THE EFFECT OF CLIMATE CHANGE ON WEATHER RELATED DISASTERS AND MIGRATION IN ETHIOPIA

Lava Sjölin

Degree of Bachelor of Science
with a major in Earth Sciences
15 hec

Department of Earth Sciences
University of Gothenburg

2022 B-1164

Faculty of Science

UNIVERSITY OF GOTHENBURG

UNIVERSITY OF GOTHENBURG
Department of Earth Sciences
Geovetarcentrum/Earth Science Centre

THE EFFECT OF CLIMATE CHANGE ON WEATHER RELATED DISASTERS AND MIGRATION IN ETHIOPIA

Lava Sjölin

ISSN 1400-3821

B1164
Bachelor of Science thesis
Göteborg 2022

Mailing address	**Address**	**Telephone**	Geovetarcentrum
Geovetarcentrum	Geovetarcentrum	031-786 19 56	Göteborg University
S 405 30 Göteborg	Guldhedsgatan 5A		S-405 30 Göteborg
			SWEDEN

ABSTRACT

The ongoing climate change has been the driving force behind an increase of natural hazards around the world, and climate scientists have predicted that the trend will continue to rise. Increased radiative forcing leads to global warming which in turn affects several of the climate systems on earth, with changes in weather and living conditions as a result. The rapid nature of the changes makes it difficult to adapt to the new conditions, leaving ecosystems and habitats in a vulnerable state with human populations exposed to disasters as a result. One way to adapt is migration, but migration is a complex process driven by many factors. Populations living in areas of the world that already have a strained climate are most exposed to disasters induced by climate change, and often have widespread poverty and conflicts within their borders. One of those places is Ethiopia, which is the study area of this paper. By reviewing previous research and analysing data on climate records, projections and disasters the aim of this study is to find what hazards are the largest threat to the people living in Ethiopia, how climate models project future progress of those hazards, which regions are the most vulnerable, and how they are going to affect migration. The results are that drought is the largest threat to people in Ethiopia and that all parts of the country are predicted to get hotter and most of them drier. Lowland regions are at lowest risk of climate disaster, and the Ethiopian highlands are going to face large changes in the quantity of land areas with agricultural potential. This can be expected to lead to losses in food availability and resources for the whole nation, but since the nature of this kind of slow-onset disasters limits the possibilities to migrate the overall displacement in the country is not assessed to alter significantly.

THE EFFECT OF CLIMATE CHANGE ON WEATHER RELATED DISASTERS AND MIGRATION IN ETHIOPIA

TABLE OF CONTENTS

1 Introduction 4
1.1 Climate change and weather disasters 4
1.2 Environmental migration 5
1.2.1 The complexity of defining environmental migration 5
1.3 Climate models and future climate projections 6
1.4 Aims 6
1.5 Study area 7
1.5.1 Geography and demography of Ethiopia 8
2 Methods 9
2.1 Observed historical weather 9
2.2 Records of natural disasters and their impact 10
2.3 Projections on future climate 10
3 Results 11
3.1 Historical climate 11
3.2 Disaster types and their impact on populations 12
3.3 Projected future climate 14
3.3.1 Temperature 14
3.3.2 Precipitation 17
4 Discussion 19
4.1 Past climate, disasters and impact 19
4.2 Predicted climate and its effect on future displacement 20
4.2.1 Risk assessment 22
5 Conclusions 22
References 24

1 INTRODUCTION

Climate change is a subject of high interest at this age, not just for scientists and policymakers, but for regular people all over the world too. Millions have already been subjected to phenomena that are highly linked to climate change, such as rising sea levels, intense storms, melting ice caps, floods and drought, and hundreds of millions more are going to experience it in the future as global warming increases. Some parts of the world are more exposed and vulnerable to these extreme conditions than other, and the right preparations need to be made in order to mitigate the resulting disasters, (IPCC, 2021 and JONES AND O'NEILL, 2016). In this paper the impact of climate change on migration in Ethiopia will be examined by analysing historical weather data, recorded natural disasters and their impact, simulations on future changes, and literature on migration as an effect of and way to adapt to climate changes.

1.1 CLIMATE CHANGE AND WEATHER DISASTERS

The reasons to why the climate can change are many, and it can change either locally or globally. It can change due to natural processes such as volcanic eruptions and variation in the solar cycles, and has always done so, but during at least the last 100 years anthropological reasons has been a driving factor behind global warming, (IPCC, 2014).

One of the main driving forces behind anthropological climate change are emissions that increase the concentration of greenhouse gases and aerosols in the atmosphere where they reinforce the heating of the planet due to feedback systems. The concentration of greenhouse gases and aerosols in the atmosphere change the influx and reflection of solar radiation and the radiation emitted from earth to space, which is why the radiation budget is sensitive to those changes. When the global mean temperature increase, the atmospheric circulation changes due to physical reasons related to the temperature of air masses, which lead to reinforcement or counteraction on local and regional climate, meaning that instead of a temperature increase spread out evenly over the globe there will be regions subjected to higher changes while other regions face little change. Thus, temperature extremes will be, and already has been observed, to occur with a higher intensity and frequency and last longer. As the moisture content in the atmosphere is enhanced with rising temperature another effect of global warming is an increase in heavy precipitation events, since extreme precipitation is directly relative to the total column of moisture. However, the total annual precipitation does not change significantly due to physical reasons. These two facts combined results in a situation with heavy precipitation but with longer intervals, (IPCC, 2013).

Weather extremes impact the natural physical environment and lead to disasters such as drought and flood events. Drought is a complex effect of combined weather phenomena with temperature and precipitation as main forces. Higher temperatures lead to higher evaporation of the shallow soil moisture which lowers the available water in the ground. This leads to a reduction of vegetation which exposes the surface to more solar radiation which then is emitted as sensible heat in a positive feedback system. As written earlier, the total mean precipitation may not change but instead the number of consecutive dry days will increase, and the precipitation events occur with longer intervals with higher intensity and frequency. This change in distribution over time results in a lower amount of available water in the ground because the soil only has a limited potential for absorption and storage of water, meaning that when the soil is saturated all exceeding water will be lost as surface runoff into the ocean, river basins or other lowland areas with flooding disasters consequently, (IPCC, 2013., SENEVIRATNE ET AL. 2010. and ZHAO ET AL. 2020).

1.2 ENVIRONMENTAL MIGRATION

One way to adapt to the changing climate is migration. Depending on what the driving force is it can range from forced short time short distance displacement to voluntary permanent international resettling. The capacity for people to migrate also looks different considering factors such as gender, socioeconomic status, age and health (Cattaneo, et al., 2019). Predictions on the impact of climate change on populations are based on risk, which is a combination calculated on the factors exposure and vulnerability, where exposure is the sum of people and assets present in zones subjected to hazards, and vulnerability is the potential damage and loss that can result from it, (Kharin, et al., 2018).

1.2.1 The complexity of defining environmental migration

It has been known for a long time that greenhouse gas emissions are going to change the climate all over the world and that preparations need to be made to mitigate disasters and adapt to the changes. PETER H. GLEICK wrote as early as 1989 about how the accumulation of greenhouse gases will impact developing countries in his article *Climate Change and International Politics: Problems Facing Developing Countries.* Yet there is still no consensus over what falls under the category of environmental migration. In some cases, it is easy to recognize environmental causes as the driving force behind displacement, as after a storm, flood or erosion on coasts, but often the complexity of the mechanisms behind displacement is hard to untangle. For example, if a region is subjected to drought it makes the crop yield scarce, which in turn increases the poverty in the region and conflict can arise over assets such as arable land, money and food, which can lead to migration flows due to the conflicts when the initial drought was the original driving force. Another mechanism that makes it complex to record and make projections on environmental refugees is the time variability in different types of migration responses, (Cattaneo, et al., 2019).

1.2.1.1 Fast-onset and slow-onset disasters

One way to categorise disasters is to separate them into fast- and slow-onset disasters, which is useful in the context of migration because the outcome of the displacements that result from them are distinctly different.

Fast-onset disasters are the ones that strike with little warning and short to no time for preparation, and they tend to cause major destruction at specific places. Examples of fast-onset disasters are floods, wildfires, landslides and hurricanes. The displacements resulting from these events are more often short distance than long distance, and since it is an event with a distinct start and ending the majority of the relocated move back to rebuild their homes. Thus, the fast-onset disasters are not the cause of large, permanent international migration streams. Some evidence suggests that there may be a link between frequent repetitions of hazards and migration, but more research is needed for it to be confirmed, (Cattaneo, et al., 2019).

Slow-onset disasters are the ones that start off small and grow worse gradually, as for example drought. The immediate impact is small, but if the drought period is extended over a long time, it may in the end cause more damage than the fast-onset disasters. Contrary to displacements forced by rapid hazards, slow-onset disasters give the affected households time to think about if, where and when they want to relocate, pack their belongings, sell assets and prepare themselves for the relocation, and is therefore sometimes considered voluntary, (Cattaneo, et al., 2019).

