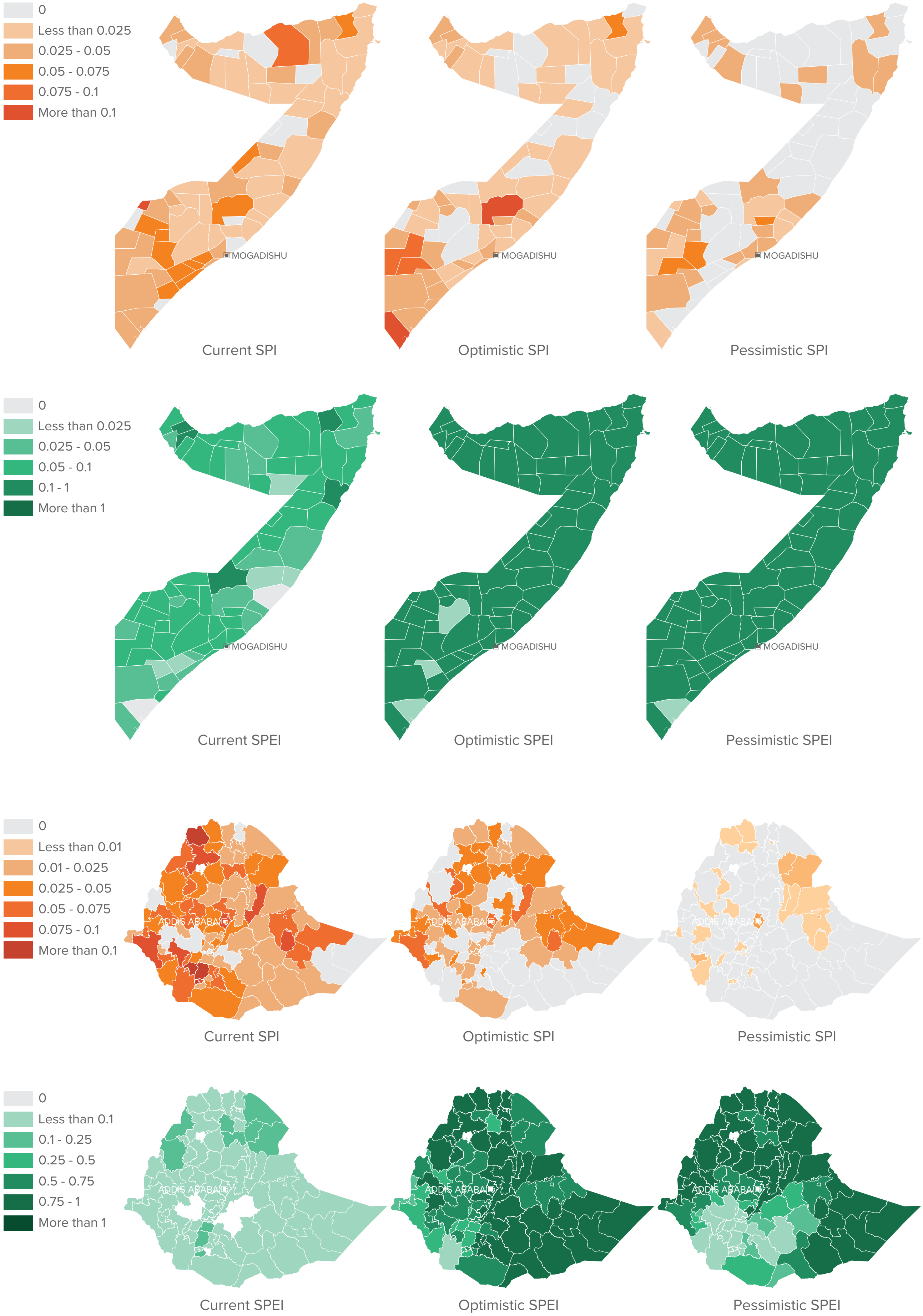
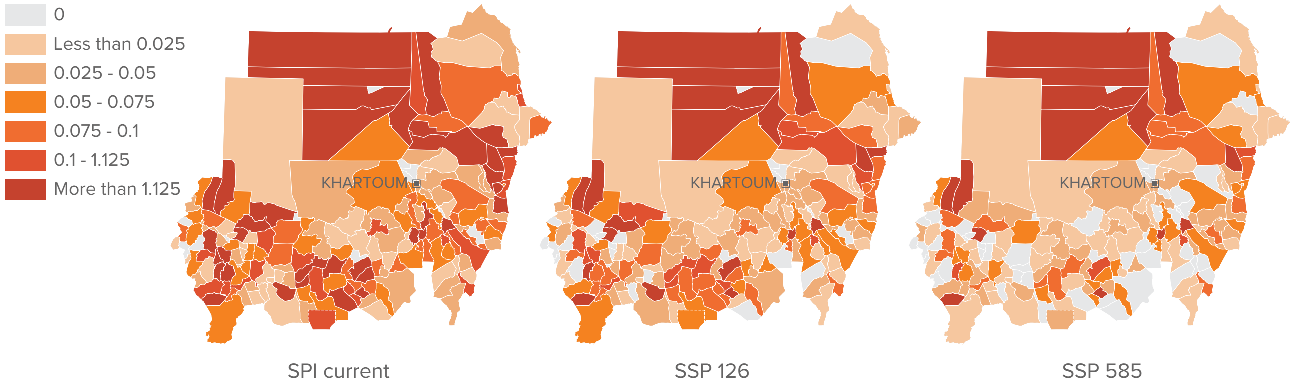
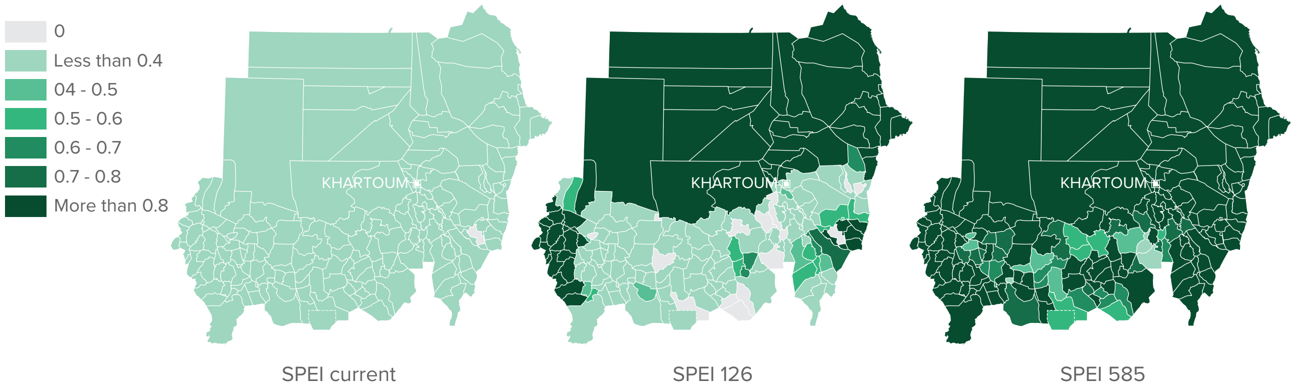


Figure 4: Annual likelihood of having the standardised precipitation index, SPI (left) or the standardised precipitation-evaporation index, SPEI (right) 1.5 standard deviations below normal, for three consecutive months.


0
Less than 0.025
0.025 - 0.05
0.05 - 0.075
0.075 - 0.1
0.1 - 1.125
More than 1.125
KHARTOUM
KHARTOUM
KHARTOUM
SPI current
SSP 126
SSP 585


0
Less than 0.4
04 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
More than 0.8
KHARTOUM
KHARTOUM
KHARTOUM
SPEI current
SPEI 126
SPEI 585

Thus, even though current trends show the opposite, the climate model used in this study projects an increase in precipitation under global warming. This is a phenomenon known as the East Africa Climate Paradox (Rowell et al 2015) and is visible as a decreasing likelihood of severe rainfall deficits in our drought hazard results.

Box 1: East Africa Climate Paradox.

In climate science, significant research efforts are underway to develop climate models that deepen our understanding of past climate conditions and anticipate future climate scenarios. These models play a crucial role in climate research, allowing scientists to simulate various climate scenarios and assess their potential impacts. The recent report by the Intergovernmental Panel on Climate Change is a notable example of research that integrates climate modelling to better support the "state of knowledge about possible climate futures".

In East Africa, existing climate models suggest an increase in precipitation during the annual long rainy season, which typically spans from March to May. Projections from these models indicate that this trend will persist throughout the region until the end of the century. The actual experience of people living in this region, however, contradicts these projections. Since the 1980s, there has been a noticeable decline in the long rainy season. These alterations in rainfall patterns pose significant challenges to the local population. This disparity between projected outcomes and observed trends is commonly referred to as the East African Climate Paradox[54, 55, 56].

Under Work Package 3 of the HABITABLE project, IDMC has also developed a report on flood displacement risk in Ethiopia, Somalia and Sudan. The methodology used incorporates a unique vulnerability assessment, considering factors often omitted in standard risk models, such as direct impacts on houses, livelihoods, and critical facilities and services. The assessment uses a probabilistic approach, integrating climatic, hydrological and hydraulic modelling, to estimate the impacts triggering displacement. The results, evaluated under current and future climate conditions with optimistic and pessimistic scenarios, indicate a potential increase in AAD of two to four times compared with current conditions, with even higher risks for pessimistic scenarios, such as a ninefold increase for Sudan.

These results underscore the significance of understanding the diverse dynamics associated with climate change impacts across different regions. Both analyses, focusing on droughts and floods respectively, demonstrate that while the risk of displacement linked to floods may increase drastically in certain regions, the impact of droughts may remain stable or even decrease in certain areas.

Vulnerabilities for drought and how to assess it

In risk modelling, it is crucial to recognise that risk deviates from vulnerability, highlighting the dynamic interplay of various factors influencing the potential impact and likelihood of adverse events. Incorporating vulnerability into drought risk equations presents several challenges, however.

Vulnerability is a complex concept influenced by various physical, social and economic factors. Capturing this complexity and integrating it into a quantifiable model poses significant challenges, including that of data availability. Reliable data on vulnerability factors, such as socioeconomic conditions, infrastructure resilience and community preparedness, may be lacking or incomplete. Inconsistent or sparse data can hinder accurate vulnerability assessments. Moreover, drought vulnerability is often connected to other risks, such as food security, water scarcity and health issues. Integrating these interdependencies into a comprehensive model adds complexity to the risk equation. Additionally, vulnerability varies across different regions and over time. Developing a model that accommodates this spatial and temporal variability requires sophisticated methodologies and dynamic data inputs.

In our modelling exercises, vulnerability is statistically derived as the link between specific drought drivers (combinations of hydrometeorological indicators and observed impact) and displacement, in Admin 2-level regions for Somalia, where comprehensive data was collected over time. Thus, region-specific socioeconomic and environmental challenges are included as the sensitivity of regions to drought triggers. As such, no a priori assumptions need to be made about vulnerability; it is instead represented by the derived link from the data analysis.

Exposure layers to assess drought displacement risk

Population data constitutes the exposure layer, a fundamental component in risk modelling. Exposure layers provide spatial information about the distribution and characteristics of populations within a specific area.

Population data was retrieved from WorldPop 2020[57], which rescales to match the corresponding UN Population Division estimates[58].

For absolute population numbers for the years 2021 and 2022, the population was estimated by extrapolating the population increase from 2016 to 2020. The specific population data of 2022 was used for Somalia to convert absolute numbers of displacements to relative numbers. This allowed us to pool and compare different regions. For Ethiopia and Sudan, no model training was done because of the lack of observed displacement data, and the WorldPop population for 2020 was used as a baseline to derive absolute numbers from relative displacement percentages.

In our climate change scenarios, we did not consider changes in exposure and vulnerability between current and future climate conditions. Nonetheless, it is worth noting that factors such as population growth and distribution may greatly alter the future "riskscape".

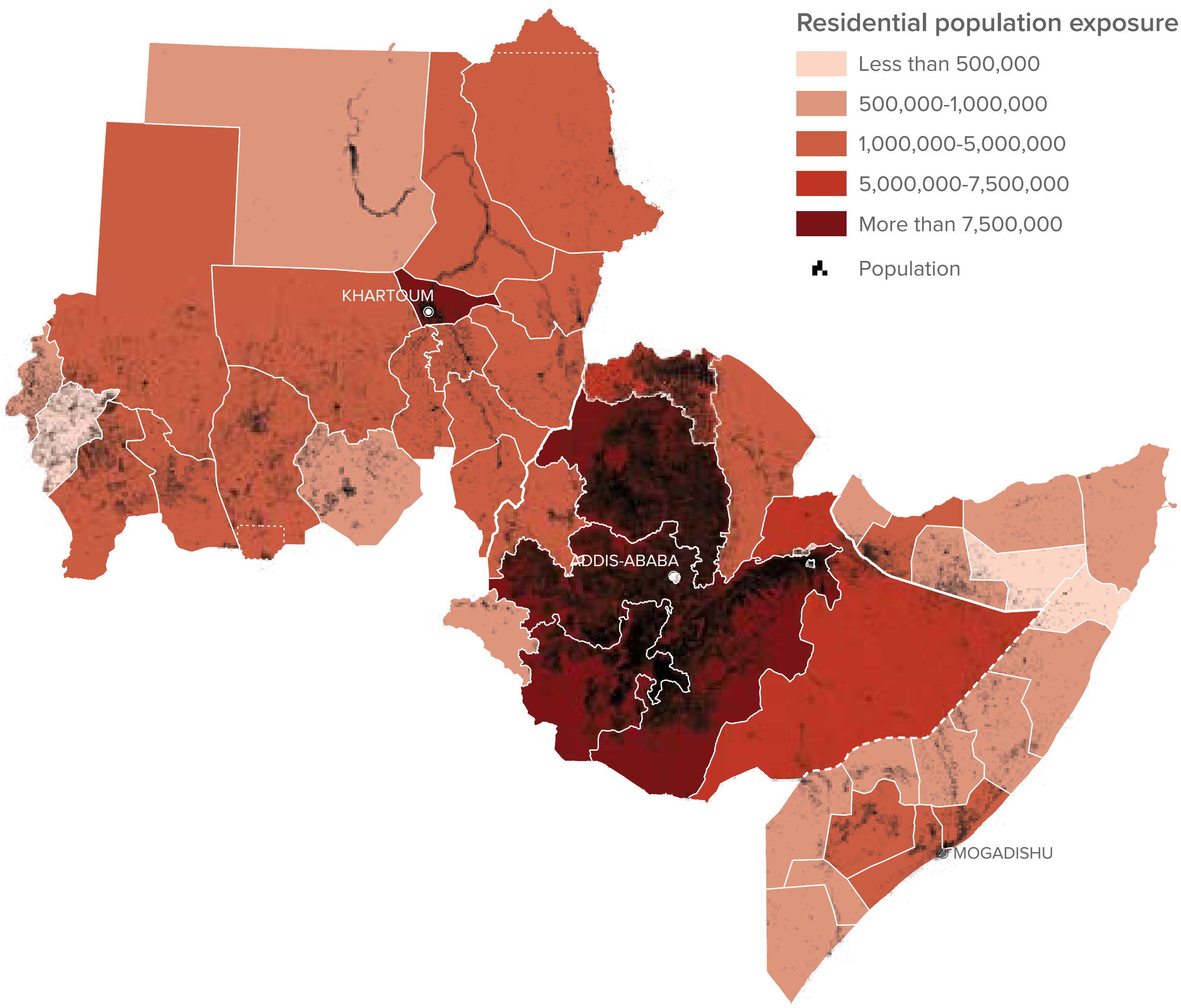


Figure 5: WorldPop and Center for International Earth Science Information Network (CIESIN) (2018). Global High Resolution Population Denominators Project.

Observed data on internal displacement from drought

In this study, we investigated drought displacement in the Northern Horn of Africa region, more specifically in Sudan, Ethiopia and Somalia. For Ethiopia and Somalia, national-level figures on drought-induced internal displacements were accessible for five years, from 2017 to 2022, through the IDMC database (GIDD).[59]

While displacements were recorded in Somalia and Ethiopia (although in the latter case with only a few data points), unfortunately, no data was available for Sudan, particularly regarding drought displacement.

Sudan is known to be exposed to recurrent drought episodes. According to the EM-DAT database, four major drought events have occurred there since 2000, affecting millions of Sudanese[60][61]. There is no evidence of displacement from these events, however, apart from anecdotal information. For example, the most recent drought in 2022 affected 11 million people, but there is no data confirming the number of displacements.