1.2.1.2 Disasters as a reducing factor

Even though climate change and disasters commonly are thought of as the cause of migration, they can also have the opposite effect. A protracted drought leads to scarce crop yield and food shortage, which leaves households with less means to finance migration. Tensions and conflicts over assets and land areas as a reaction to sparse resources is another factor with a reducing effect on means available for relocation. Countries with developing economies have less possibilities to support adaptations to climate change or offer financial relief to affected households, which makes them more vulnerable to the effects of climate change. Another factor to consider is the stricter rules many richer countries has implemented for migrants from developing countries, meaning that international migration may not be possible even with the means needed are available, (Gröschl & Steinwachs, 2017).

1.3 CLIMATE MODELS AND FUTURE CLIMATE PROJECTIONS

Different models for predicting climate change have been developed. Based on complex equations based on climatic systems on earth, such as oceans, atmosphere, land and glaciers, projections of future scenarios are calculated. The three models used by IPCC in their interactive atlas (Gutiérrez, et al., 2021) are CMIP5, CMIP6 and CORDEX. CMIP is an abbreviation of Couple Model Intercomparison and consists of models of climate systems which are coupled to interact with each other to simulate a conjoint model of the global climate. CMIP5 was the 5th phase of the CMIP-programme, and it was developed during 2010-2014. CMIP6 is the most recent model and the phase of developing it began in 2016. CORDEX is short for Coordinated Regional Climate Downscaling Experiment, with the objective to make simulations of the future climate for smaller regions instead of the global climate as is done with the CMIP-simulations.

(IPCC, 2021) writes in their Summary for Policymakers that the climate models with high confidence projects that one effect of global warming is going to be a higher frequency of extreme weather such as heat waves and heavy rain, and that some of it has already been observed in consistency with the models that were projected in earlier years. Furthermore, the report states that global warming is not going to be evenly spread over the world, but that some regions are expected to be more affected by rising temperatures and thereby its following effects. These regions are more probable to be mid-latitudinal and more inland than coastal. (Kharin, et al., 2018), explains that simple indicators can be used to observe ongoing changes in the weather extremes of a region, such as measuring the annual maximum and minimum daily temperature, and the annual maximum precipitation for one day. By comparing projections from different models and scenarios they showed that all models agreed that the temperature of heat waves are not changing much, but the frequency of the events are increasing. Contrariwise the amount of precipitation is predicted to increase, and thereby heavy precipitation events with higher intensity or longer duration can be expected. This goes against the predictions of (IPCC, 2013) that stated that the total amount of precipitation is not expected to increase, but they both agree that the intensity and duration will increase.

1.4 AIMS

The object of this paper is to:

- Examine if there is a link between recorded weather and natural disasters in Ethiopia
- Asses which regions in Ethiopia are at highest risk for future natural disasters, based on simulations and literature review
- Estimate the following impact on migration

This will be done by analysing recorded data, reviewing literature and with climate model simulations.

1.5 STUDY AREA

The area of interest in this paper is the southeastern African country Ethiopia, situated just above the equator with a total land area of 1.1 million km^2 (*Figure 1*). The south and southwest parts of the nation have equatorial climate with rain forests and high humidity, while the east and southeast parts are arid with a desert-like climate. Ethiopia also has mountainous regions with alpine climate both in the north and in the middle of the land area (*Figure* 2). Overall, the climate is highly variable throughout the country (Rubel & Kottek, 2010). It is densely populated with almost 115 million people (The World Bank Group, 2022b). According to (Norwegian Refugee Council/Internal Displacement Monitoring Centre, 2019), Ethiopia had the third highest number of people displaced during 2018 with 2.9 million people migrating because of conflict and violence, and 300,000 due to climate related disasters such as drought conditions.

Projections done by (Betts, et al., 2018), predict that the rise in mean annual daily maximum temperature is lower than in most other areas, which can be explained by its location near the coast and in near proximity to the equator, (Déqué, et al., 2016), but that it instead is expected to have among the highest number of days with extreme heat. Simulations that were done to make projections on the number of consecutive dry days gave ambiguous results which in the end cancelled each other out.

According to DÉQUÉ, ET AL. (2016) the total days with precipitation in tropical Africa are going to decrease as an effect of global warming, while at the same time the total amount of precipitation is going to increase. The simulations made by BETTS, ET AL., (2018) predict that the annual maximum rainfall over 5 days is going to increase in almost all parts of the world, but that the region Ethiopia belongs to is going to see little change. It is, however, one of the regions that is projected to have the highest increase in the average length of flood events.

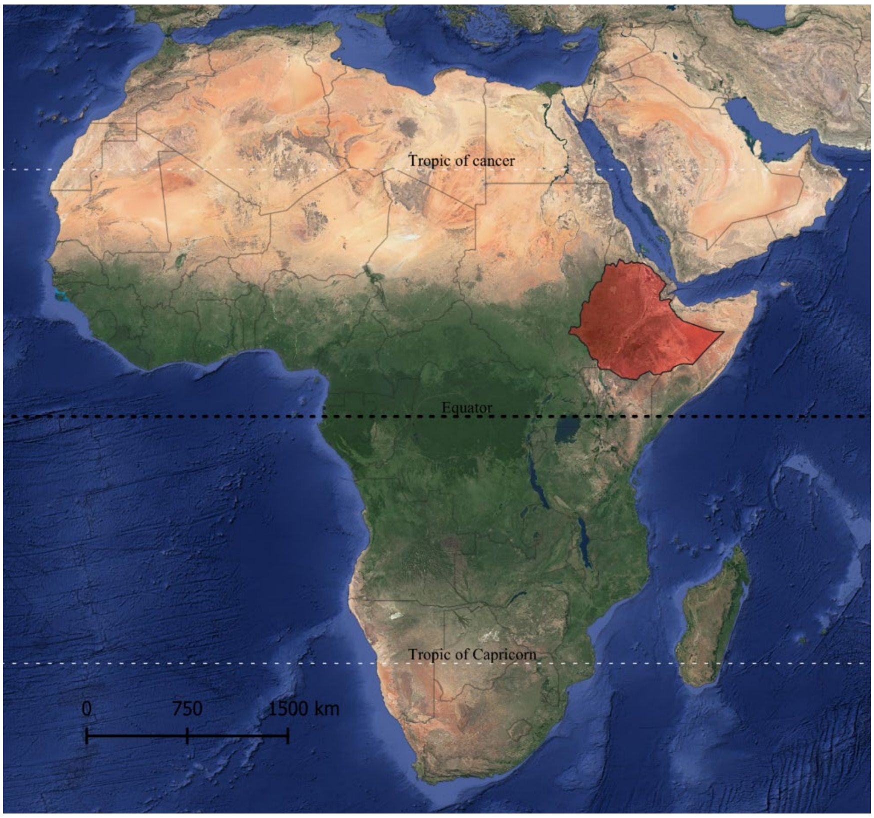


Figure 1. Overview map of the terrain in Africa, with Ethiopia highlighted in red and the equator and tropical circles shown as dotted lines. The satellite picture is from Google satellite QuickMap, and the dataset for country borders was made by Bjørn Sandvik and downloaded from thematicmapping.org. The map and shapefile were reworked with QGIS with the reference system WGS 84.

1.5.1 Geography and demography of Ethiopia

The climate of Ethiopia is highly diverse, varying from alpine to arid. The geology varies between mountainous alpine regions, high altitude plateaus with fertile soils, low altitude humid regions with dense rainforests, low altitude arid regions with high tectonic and volcanic activities, and vast semi-arid to arid plateaus, and with the Great Rift Valley crosscutting the country. The three main zones this report will focus on are the Ethiopian highlands, the Danakil desert and the Ogaden desert (*Figure 2*), because of their distinct climatological characteristics and the populations that live there.

The Ethiopian highlands lie within the regions Tigray, Amhara, Oromia, and Southern Nations and Nationalities and People (SNNP), and is home to 80% of the population. 70% of the population in Ethiopia are farmers, and almost all of them live in the highlands, which also comprise 89% of the total livestock population (The Africa Research in Sustainable Intensification for the Next Generation, 2022). According to THE WORLD BANK GROUP (2022C) 80% of the nation's total income from exports is from agricultural produce, which means that the area is of great importance not only for food access, but also for the economy. The mean annual temperature in the highest altitudes is below 0, but in the plateau areas and slopes it ranges from 10 to 20 degrees Celsius, and rainfall is similarly dependent on altitude with up to 900 millimetres of annual precipitation on the high-altitude areas. The high-altitude plateaus are the most important agricultural areas due to its climate and fertile soils (The Africa Research in Sustainable Intensification for the Next Generation, 2022).

The Danakil desert is situated in the Afar region in the east and stretches into the neighbouring countries Eritrea and Djibouti. With a mean annual temperature of 34.4 degrees Celsius with daily maxima over 50 degrees, the Danakil desert is considered the hottest place on earth. The area lies within the Great Rift Valley (*Figure 2*) and the geologic features of the place are therefore characterised by volcanic and tectonic activities. Lying in a rift zone, Danakil is also one of the lowest situated places on earth. The mean annual precipitation is around 25 millimetres (Atlas of Humanity, 2022), which makes it one of the driest places on earth. Despite the inhospitable nature of the area there are people living there, an ethnic group called the Afar people. The Afars are a nomadic people that moves in the Danakil desert without considering the borders between countries and there is therefore no exact number on how many they are, but they are estimated to be around 3 million people (Worldmark Encyclopedia of Cultures and Daily Life, 2022).

In the southeast part of the country, in the Somali region, lies the Ogaden desert with around 5 million inhabitants. The west of Ogaden is on higher elevation with a landscape similar to the highlands, and some agriculture is engaged here. The middle and west of Ogaden is a plateau gently sloping with around 0.4 metres over several kilometres with vast red sand plains. The plateau is flat, and its only morphological features are river valleys. The precipitation in the area has the highest variability in Africa, with the east plateau below 500 metres elevation having a mean annual precipitation around 400 millimetres while the westernmost parts with an elevation above 1500 metres having a mean annual precipitation of above 800 millimetres, but it is very irregular. The region overall is classified as hot arid in the south to hot semiarid in the north according to the Köppen classification. The irregular pattern of precipitation has turned the soils into heavy clay-rich vertisols and is the reason why most of the region is not suitable for agriculture (Mège, Purcell, Pochat, & Guidat, 2015).

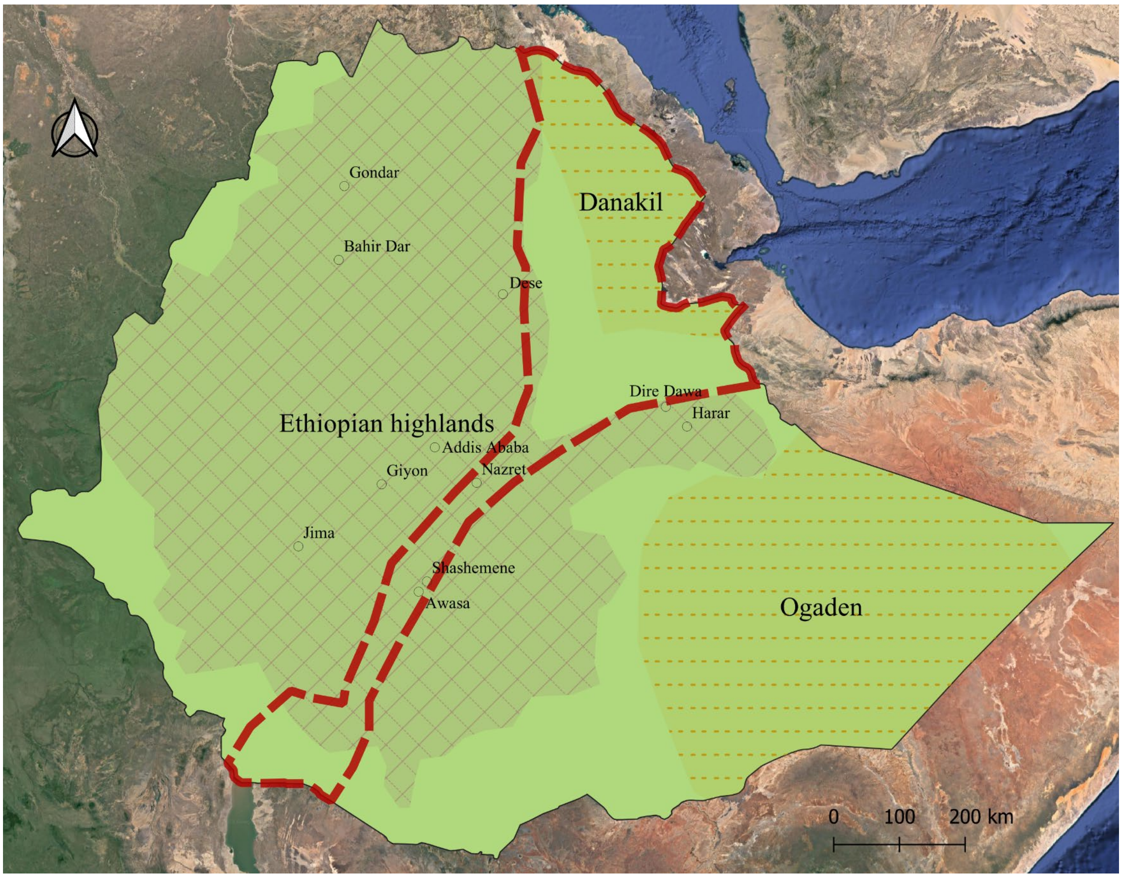


Figure 2. Overview of Ethiopia with the main geological features and most populated cities. The Ethiopian highlands covers most of the western Ethiopia, and the Danakil and Ogaden deserts make up large parts of the east of the country. The Great Rift Valley is marked with a dashed red line. The satellite picture is from Google satellite QuickMap, the dataset for country borders was made by Bjørn Sandvik and downloaded from thematicmapping.org, and the datasets with cities and regions were downloaded from naturalearthdata.com. The map and shapefiles were reworked with QGIS with the reference system WGS 84.

2 METHODS

2.1 OBSERVED HISTORICAL WEATHER

Spreadsheets with recorded climate data were downloaded as XLS documents from CLIMATE CHANGE KNOWLEDGE PORTAL, 2022 (CCKP), which is a platform that provides climate related data for the World Bank Group. The dataset for temperature was chosen as "Observed average annual mean temperature of Ethiopia 1901-2020", and the dataset for precipitation was chosen as "Observed average annual precipitation of Ethiopia". On both datasets all years before 1965 were removed to fit with the data on weather induced disasters described in the next section.

Both datasets downloaded from CCKP contained one set of data with original observations, and one set of data which were smoothed with 5 years. Smoothed data is good for making trending patterns stand out more, but the original observation sets were chosen for this paper because smoothing can eliminate important data points. The XLS files were opened with Microsoft Excel and converted to Comma Separated Values (CSV) files, after which they were imported to the programming software MATLAB to be plotted as graphs (*figures 3 and 4*).

Regression analyses were made on both graphs with the equation $y = mx + c$, where y is the dependent variable, m is the number of the gradient, x is the dependent variable, and c is the interception point.

2.2 Records of natural disasters and their impact

Statistics of impacts caused by natural disasters were retrieved with the mapping tool on the Emergency Events Database, 2022, (EM-DAT). EM-DAT is a database that contains information about the occurrence and effects of natural and technological disasters from 1900 until present day. Excluded from the data was records from technological and complex disasters, only disasters classified as natural were included. From this data the subgroups geophysical, biological and extra-terrestrial were excluded, and meteorological, hydrological and climatological disasters were included. These subgroups contain disaster types categorised as extreme temperatures, fog, storms, wave actions, landslides, floods, wildfires, glacial lake outbursts and drought. The time span chosen was from 1900 to 2022, but the records on Ethiopia begin in 1965, and that is why the start year of the statistics used in this paper from now on is 1965. The records of the years 2020-2022 were removed because the observed weather data described in the previous section ends with the year 2020.

From the data collected from EM-DAT only three categories were used when analysing the statistics; the year of the incident, the disaster type and the total number of people affected by the disaster. The category of total number of people affected includes the number of deaths, injuries and people made homeless as a result of the incident. The reason the total number of affected people were chosen is because the number of people migrating because of it is hard to measure because of the reasons explained in section *1.2.1 The complexity of defining environmental migration*, but migration in large part can be related to the impact a disaster has on these three things. The data was converted to CSV files in Microsoft Excel and then imported to MATLAB where they were plotted as graphs.

2.3 Projections on future climate

Modelled data on future climate in Africa were downloaded as Geostationary Earth Orbit Tagged Image File Format (GeoTIFF)-files from the IPCC interactive atlas (Gutiérrez, et al., 2021). The climate model chosen for this paper was CORDEX Africa, since it focuses on regional weather instead of global weather as the CMIP-models does. The period chosen was 2041-2060 (medium term), and the scenario to base the projections on was the Representative Concentration Pathway (RCP) 2.6 which describes the modelled climate change if earth were to warm up 2° Celsius, and the baseline chosen was 1986-2005. All datasets are projections of annual weather. The variables chosen were annual mean temperature, annual mean daily maximum temperature, total annual precipitation and the maximum number of consecutive dry days. These four variables were chosen because when combined they are good indicators on how the changes will affect the regional weather. The datafiles were then reworked in QGIS, a software with tools for managing, analysing and visualising geographic data. A shapefile with country borders was downloaded from thematicmapping.org (Sandvik, 2022) to clip the GeoTIFF-files from IPCC to only include Africa in one version and Ethiopia in another version, and one shapefile with the most populated cities as dot features and one shapefile with morphological features were downloaded from Natural Earth, (2012). The values the maps were based on were divided into appropriate intervals and then colour gradients were chosen to make the ranges clear and easy to read.

3 Results

3.1 Historical climate

The plotted weather data shows that both the recorded mean annual temperature and the total annual precipitation has been increasing during the last 57 years. The trendline for the change in temperature in *Figure 3* shows an increase of 1.1681 degrees Celsius during the measured period. The trendline for precipitation in *Figure 4* has a gentler slope and shows an increase of 40.2635 millimetres. The two graphs are plotted together in *Figure 5* to ease the visualisation of the relationship between them.