In Ethiopia, data points are available at Admin 1 level through rigorous data collection efforts by IOM-DTM. In Ethiopia and Somalia, information about people displaced by drought has been gathered through people from affected households seeking assistance with shelter and non-food items. Families seeking refuge with relatives were not tracked by these assessments.

Compared with Ethiopia, Somalia offers additional, highly detailed data, provided by the PRMN of UNHCR.[62] This data set records flows of movements and contains monthly numbers of displaced people, by departure location, on Admin 2 level in Somalia. The identification and location of the different settlements of IDPs in Somalia has been considered using the Camp Coordination and Camp Management (CCCM) list of sites of IDPs for the second quarter of 2023, referencing more than thousands of points.[63] A large advantage of this data is that the reason for displacement is classified by hazard, which made it possible to select only drought-related displacements. This data set also covers a longer period, from 2016 to 2022, with solid information on drought-induced internal displacements.

To evaluate the effect of droughts on population movements, figures were normalized by dividing the monthly number of drought-related IDPs by the population count per Admin 2 level from WorldPop (2018). This makes the number of

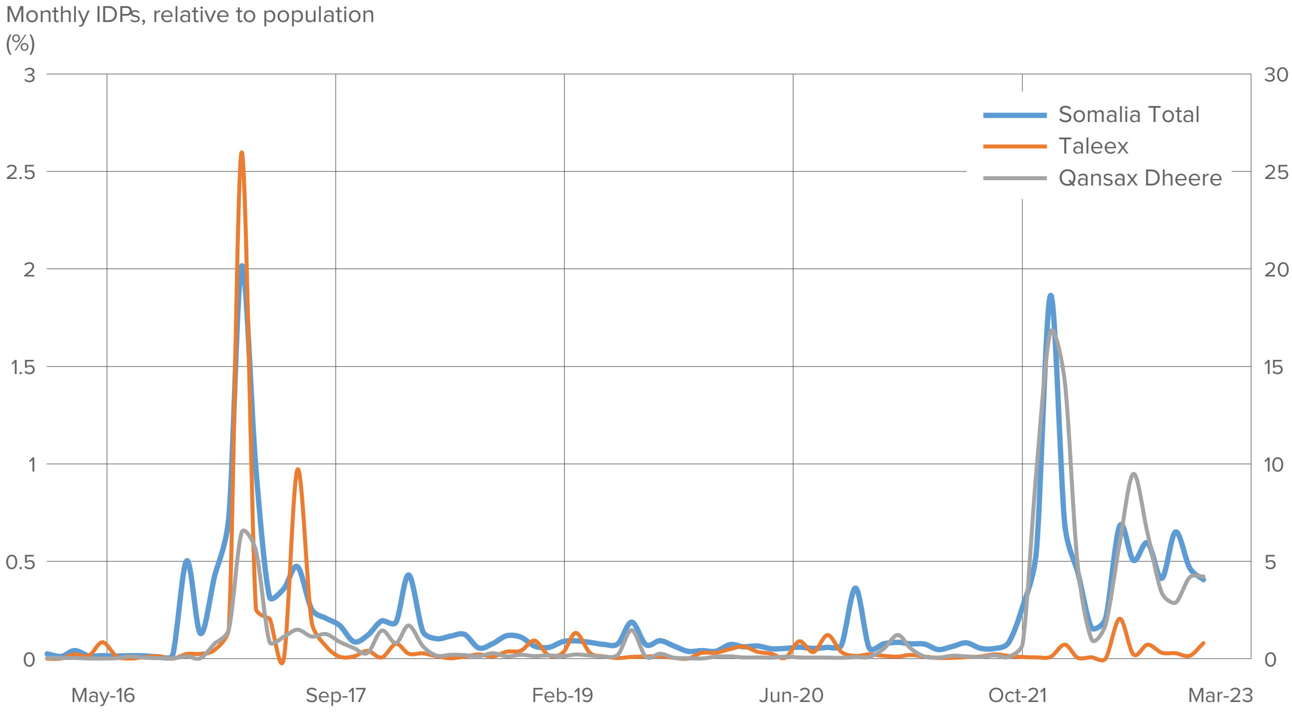


Figure 6: Numbers for 2016 to 2022. The line for the whole of Somalia shows that there are two large peaks, one in early 2017 and one in early 2022. The peak in 2017 was mainly because of IDPs in the north of Somalia (including Taleex). The peak in early 2022 was more concentrated in the centre of Somalia (including Qansax Dheere).

drought-induced IDPs more comparable over regions and time. Then, 15 different categories, ranging from 0 per cent to 5 per cent drought-induced IDPs, were defined.

Figure 6 illustrates a timeline of the average relative IDPs for two provinces across Somalia. This indicates that the year 2017 registered a high amount of drought-related IDPs, especially in the provinces of Bay and Sool. No clear seasonality in population movements can be seen in the data set. This gives confidence that the results are not related to seasonal migration of, for instance, pastoralists.

Drought-driven displacement modelling method

The method we used for modelling drought-driven displacement involved employing an impact-based approach coupled with ML models, specifically decision trees. This approach establishes a quantitative relationship between observed impacts and drought hazards, facilitating insights into the vulnerability of affected systems and sectors. By discerning which combinations of drought drivers lead to increased displacement in which regions, this method enabled the estimation of associated risk under various climatic conditions, including present and future scenarios.

The methodology consisted of four steps as follows.

The **first step** entailed the computation of drought hazard indices.

Various physical drivers for drought were evaluated: precipitation, potential evaporation and soil moisture, as presented in the drought hazard assessment section. For each of these physical drivers, a multitude of indices (absolute, relative, standardised) was determined. The indices were based on GLEAM data.[64]

The **second step** involved the identification of impact data.

Consistent, continuous data on drought-related impacts is key to calibrating the approaches used to quantify drought displacement risk. Records on displacement data, as described in the "Data on internally displaced people" section, were normalised with population and split into 15 categories of displacement level, between 0 and 5 per cent. The impact categories were then converted to a binary classification: exceeding the displacement level or not. This resulted in an impact record per severity category (i.e. IDPs exceeding 1 per cent, 2 per cent, etc. of the population) per month per region.

The **third step** involved calibration of the ML models. This was done for each displacement level (the 15 categories) for each region:

- We extracted hazard data covering the duration of displacement observations. This data was then bootstrapped 100 times, ensuring an even distribution of impactful and non-impactful events between training and testing data sets. We shuffled the data each time before splitting it, using a function called StratifiedShuffleSplit from the sklearn Python package. Following this, we proceeded with the analysis for each of these sampled data sets:
  - For the train data, the hyperparameters "selection criterion" ("gini", "entropy", "log_loss"), "splitter" ("best", "random") and "depth" (2, 3) were tuned. This was achieved by doing a grid search to identify the specific ML model settings resulting in the most balanced accuracy.
  - A decision tree algorithm (from sklearn Python package) was then used with these hyperparameters to identify hazardous conditions likely to lead to increased displacement.
  - Accuracy, balanced accuracy and precision were calculated based on the test data set.
  - The fitted decision tree was applied on the full historic data set (not only on the bootstrapped data over the observation period) and projected climate conditions.[65]
  - Finally, by combining estimates from 100 bootstrapped trees, we calculated the average of the likelihood of impact per year.

The **fourth step** consisted of estimating the two main metrics: AAD and PMD. The exceedance probability curve was computed by fitting a generalised extreme value (GEV) distribution over the yearly values of displacements. The integral behind that curve gave the AAD. The exceedance probability curve was converted into the PMD by expressing the rarity in return period (RP) instead of probability (p=1/RP). This allowed focus on the tail of the curve, so the rarest events with highest return periods.

For Somalia, where ample observations about internal displacement were available, analysis could be performed at Admin level 2, or district level. This gave more precise results, as it is reasonable to assume that vulnerability (sensitivity and coping capacity) to droughts within one district is similar, although it may vary between different districts.

For Ethiopia and Sudan, observed data was not sufficient for a direct calibration, as described in the previous section on observed data, and extrapolation from the more data-rich Somalia was necessary. For this, some Somalian administrative regions were clustered based on their environmental vulnerability (water availability profile as defined by their Köppen-Geiger climate zones) to drought risks. Then, the link between impact and hazard (decision trees fitted in Somalia) was applied to estimate risk in regions with similar vulnerability in Ethiopia and Sudan.