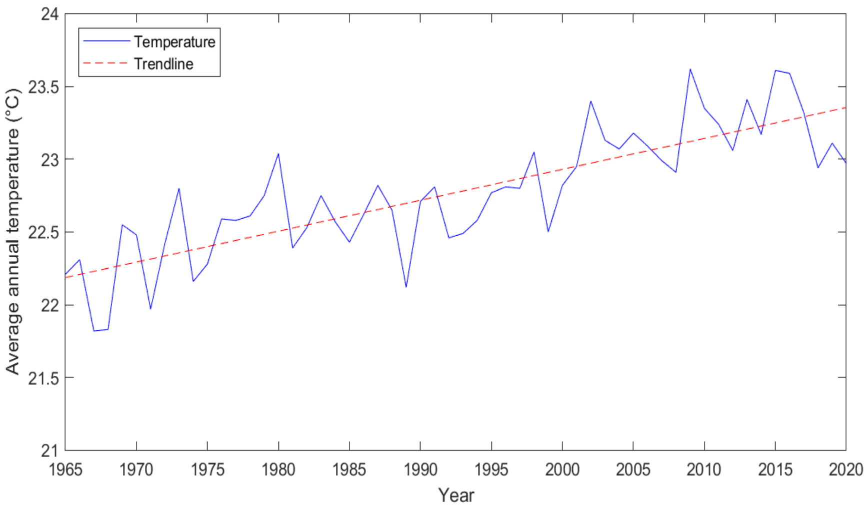
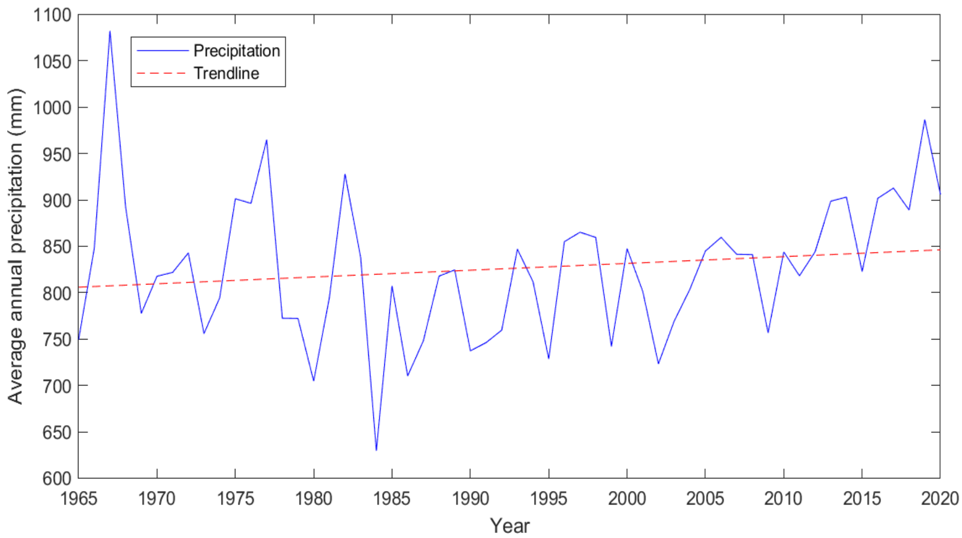


Figure 3. Line chart showing the recorded average annual temperature and the trend of the temperature change in Ethiopia between the years 1965 and 2020, with the data collected from The World Bank Group, (2022a), plotted in MATLAB.

Figure 4. Line chart showing the recorded average annual precipitation and the trend of the precipitation change in Ethiopia between the years 1965 and 2020, with the data collected from The World Bank Group, (2022a), plotted in MATLAB.



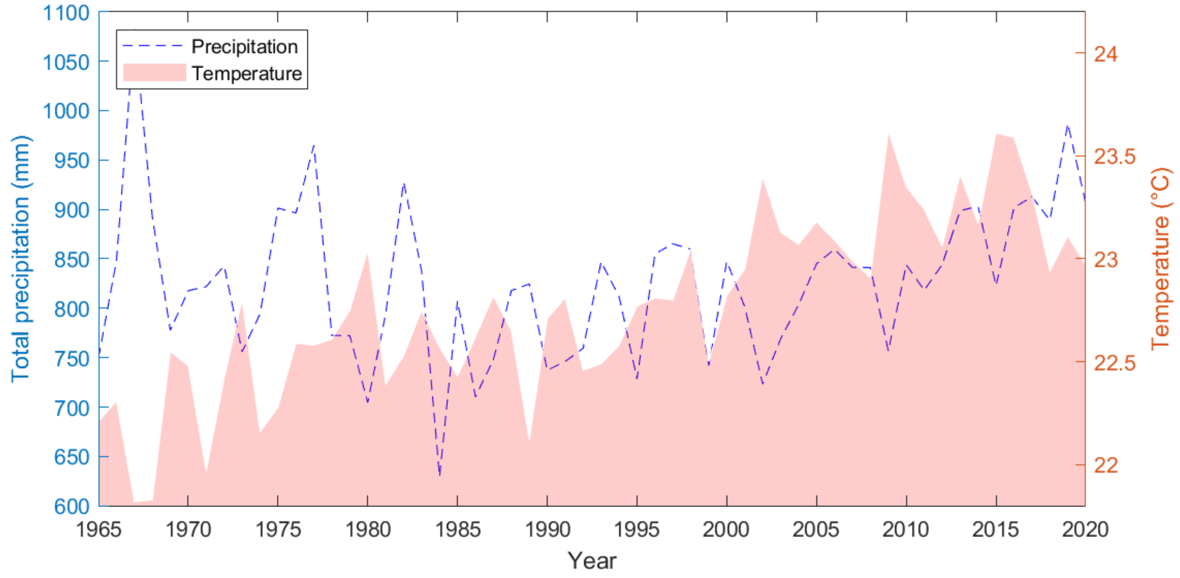


Figure 5. Combined line graph showing the recorded total annual precipitation and mean annual temperature in Ethiopia during the years 1965-2020. The data was downloaded from The World Bank Group, (2022a), plotted in MATLAB.

3.2 DISASTER TYPES AND THEIR IMPACT ON POPULATIONS

The data on natural disasters and their impact shows that the number of people affected by climate related disasters has been growing since the recordings began, that flood is the most common natural disaster, and that drought is the disaster type with highest impact on populations.

In *Figure 6* the total number of people affected by natural disasters each year between 1965 and 2020 is plotted as bars, combined with the temperature graph from *Figure 3*. The peak in the year of 2003 is a drought event that lasted a year and reached over regions in Ethiopia, Eritrea, South Africa and Somalia, with 12.6 million people affected as a result. The smaller peak in 2015 is also a drought. It lasted two years and affected 10.2 million people in regions in Ethiopia, Somalia and South Africa. All 7 smaller peaks are also drought events. The total number of people affected by the disasters represented is 94 917 129. In the chart all the impact of the events is represented by the starting year of it, even if they lasted over several years.

The total number of climate related disasters accounted for in this paper is 84, and they all belong to one of the four disaster types: flood, drought, landslide and wildfire. One wildfire took place in the year 2000, and that is the only one documented on EM-DAT. In *Figure 7* each disaster type is presented as the percentage of their frequency and total impact compared to the other disaster types. The most common disaster type is flood, representing almost 70% of the events, followed by drought which stands for 21% of them. In affecting people, drought stands for 95% of the impact, while flood stands for 5% of it. Landslide and wildfire combined stands for less than 1% of the impact. The exact numbers of frequency and impact for each event, and the total number, can be read in *Table 1*.

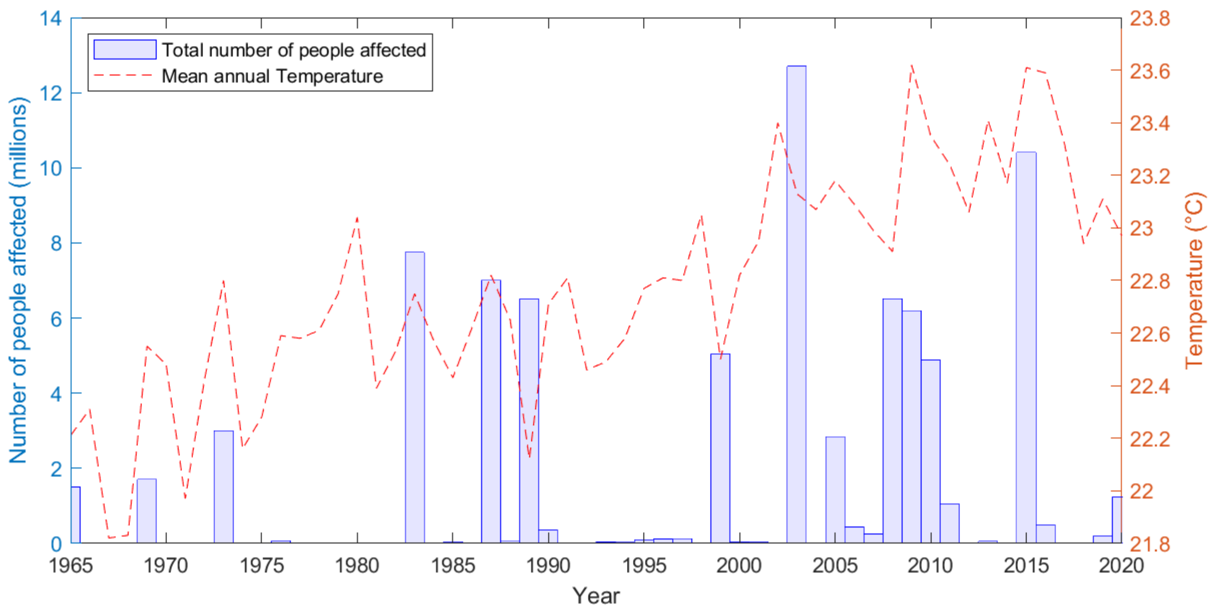


Figure 6. Combined line chart and bar graph to visualise the relationship between recorded temperature and weather-induced disasters with considerable effect on people between the years 1965 and 2020. The datasets are downloaded from The World Bank Group, (2022a), and Centre for Research on the Epidemiology of Disasters, (2022).

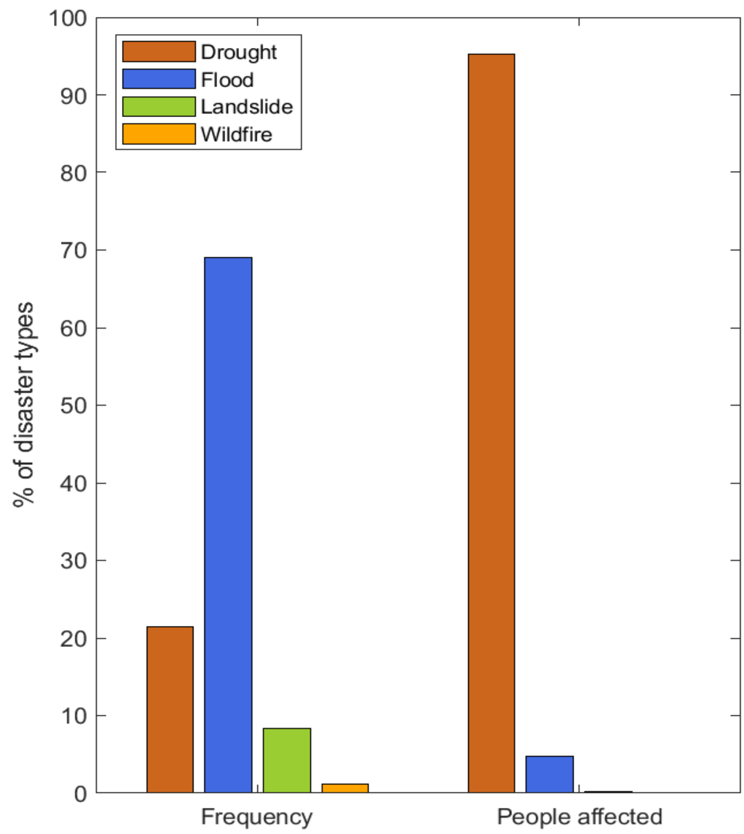


Figure 7. Bar chart showing the distribution of frequency and impact of the natural disaster types in Ethiopia between the years 1965 and 2020. The data is collected from EM-DAT and reworked in MATLAB.

Table 1. The total number of events and people affected by each disaster type. The data is downloaded from EM-DAT.

Disaster type	Number of events	Number of people affected
Drought	18	90 341 879
Flood	58	4 575 030
Landslide	7	215
Wildfire	1	5
Total	84	94 916 909

3.3 PROJECTED FUTURE CLIMATE

3.3.1 Temperature

The data from the RCP2.6 models shows that all of Africa will have an increase in temperature, even though not all parts are going to have the exact same scale of change. *Figure 8* and *Figure 9* shows the range and gradient of the projected temperature change in Africa in a scenario with a total global warming of 2 degrees Celsius in the medium-term future (years 2041-2060), compared to the baseline (years 1986-2005). *Figure 8* is the predicted change in annual mean temperature, and *Figure 9* the predicted change of annual mean maximum temperature. The mitigating effect of proximity to the ocean and the equator is confirmed by both projections. The coasts that surround the continent are all expected to undergo less change than the inland areas, except from the northeast and northwest coast where the mitigating effect is prohibited by southern Europe respectively the Arabian Peninsula. Areas closer to the tropical circles are experiencing the highest temperature increases. Overall, these simulations show that the annual mean temperature in most areas is going to rise more than the annual mean maximum daily temperature. The maximum temperature does however have a range that reaches 0.1 degrees higher than the total mean.

Zooming in on Ethiopia, the model predicts an intermediate increase in temperature, with the change ranging from 1.0 to 1.4 degrees Celsius (*Figure 10*). The Ethiopian highlands and the north of the Danakil desert are expected to have the highest increase, and the Ogaden desert is expected to have the lowest temperature increase. *Figure 11* shows the change in annual mean maximum daily temperature, and the same pattern can be seen there as in *Figure 10*, except from in the Gambella region furthest to the west. The Gambella region is expected to face more extreme peaks in the daily temperature.

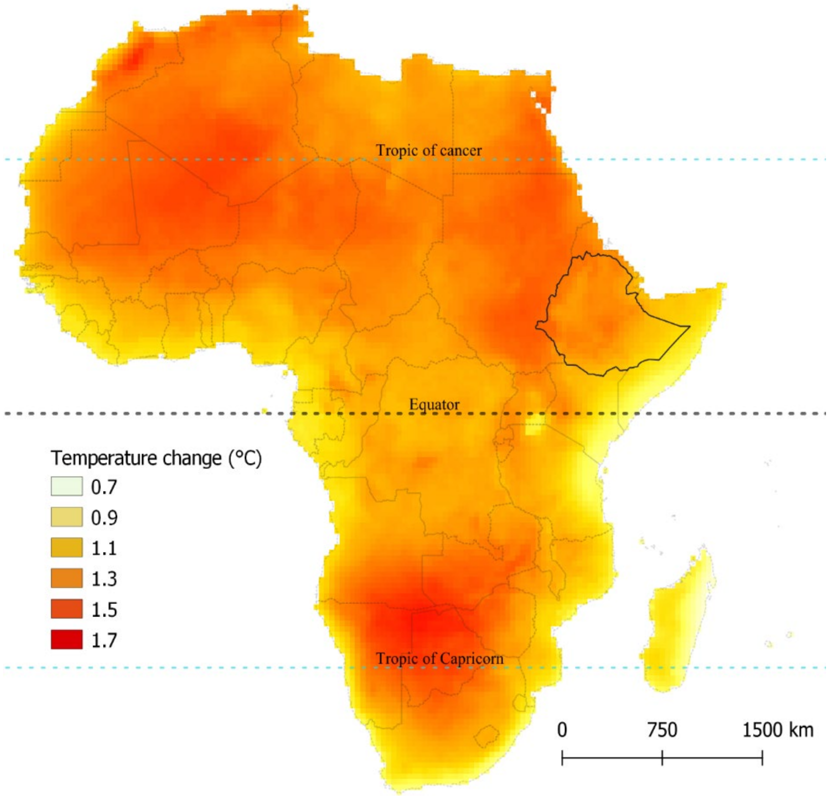


Figure 8. The projected change in mean annual temperature in Africa in the RCP 2.6 scenario projected by the CORDEX Africa model. The change is measured in degrees Celsius.