The Somalian climate zone that best reflected Ethiopia's was selected through a recalibration and bias correction using the few data points available on Admin 1 level, from IOM-DTM. For Sudan, it was assumed that all its regions show the same environmental vulnerability as the steppe regions in Somalia. This was done under the assumption that the hazard–impact cause–consequence relationship is similar within one cluster of regions, and that this relationship is applicable in other countries too.

Photo: FAO/IFAD/WFP/Michael Tewelde
31 August, 2017, Somali Region, Ethiopia - Food distribution in Gode wereda Dolo Baad distribution centre.

Drought-induced displacement

In this section, we present the results of our analysis on drought-driven displacement. Our methodology for modelling drought-induced displacement involved using an impact-based approach based on machine learning models, particularly decision trees. Through this approach, we aim to provide insights into the patterns and dynamics of displacement triggered by drought events. The outcomes contribute valuable information for informed decision-making, enabling effective disaster preparedness and mitigation strategies tailored to each country's unique situation.

Validation process

Validating the performance of a model is crucial to ensure its reliability and accuracy in predicting internal displacement. In this section, we undertake a validation process by comparing the average annual number of movements observed with the corresponding figures simulated by our model. This validation was performed in Somalia for the period of 2016 to 2022, when observations are available at district level.

The number of potentially displaced people was aggregated at the district level in Somalia. These impacts were then used to determine the average annual displacement (AAD) and probable maximum displaced (PMD) values, under two future climate scenarios: optimistic and pessimistic.

Box 2 shows a spatial comparison between observed and simulated AADs, respectively in absolute and relative terms. A similar spatial pattern between simulations and observations can be observed, with some overestimations in place. The main deviation can be found in the southern coastal regions, west of Mogadishu around Buur Hakaba district (which has almost 10 per cent point deviation). There are various reasons for this deviation (e.g. under-reporting of drought-induced displacements, ongoing conflicts and violent situations, local anchoring factors, occupation, gaps in data collection). Nevertheless, because of the overall good agreement in terms of spatial pattern and, on average, low errors, these results justify the statistical model's ability to estimate drought-induced displacement.

The scatter plot in figure 8 illustrates a comparison between the predicted and observed drought AAD from the PRMN data set. A good fit is shown by the two series with $R2 > 0.6$, with a median difference (over-estimation) of 0.4 (mean deviation 1.4+-0.2).

A few outliers exist, with maximum differences observed in Doolow (predicted AAD of 12 per cent while observed only 5 per cent) and Ceel Barde (predicted AAD of 15 per cent while observed 22 per cent), but only 11 of the 74 districts had a deviation of more than 2 per cent.

Box 2: Somalia observed and simulated average annual drought-induced displacements. The reference period is 2016–2022

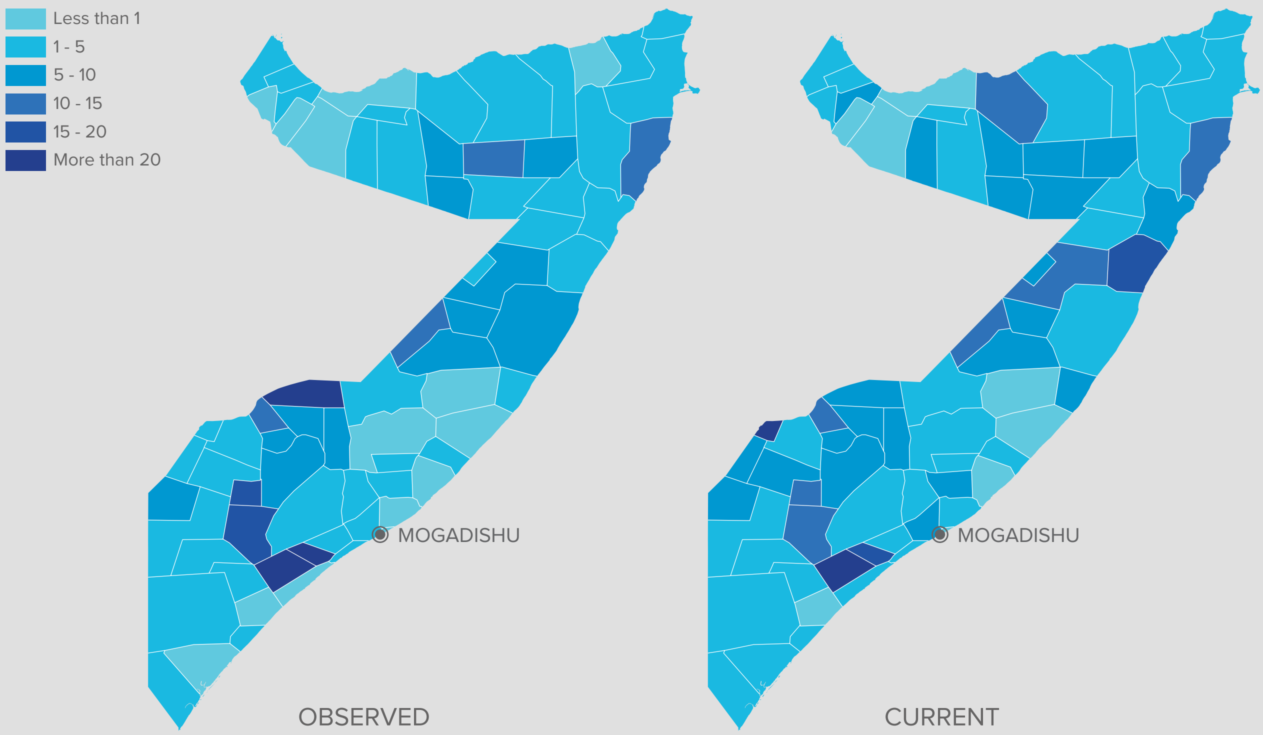


Figure 7a: Somalia average annual drought-induced displacements, relative to population (%) (Trained per province using non-zero observations 2016–2022)

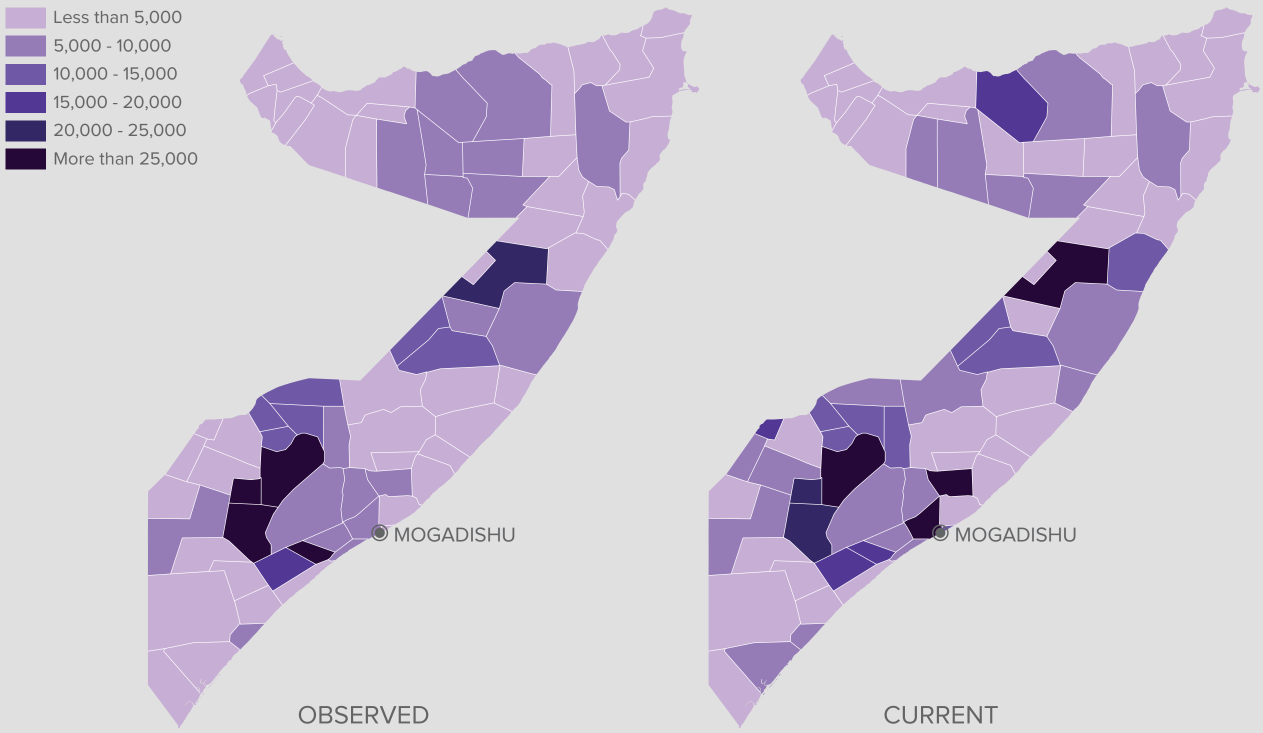


Figure 7b: Somalia average annual drought-induced displacements (using 2000 population)