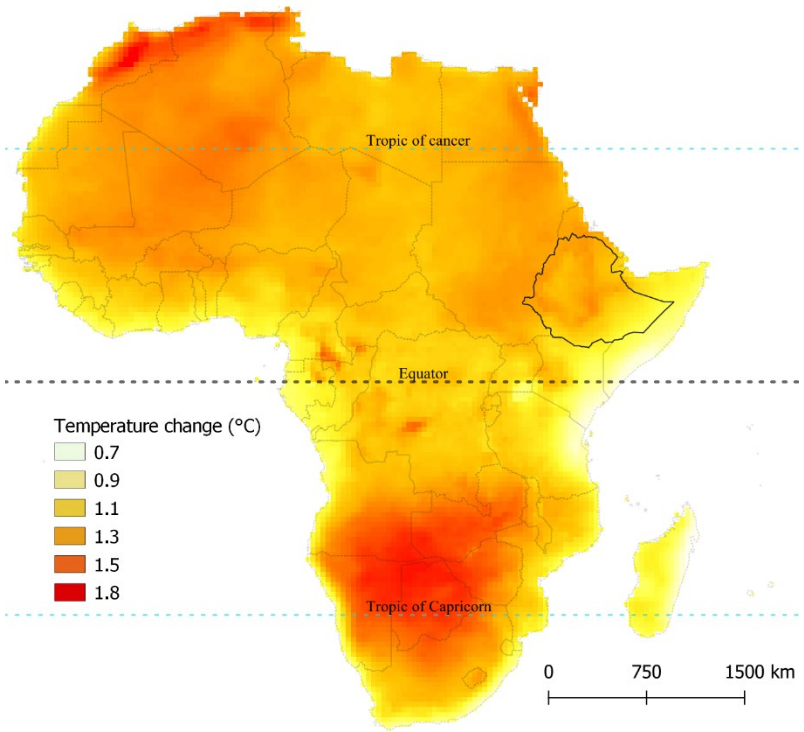
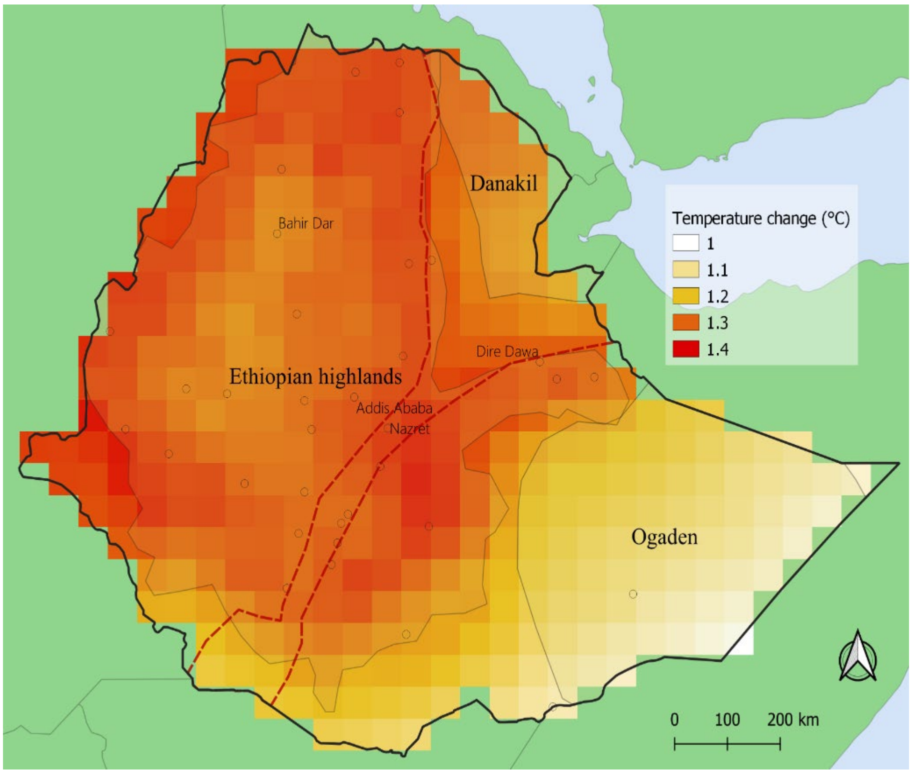


Figure 9. The projected change in annual mean maximum daily temperature in Africa in the RCP 2.6 scenario projected by the CORDEX Africa model. The change is measured in degrees Celsius.

Figure 10. The predicted change in annual mean temperature in Ethiopia in the RCP 2.6 scenario projected by the CORDEX Africa model. The change is measured in degrees Celsius. The extension of the Ethiopian Highlands is outlined in a transparent grey colour, and the cities with the highest population are marked and labelled. Smaller cities are marked with a black circle but not labelled. The Great Rift Valley is outlined with a red dashed line.



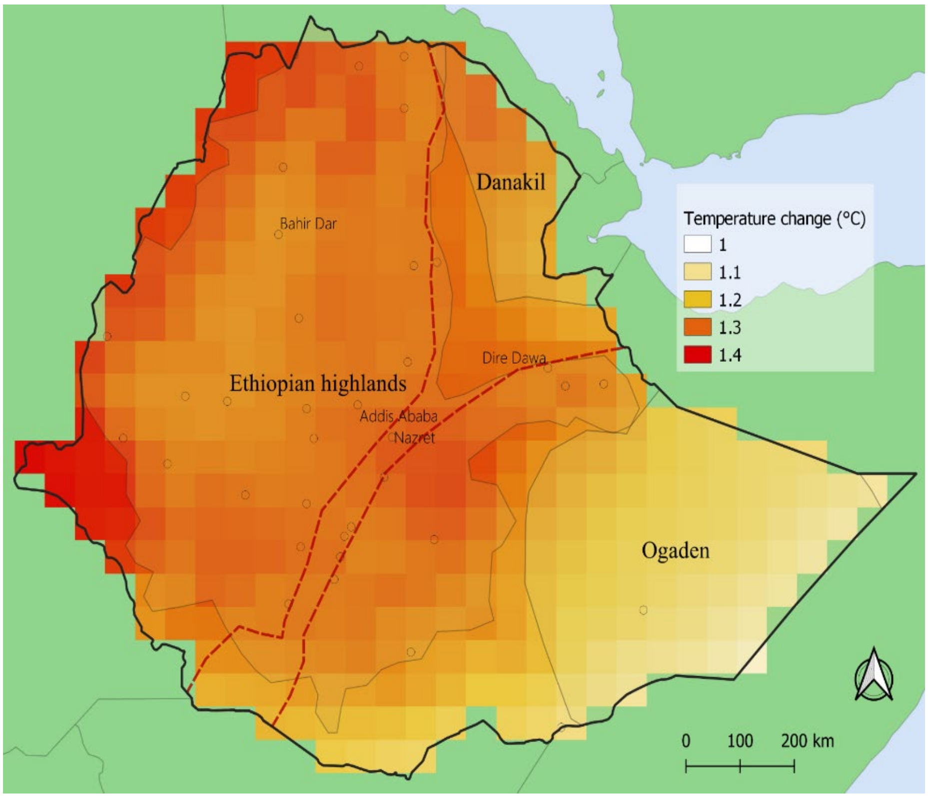


Figure 11. The predicted change in annual mean maximum temperature in Ethiopia in the RCP 2.6 scenario projected by the CORDEX Africa model. The change is measured in degrees Celsius. The extension of the Ethiopian Highlands is outlined in a transparent grey colour, and the cities with the highest population are marked and labelled. Smaller cities are marked with a black circle but not labelled. The Great Rift Valley is outlined with a red dashed line.

3.3.2 Precipitation

Figure 12 and *Figure 13* shows the projection on the change in total annual precipitation for Africa respectively Ethiopia. The mitigating effect of proximity to the equator and ocean on the impact of climate change is again confirmed by the model, and that the regions close to the tropical circles are the most affected. Some areas are expected to see an increase in total annual precipitation, while other areas are predicted to have a decrease. The Sahara Desert in the north of Africa is expected to get the largest decrease in total annual precipitation with some areas expecting a reduction of 26 millimetres per year. Almost all areas in Ethiopia are expected a decrease in precipitation, with the maximum changes over the Great Rift Valley crossing the middle of the country, and the Gambella region to the west. The only areas that are expected to have an increase in precipitation are the easternmost parts of the Ogaden desert and possibly a few of the northern parts of the Ethiopian highlands.

The expected change in maximum number of consecutive dry days in Africa can be seen in *Figure 14*, and with Ethiopia in focus in *Figure 15*. The mitigating effect of the proximity to the equator is confirmed by this projection too, but the effects of the proximity to the ocean can not be seen. Some of the inner parts of the Sahara Desert and areas around the equator are expected a decrease in the maximum number of consecutive dry days, but the rest of the continent is expected an increase. In Ethiopia the expected trend in almost the whole country is an increase in the maximum number of consecutive dry days. The largest increase is expected in the northern parts of the Danakil desert and in the western parts of the Ethiopian highlands. Only in the southernmost parts of the country, on the border to the Chalbi desert in Kenya, is a decrease expected.

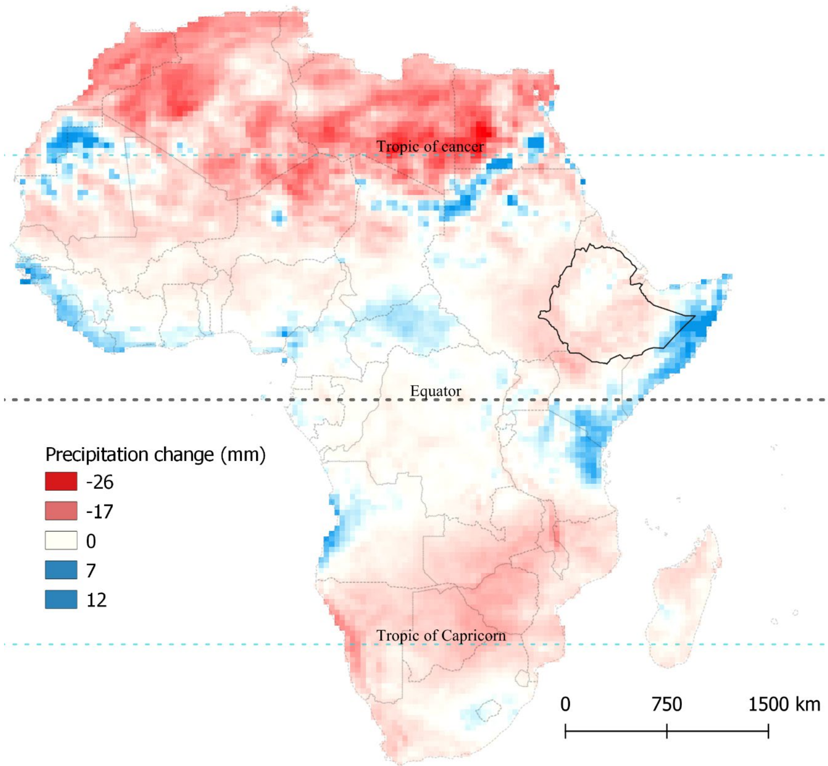


Figure 12. The projected change in annual mean total precipitation in the RCP 2.6 scenario projected by the CORDEX Africa model. The change is shown in millimetres.