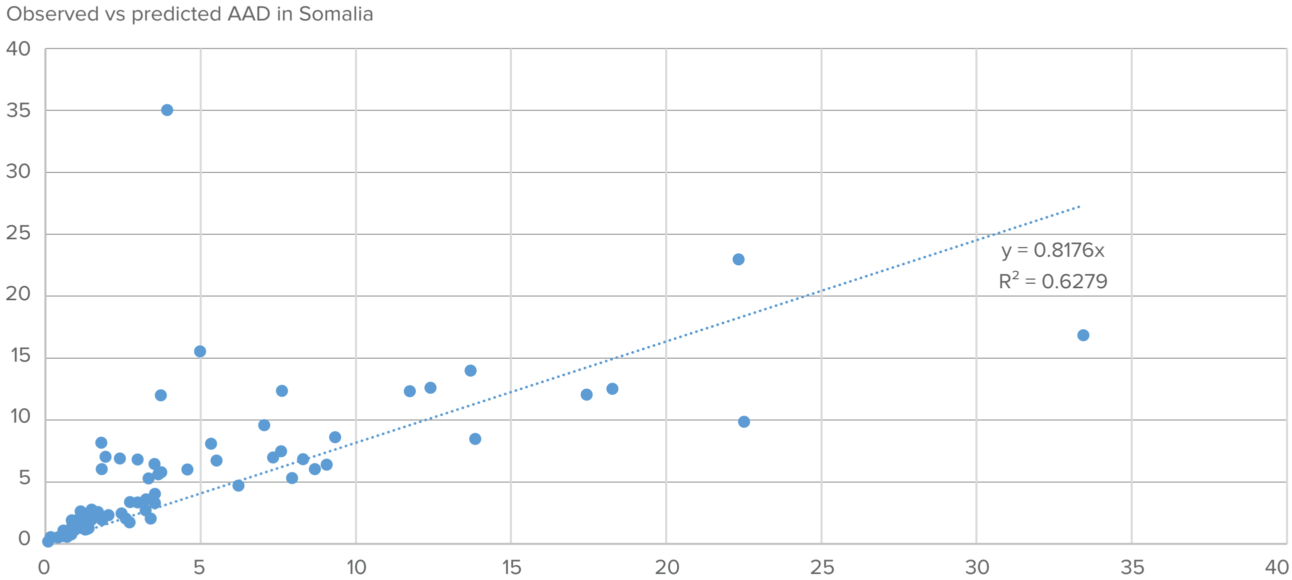


Figure 8: Observed versus predicted average AAD in Somalian districts. The reference period is 2016–2022.

Somalia

Somalia is a country characterised by a predominantly arid and semi-arid climate.

Drought is a recurrent and devastating phenomenon in Somalia, often leading to widespread food insecurity, water scarcity and displacement of populations. The country's dependence on rain-fed agriculture and pastoralism makes it particularly vulnerable to the impacts of drought, because livelihoods are heavily reliant on seasonal rainfall patterns.

Drought-induced displacement is a common occurrence in Somalia, with communities often forced to move in search of food, water and pasture for their livestock.

The country is also exposed to the El Niño-Southern Oscillation (ENSO). ENSO exerts various impacts on Somalia's climate variability, leading to increased rainfall and flooding during El Niño events, while causing droughts during La Niña years.

The analysis of drought displacement risk in Somalia at a country level shows an AAD value of around 610,000 people, corresponding to about 3.5 per cent of the overall population. The results highlight a non-negligible influence of climate change. Both the optimistic and pessimistic scenarios show AAD values that increase, by 22 per cent under optimistic and 55 per cent under pessimistic scenarios (see figure 9).

In absolute terms, significant increase is estimated

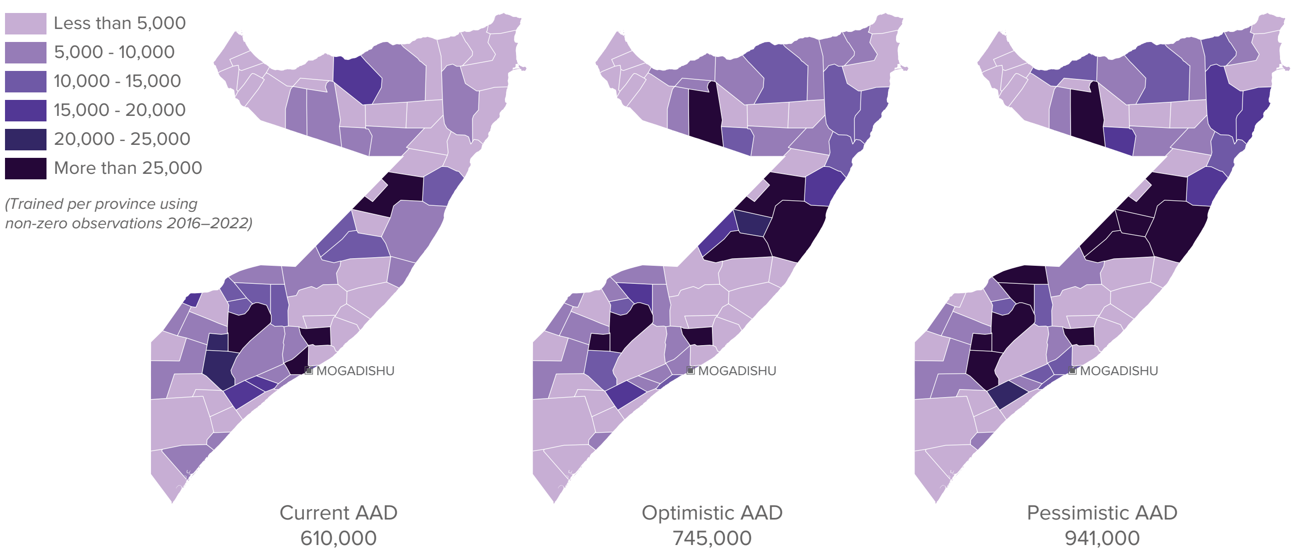


Figure 9: AAD in Somalia under current (left), projected optimistic (middle) and projected pessimistic (right) climate conditions.

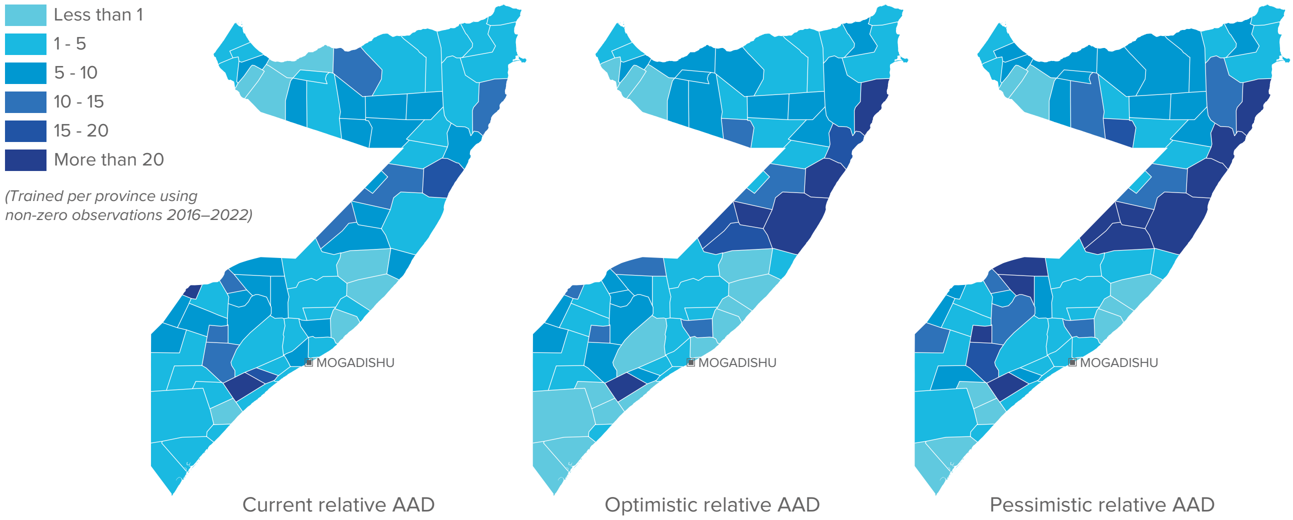


Figure 10: AAD as a percentage of the total population in Somalia, under current (left), projected optimistic (middle) and projected pessimistic (right) climate conditions.

in the central area (provinces of Hobyo, Gaalkacyo, Dhuusamarreb and Cadaado), in the district of Burco in the north, and the districts of Kurtunwaarey, Sablaale, Diinsoor, Ceel Barde, Baidoa, Qansax Dheere, Xudur and Jowhar.

In relative terms (compared with the total population), however, the main increase is particularly large in the north-east and along the coast (see figure 10). The pattern seems to become more even, with the hotspots observed under the current climate still being high, but not standing out as much. Some of the coastal districts may become the future hotspots of IDPs in Somalia.

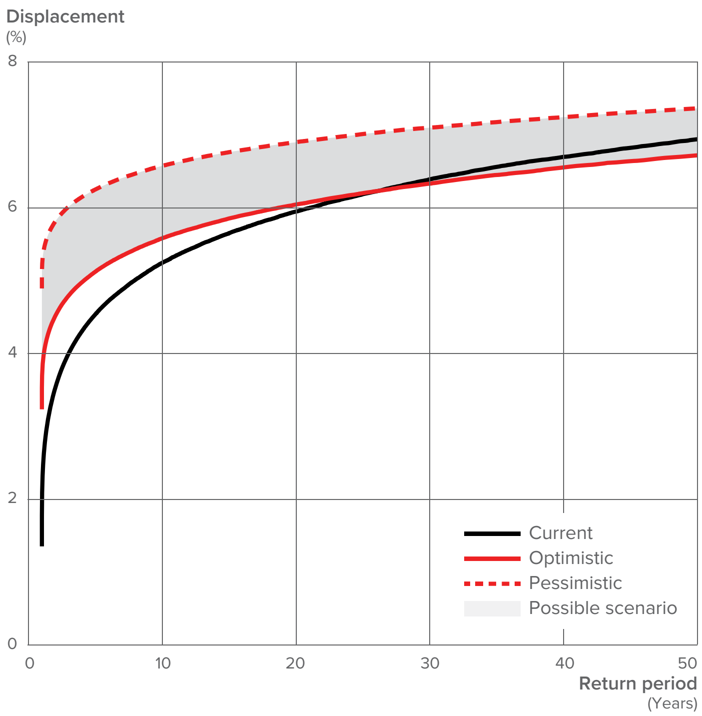


Figure 11: PMD curves for Somalia. Displacements, as a function of return period of the event, are expressed as a percentage of total population. The continuous black line represents the current climate scenario, while the continuous red line and the red dotted line depict optimistic and pessimistic climate scenarios respectively.

While the AAD expresses an average number of expected displacements as a result of drought events, it tends to hide potential outliers. Figure 11 compares the PMD curves for current and projected conditions, showing the number of potentially displaced people in connection to frequent (low return period) or rare (high return period) events.

Figure 11 represents the PMD results at country level. Both projected scenarios show a general increase in the number of displacements for return periods less than 25 years. For a five-year event, 4.5 per cent of the population are estimated to be displaced in the current conditions. This number would increase to 5.1 per cent in the projected optimistic scenario and to 6.2 per cent in the pessimistic scenario. This is mainly because of the increase in temperature and evapotranspiration (see section 2.2.1). Instead, in the optimistic scenario, drought impact would slightly decrease for events rarer than 25-year return period. Uncertainty increases with return period, however.

Ethiopia

Ethiopia experiences a diverse range of climates as a result of its varied topography, characterised by a semi-arid to arid climate with the presence of several climatic zones, including highland, lowland and desert regions.

The climate variability in Ethiopia is influenced by several factors, including ENSO. These climate phenomena can lead to irregular rainfall patterns, exacerbating the frequency and severity of drought events in the country.

Drought is a recurrent and significant challenge in Ethiopia, particularly in the lowland and semi-arid regions. The country's agricultural sector, which is largely rain-fed, is highly vulnerable to fluctuations in rainfall patterns and therefore susceptible to the impacts of drought.

The analysis of drought displacement risk at country level shows an AAD value of around 131,000 people, corresponding to about 0.1 per cent of the overall population. The results highlight a non-negligible influence of climate change. Despite the optimistic scenario projecting a substantial increase in displacement of around 135 per cent, the risk of drought-induced displacement decreases significantly under the pessimistic scenario by about -85 per cent, mainly because of the East Africa Climate Paradox (see box 1).

Figure 12 and figure 13 show AAD in Ethiopia under current climate conditions and future projected optimistic and pessimistic conditions, in terms of both absolute amount of people and percentage of the population.

There are some drought displacement hotspots in the eastern, drier regions of Ethiopia (for Afar region, AAD is 7,500 people, corresponding to 1.4 per cent of the total population of the region; for Somali region, AAD is 37,500 people, corresponding to 2 per cent of the total population of the region).

As a result of rising rainfall, the risk appears to diminish under climate change, especially in a much hotter and wetter pessimistic scenario. Under optimistic climate scenarios, however, the risk of becoming displaced by drought increases, because of drier soil and higher temperatures in Amhara (eight times higher), Tigray (four times higher) and Oromia (three times higher). This increase is counteracted by the higher precipitation levels forecasted in the pessimistic scenario (see section 2.2.1), which would lead to a decrease in drought-induced displacements.

The PMD results at country level show intricated behaviour, resulting from a complex evolution of climate drivers.

In the current climate conditions, there is a significant difference between rare and frequent events. A 10-year event would generate a number of displacements, corresponding to around 1.5 per cent of the population, and this number doubles if we consider a 50-year event. In both projected scenarios, PMD curves are less steep, with reduced differences between high and low return periods, in comparison with the current situation.

The pessimistic scenario shows a general reduction in the number of displacements, except for very

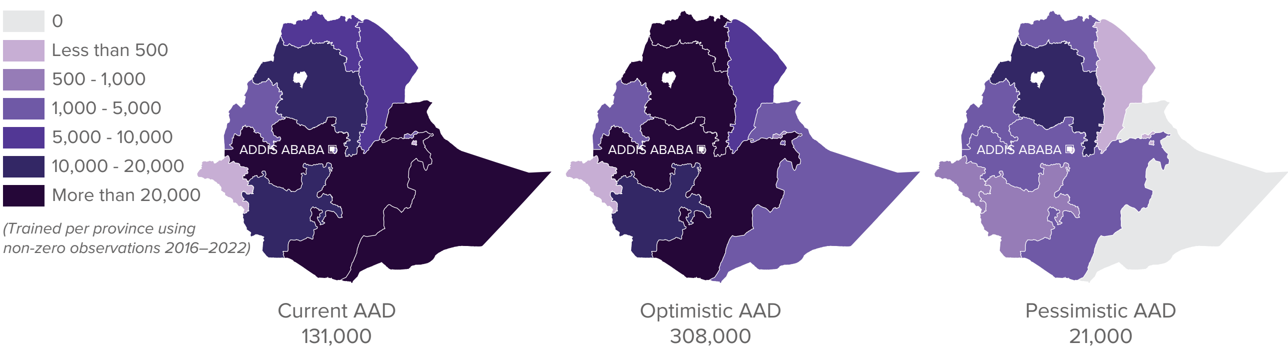


Figure 12: AAD in Ethiopia under current (left), projected optimistic (middle) and projected pessimistic (right) climate conditions.