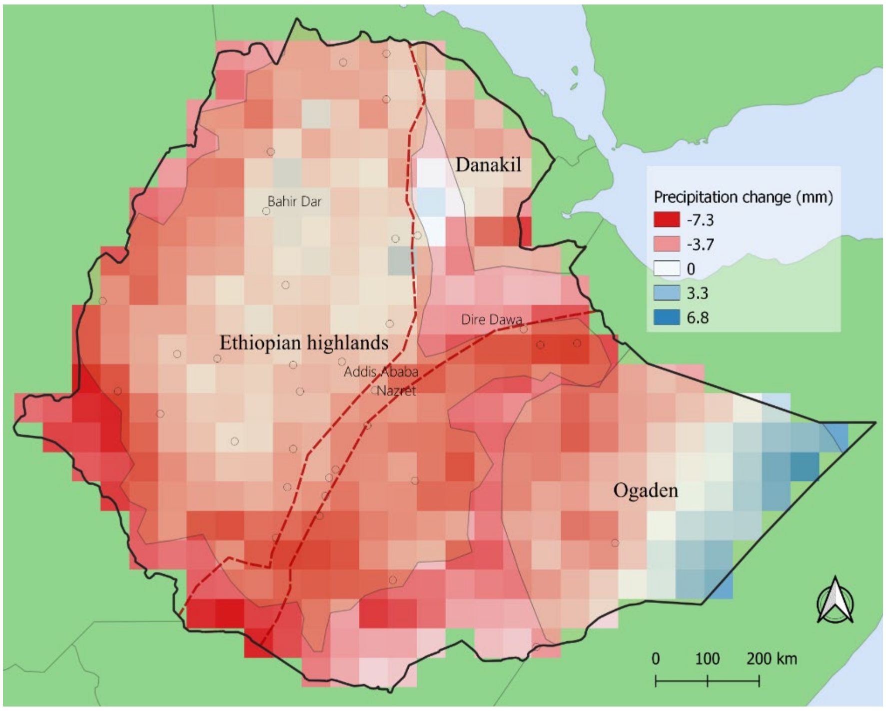


Figure 13. The projected change in annual mean total precipitation in Ethiopia in the RCP 2.6 scenario projected by the CORDEX Africa model. The change is shown in millimetres. The extension of the Ethiopian Highlands is outlined in a transparent grey colour, and the cities with the highest population are marked and labelled. Smaller cities are marked with a black circle but not labelled. The Great Rift Valley is outlined with a red dashed line.

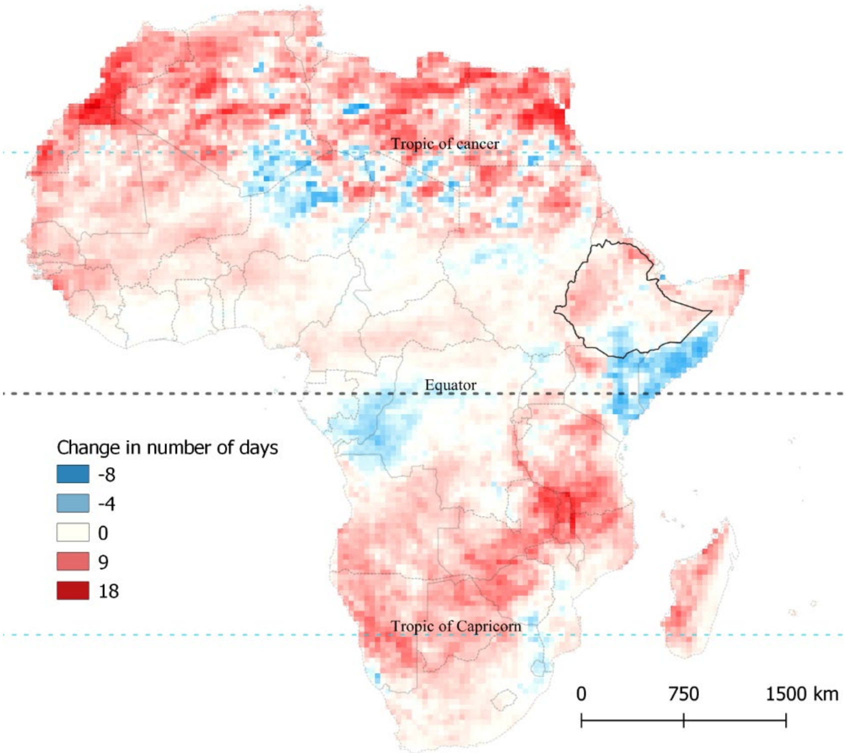


Figure 14. The projected change in number of consecutive dry days in Africa in the RCP 2.6 scenario projected by the CORDEX Africa model.

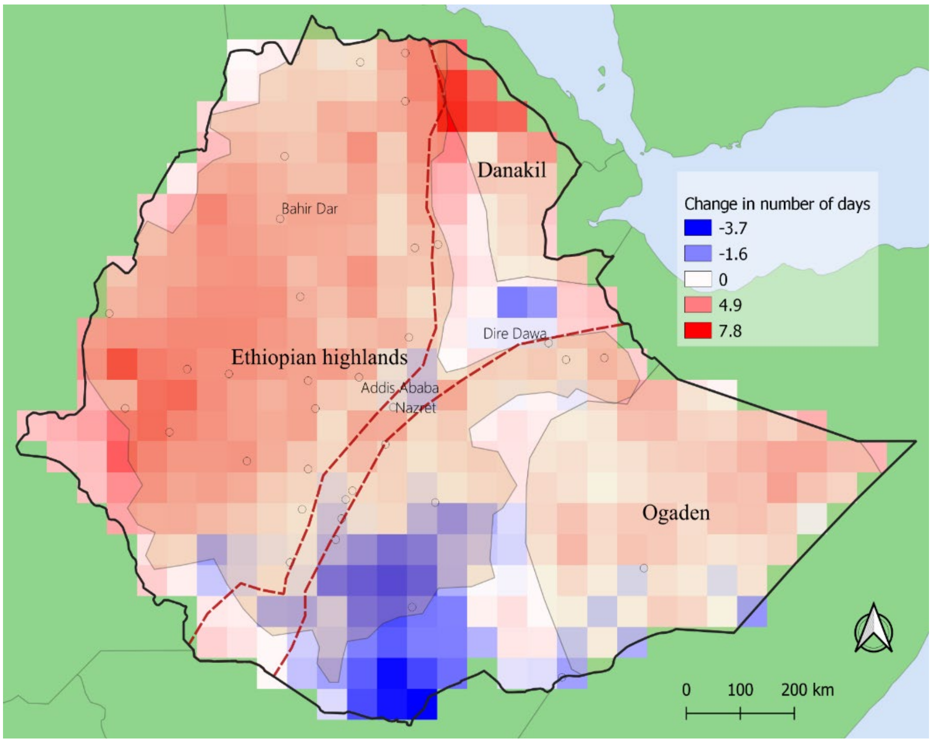


Figure 15 The projected change in the number of consecutive dry days in Ethiopia in the RCP 2.6 scenario projected by the CORDEX Africa model. The extension of the Ethiopian Highlands is outlined in a transparent grey colour, and the cities with the highest population are marked and labelled. Smaller cities are marked with a black circle but not labelled. The Great Rift Valley is outlined with a red dashed line.

4 DISCUSSION

4.1 PAST CLIMATE, DISASTERS AND IMPACT

The weather plots showing recorded temperature and precipitation (*Figures 3 and 4*) shows that the temperature in the region has been rising, in consistency with the projections made by climate models (IPCC, 2021), and that the precipitation is almost constant. The time period measured is too short to make and assumptions on any long-term trend, or to make any predictions on future weather. To get a complete and more accurate analysis of the weather and climate in the region longer weather records are needed. The pattern in *Figure 5* does however show that years with peaks in temperature coincides with troughs in precipitation, and years with peaks in precipitation coincides with troughs in temperature, meaning that significant for the climate in the region is that the years vary between being hot and dry, and cool and wet. An increase in temperature can therefore make the hot and dry years even more intense, resulting in reduced crop yields and an increase in acute water scarcity.

As described previously, a higher intensity on heat waves or longer periods of drought leads to reduction in soil moisture which in turn harms vegetation and agriculture which in a feedback loop leads to a higher surface temperature (Seneviratne, et al., 2010), and it is therefore reasonable to believe that the increased observed temperature without corresponding increase in precipitation can be connected to the increase in disaster impact presented in *Figure 6*. Not only do the peaks in *Figure 6* increase in frequency, but they also grow in size. There can, however, be other reasons to the growing trend of how many people are affected by natural disasters per year. For instance, the human population is growing all over the world, and therefore naturally more people will be at risk for disaster. Another reason could be that the systems for reporting and documenting disasters and their effects has become better and more efficient, and that information can be reported and shared easier between countries and organisations with newer technology. Natural cycles in the atmospheric circulation and solar radiation are the reasons why the disasters and their impact on populations vary much from year to year, but the overall growing trend is in line with the predictions made by climate scientists (IPCC, 2013), and it is expected to continue to grow.