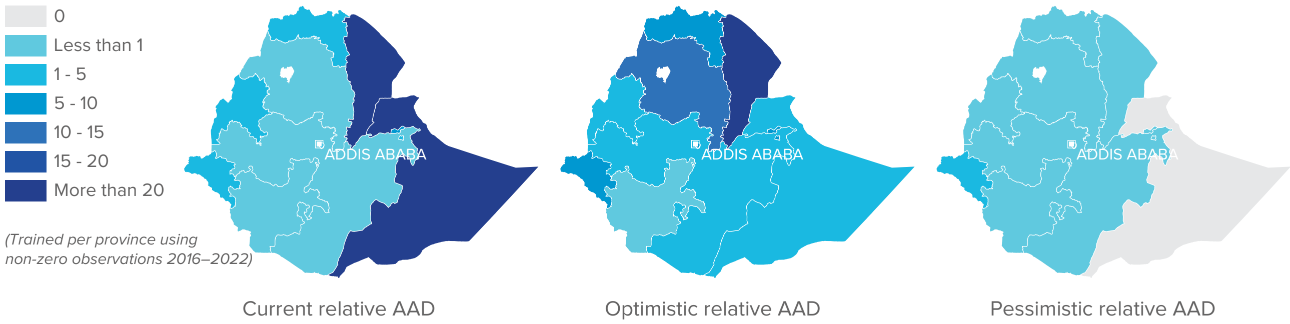


Figure 13: AAD as a percentage of the total population in Ethiopia, under current (left), projected optimistic (middle) and projected pessimistic (right) climate conditions.

low return periods. This is mainly because of the projected increase in precipitation. In the optimistic scenario, meanwhile drought impact would increase for frequent events up to a 25-year return period (this is in line with the slight increase in absolute AAD for this scenario) and decrease for rarer events (higher return periods).

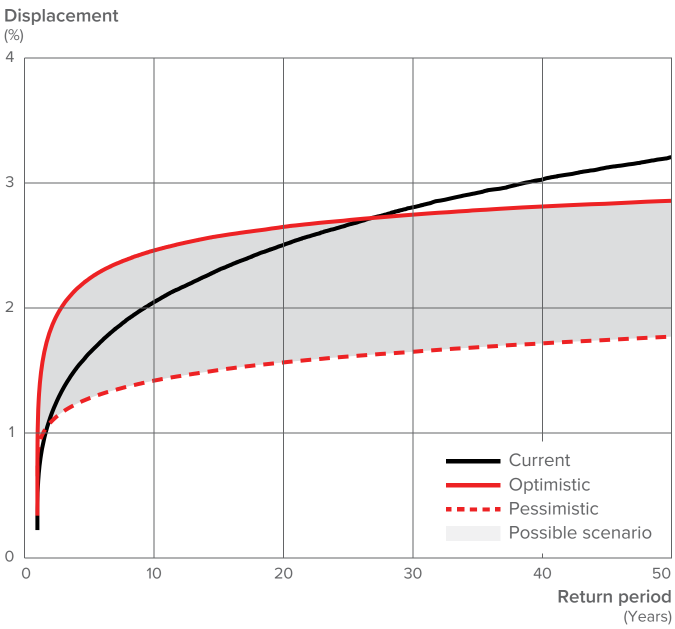


Figure 14: PMD curves for Ethiopia. Displacements, as function of return period of the event, are expressed as a percentage of total population. The continuous black line represents the current climate scenario, while the continuous red line and the red dotted line depict optimistic and pessimistic climate scenarios respectively.

Sudan

Sudan experiences a diverse range of climates that vary across different regions of the country. It is generally characterised as arid and semi-arid, however, with some areas experiencing desert conditions. Overall, Sudan's climate is largely influenced by its location in the arid and semi-arid belt of Africa, with varying levels of rainfall and temperature across different regions. Droughts, water scarcity and desertification are significant challenges faced by the country as a result of its climatic conditions.

Although Sudan lacks empirical data about drought internal displacement, millions of Sudanese are regularly affected by drought episodes.

Figure 15 and figure 16 show the results of AAD for drought in Sudan under current climate conditions and future projected optimistic and pessimistic conditions.

The analysis of drought displacement risk at country level shows an AAD value of around 900,000 people, corresponding to about 2 per cent of the overall population. The results highlight a non-negligible influence of climate change. Both the optimistic and pessimistic scenarios project a slight decrease by about -5 per cent and -9 per cent respectively, mainly because of the East Africa Climate Paradox (see box 1).

Indeed, because of the projected increases in precipitation, the number of drought-induced displacements are expected to reduce in some

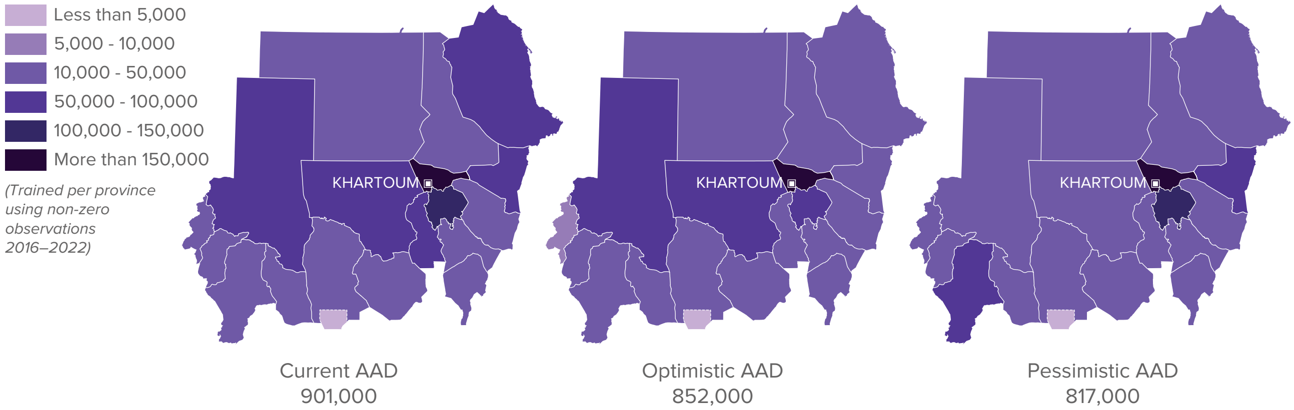


Figure 15: AAD in Sudan under current (left), projected optimistic (middle) and projected pessimistic (right) climate conditions.

regions under both optimistic and pessimistic climate change scenarios. In absolute terms, a lower number of displacements is also expected nationwide under such climate change.

Some differences emerge at the subnational level, however. Conditions in Gazira state could improve under the pessimistic scenario, with a decrease of 13 per cent in drought displacement risk. On the other hand, while drought displacement risk remains stable under both optimistic and pessimistic scenarios in all the northern provinces of the country, provinces in the south (such as South and East Darfur, South Kordofan, and Blue Nile) could experience an increase in drought-induced displacement. For instance, South Kordofan could have an increase of around 55 per cent under pessimistic scenarios, while Blue Nile could experience a similar increase under both optimistic and pessimistic scenarios. This further underscores the projected increases in precipitation in different regions under varying climate scenarios.

All curves in figure 17 present approximately the same trend, with reduced differences between high and low return periods. In alignment with the decrease in AAD projected under future climate conditions, both optimistic and pessimistic scenarios indicate a slight reduction in the number of displacements, primarily attributed to the anticipated increase in precipitation. Specifically, in the current climate conditions, a 10-year event would displace 2.4 per cent of the total population. This figure decreases to 2.2 per cent and 2 per cent in the optimistic and pessimistic climate scenarios, respectively.

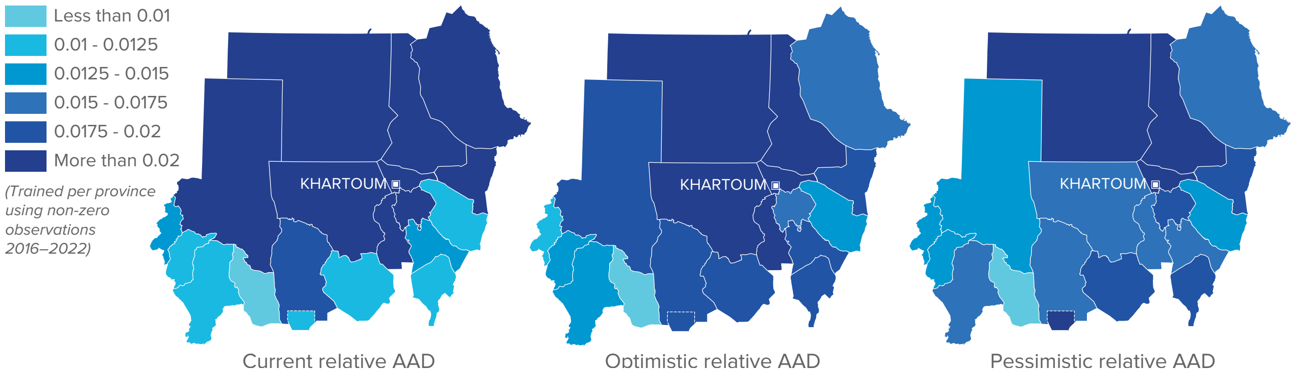


Figure 16: AAD as a percentage of the total population in Somalia, under current (left), projected optimistic (middle) and projected pessimistic (right) climate conditions.

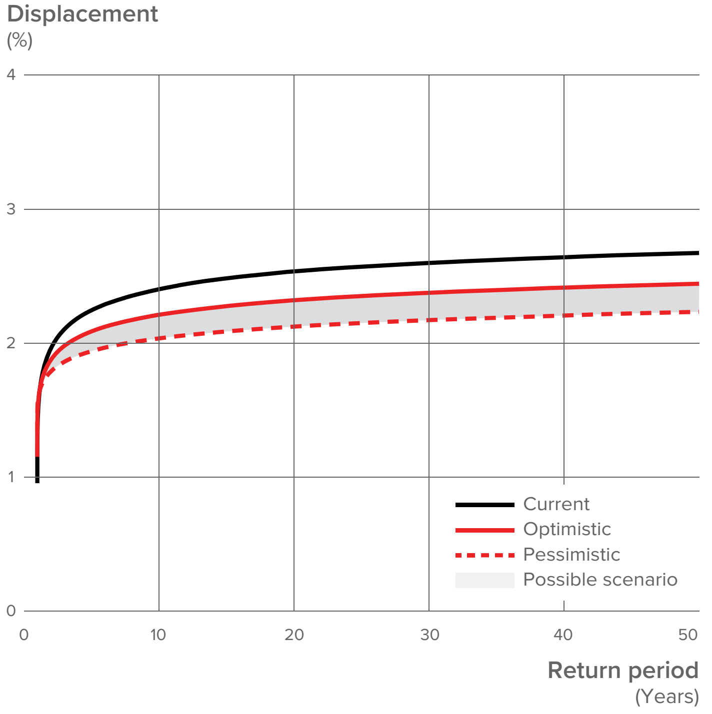


Figure 17: PMD curves for Sudan. Displacements, as function of return period of the event, are expressed as a percentage of total population. The continuous black line represents the current climate scenario, while the continuous red line and the red dotted line depict optimistic and pessimistic climate scenarios respectively.

Discussion and conclusion

The risks associated with drought extend far beyond measurable impacts, encompassing communities, ecosystems and economies. Vulnerable populations bear a disproportionate burden of these consequences. Yet, with an improved understanding of the interconnectedness of global drought and other complex risks, an opportunity arises for enacting the necessary changes to reduce risks and enhance drought resilience.

The Horn of Africa has been suffering its worst drought in 40 years since October 2020, with extended dry conditions punctuated by short intense rainfall that has often led to flash flooding. Across Ethiopia, Sudan and Somalia, the rainy season and sporadic rains in certain areas have given rise to devastating floods, aggravating the impacts of the drought and resulting in significant losses of livestock, livelihoods and homes. There have been five consecutive seasons of rainfall below normal levels. Millions of people have needed humanitarian assistance and have been at risk of acute food insecurity and potentially famine.

This report creates and applies a drought displacement risk model that involves a novel method, modelling drought-induced displacement using an impact-based approach based on machine learning (ML) models, particularly decision trees.

ML models are trained to learn the relationship between impact (drought-induced displacement) and drought hazard indicators or indices per region, and this relationship was used to estimate drought displacement risk (in terms of likelihood of experiencing certain impacts). This was summarised in the average annual displacement risk metric, indicating the estimated average annual drought-induced displacement and probable maximum displacement, or the probability (expressed in return period) to exceed a certain displacement amount. As a data-driven approach, the accuracy of estimated risk depends strongly on the quality of the impact and hazard information available.

The data-driven, impact-based drought disaster risk analysis, providing a probabilistic estimate of drought-induced displacement, shows a clear connection between droughts and reported numbers of internally displaced people (IDPs). Indeed, for Somalia, where plenty of observations on IDPs' region of origin and cause of displacement were available, the model performance was good, proving reliable risk assessments under current climate conditions. Given the climate models and projections for precipitation and temperature under climate scenarios, the future risk assessment can also be seen as robust.

Here, the East African Climate Paradox needs to be considered, however, because in general, climate models are challenged to make predictions in this region, and the paradox may influence input drought indicators for future scenarios. Moreover, neither changes in socioeconomic and political conditions, affecting vulnerability, nor changes in demographics, altering exposure, were taken into consideration in the future risk estimations. These two risk factors are dynamic but would not have resulted in more robust estimates, given the uncertainty in how they might change, which is influenced by climate and other risks and global trends.

The 20 data points on yearly scale for regions in Ethiopia provided enough information to recalibrate the Somalian model for this country. This helped in evaluating which type of training (based on the Somali situation in tropical, steppe or desert Köppen climate zones) best fit the Ethiopian case. As no validation data was available for Sudan, the data-driven method could only be extrapolated to this region. It was assumed that similar hydrometeorological conditions would lead to similar (relative) responses in internal displacement, but future work with more data should verify this.

The results indicate that in Somalia, drought displacement risk may increase slightly under both optimistic and pessimistic scenarios, by 22 per cent and 54 per cent respectively, in comparison with current conditions. Conversely, in Sudan, there might be a decrease in risk by 5 per cent to 9 per cent under both scenarios. Ethiopia exemplifies the East African Climate Paradox even more starkly, with the risk of drought displacement potentially doubling under the optimistic scenario, while dropping to one-sixth of current levels under the pessimistic scenario.

The model's results have extensive utility, informing both national and subnational disaster risk reduction measures. They enable the identification of areas where drought could potentially push people to flee and help determine the necessary investment to support displaced populations.

Essentially, these results empower decision-makers to adopt risk-informed approaches to prevent displacement and mitigate its impacts. Through this report, we aim to present recommendations that can serve as a foundation for developing comprehensive policies and strategies geared towards mitigating displacement risks associated with drought, while safeguarding the rights and wellbeing of affected populations.

We need to witness tangible steps in terms of:

- **Vulnerable Populations**

Identify and target vulnerable populations who are at higher risk of displacement. Develop tailored strategies to protect their rights and wellbeing.

- **Conflict and disaster**

Recognise and address the potential links between conflict- and disaster-induced displacement, especially in areas where both risks are prevalent.

- **Community-based adaptation**

Support community-based adaptation initiatives that empower local communities to better prepare for and respond to drought.

- **Livelihood diversification**

Promoting livelihood diversification strategies, such as alternative income-generating activities and resilient agricultural practices, can help communities reduce their vulnerability to drought-related displacement by providing alternative sources of income and food security.

- **Social protection programmes**

Implementing social protection programmes, such as cash transfers, food assistance and livelihood support, can help vulnerable populations cope with the impacts of drought and reduce the likelihood of displacement.

- **Sustainable water management**

Investing in sustainable water management practices, such as water conservation, rainwater harvesting and improved irrigation techniques, can help mitigate the impact of droughts on water availability and reduce population displacement.

- **Early warning systems**

Efforts should be strengthened following the release of the 2023 Global Status of Multi-Hazard Early Warning Systems report at COP28. Implementing effective early warning systems to alert communities and authorities about impending drought conditions can help minimise displacement by enabling timely preparedness and response measures.

Continued investment in **data collection and research** will also improve the understanding of displacement (roots and causes), vulnerabilities and impacts. Further research could also include conflict, antecedent food security, long-term desertification trends, access to roads, cities and markets, and other vulnerability proxies to improve the ML-based method.

With support from the EU, this cutting-edge methodology establishes a solid foundation for developing innovative approaches to assess displacement risk associated with drought, ranging from the subnational to the global scale. The risk of disaster-induced displacement is a global reality, affecting every country. Now is the opportune time to demonstrate our collective commitment to the principle of leaving no one behind, particularly those who are already enduring the challenges of protracted and repeated displacement.

Given the significant improvements in data recording, it is expected that Admin level 2 data on a yearly time scale will be available soon, and then vulnerability dynamics can be included, too.

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