The graph in *Figure 6* also shows the relationship between temperature and disaster impact. A correlation between heat waves and years with high disaster impact can be perceived, but sometimes with the heat waves delayed by a year or two from the years with high disaster impact. This is likely because when the impact from each disaster was calculated and plotted, every disaster was presented with its starting year. Some of the drought events lasted up to five years, and it is reasonable to assume that the largest effects of an extended drought would be in the end of the drought and not in the beginning. The peak in 1989 is a drought that left 6.5 million people affected. It started in October 1989 and ended sometime during 1994. The peak in 1999 was a drought that began in September 1999 and ended in December 2000 and left 4.9 million people affected. By dividing the number of affected people between the years in a more realistic way, a chart with a more accurate relationship between the two factors could have been obtained.

One noticeable thing in the disaster records is that several flood events happened during periods of drought. For instance, 4 flood events took place during the drought that lasted between 1999 and 2000. This can be explained by the fact that precipitation is decreasing in frequency but not in total amount, as can be seen in *Figure 4*, leaving more dry days between periods of rain and when the rain comes it is more intense. As explained in section **1.1 Climate change and weather disasters**, more intense precipitation events will saturate the soil and leave the system as runoff (Zhao, Weng, Chen, & Yang, 2020), which in the end means that the region is left with less water available annually than if the precipitation events were to be more frequent but less intense or with shorter duration.

The total number of climate related disasters that has taken place in Ethiopia since 1965 is 84, with floods being the most frequent one standing for 70% of the events. The second most frequent disaster type is drought, that stands for 20% of the events (*Figure 7*). When comparing these numbers with how big an impact they have on people it becomes clear that even though floods are the most common type of natural disaster, they only have a fraction of an impact on the population compared to the drought events. Droughts stand for 95% of all the deaths, injuries and home losses in Ethiopia during the last 57 years (*Figure 7*). The explanation to this could be that drought affects larger areas and for a longer time, and if it is within regions with a lot of farmlands it also affects not only the food access for the whole region but also the resources the farmers would have gained from selling produce, and that can be a provocation for conflicts. The conclusion that can be made from this knowledge is that when doing a risk assessment for displacement in the region the primal focus should be on drought disasters and their effects.

There are more comprehensive studies on recorded weather and climate change already done, and possibly data better fit for the purpose of this paper to find but it is beyond the scope of this study due to the time constraint.

4.2 PREDICTED CLIMATE AND ITS EFFECT ON FUTURE DISPLACEMENT

The projections made in this paper were made by the CORDEX Africa model. There are several other models that can be used, and evaluating more than one model would give a better comprehensive result. The scenario RCP2.6 is the most stringent pathway evaluated by IPCC, and it requires major effort and collaboration between all countries to be reached. This means that the results presented in section **3.3 Projected future climate** are the “best case scenario” for the global climate.

The results show that the temperature is going to increase in all regions evaluated in this paper. Ethiopia is not going to face the largest increase, but some regions will be more exposed than others. The Ethiopian highlands are home to 80% of the Ethiopian population (The Africa Research in Sustainable Intensification for the Next Generation, 2022) and are also subjected to the largest changes according to the climate models. An increase in temperature and a decrease in precipitation, combined with an increase of maximum dry days between precipitation events means that the drought events are going to be hotter, drier and longer. With a population out of which 70% are dependent on agriculture the area is highly vulnerable to the changes. The food access in the region and the country's economy is at high risk since the food export stands for almost 80% of the total income on merchandise. Overall agriculture is the foundation of their economy, with almost 50% of their Gross Domestic Product (GDP). The lowlands already have low potential for agriculture due to the sandy soils in the deserts. Another part of Ethiopia that is projected to undergo large changes is the Gambella region in the westernmost parts of the country. Here lies the Gambella national park, which is home to a vast flora and fauna. Together with the highlands the Gambella region is to expect the highest temperature increase and the biggest decrease in precipitation, with longer periods of drought. The region is only home to less than 4 permille of the population, so changes here will be a threat to nature and wildlife but no big assets or populations are exposed. There is already work going on for limiting the use of land more because the region is a protected area, so in the future there might already be fewer people living there.

The results for the Danakil desert in northeastern Ethiopia may look positive on a first glance, the temperature is predicted to only increase moderately, and the precipitation will not decrease as much as in other parts of the nation, but since the desert already is one of the hottest and driest spots on earth, these small changes can have devastating effects for those who live there. As seen in *Figure 15,* the Danakil desert is expected to have their maximum number of consecutive dry days extended with up to almost 8 days. When the climate gets even more inhospitable the 3 million people who live there today may need to relocate.

The Ogaden desert has been projected to have the smallest increase in both mean temperature and daily maximum temperature. The precipitation is not projected to decrease a lot over the area, and some places are even expected to have higher amounts of precipitation and shorter drought periods than present day. This combination might even have a positive effect on the conditions for possible vegetation and agriculture in the area.

No climate model or modelled simulation can be exactly accurate, and these results are only simulations from one scenario made with one model. Even though the different models in large part agree in their simulations, the exact range and distribution on the changes cannot be precisely established. The climate scientists have, however, made extensive research all over the world using interdisciplinary methods and perspectives and the main patterns of the results are to be seen as reliable (IPCC, 2021). The interpretation on how the simulations affect each area is based on only four variables, and to properly evaluate the effects, simulations on more variables are needed and a broader analysis of the soil, vegetation, biodiversity and overall vulnerability of the sites must be done. The effect on seasonal variations is one important factor to look further into, since the agriculture in Ethiopia has two major crop seasons and is dependent on the rainfall during both periods which means that it is not only the total annual precipitation and the intensity and duration of the precipitation events that is important, but also that they coincide with the two crop periods.

4.2.1 Risk assessment

According to the findings in the analysis of the climate data and simulations, the Ethiopian highlands are going to be at highest risk of large impact due to climate change. They have high exposure to the parameters projected, and they are most vulnerable to change due to the population density and the wide agricultural importance. Drought is the disaster that has the largest impact on the population. As stated earlier, slow-onset disasters can have a mitigating effect on migration, which means that even though millions of more people will be exposed to drought conditions due the impact of climate change, the effect on migration could be small. In addition, Ethiopia is a developing country with high poverty and is already a conflict zone. Both factors further decrease the expected possibility for the affected people to migrate. Another repressive factor is that many developed countries reject refugees from developing countries which impair the possibilities for long-distance displacement. As Ethiopia already has one of the largest numbers of displacements in the world, the effect of climate change on migration is assessed to be low, but that millions of people will be exposed to disasters resulting from it and that action must be taken to limit the hazards. This could be done with on-site adaptation strategies such as providing irrigation systems and water reservoirs accessible for the farmers, implementing watershed management, developing more drought resilient crops and preserving vegetated land cover to lower the local temperature and retain water. More research must be done to assess what adaptation strategies are best fitted to limit the effects of climate change, and how to implement them as efficient as possible.

5 CONCLUSIONS

Records of natural disasters, their impacts on human populations, historical weather and climate models for future scenarios have been reviewed in this paper. The results from recorded data shows that the temperature in Ethiopia appears to be rising while precipitation is basically unchanged, and that the frequency and size of natural disasters is growing. To gain a better understanding of, and a more statistically valid trend of the climate and weather more recorded data from longer periods of time are needed. The most predominant of the disaster types analysed is flood, but drought is the one with the highest impact on human populations. If a global warming of 2 degrees Celsius takes place, the effect would be an annual mean temperature increase of 0.7-1.7 degrees unevenly distributed over the area, with an increase of annual mean daily maximum temperature in the same size range. The annual total precipitation will decrease with up to 7.3 millimetres in almost all regions studied except from a small part of Ogaden and possibly in small areas in the northeast highlands, and the annual mean maximum days between precipitation events will increase with up to 7.8 days in all of Ethiopia except from the southern lowlands. The results in this paper are based on only one of the available climate models. More simulations and projections need to be made in order to get an as acurate result as possible.

The Ethiopian highlands is the region which will be most at risk of the projected climate change due to the combined effects of temperature increase, precipitation decrease, high population density and large-scale agricultural land use which is the foundation to the economy and food access in the whole country. The effects of climate change on migration is assessed to be small due to the economic and political condition in the country, but the effects on humans in the area will be large and adaptation strategies are required in order to avoid a catastrophe on a national scale. More research is needed to properly assess which areas on a local scale will need the most adaptations, which adaptations are needed and how to implement them as cost effectively as possible.

Acknowledgements

First I would like to thank my advisor, Deliang Chen, for his expertise and all the help and guidance throughout this work. I also want to thank my examiner Fredrik Lindberg, course leader Mark D. Johnson, and my peers Nora Jonhäll, Albin Nordås and Kristin Winblad for their input and suggestions, with a special thank to my peer Julia Backman who was a well needed sounding board during the initial process of this work. I want to thank Lars Haulin, Johan Fredlund, Adam Axelsson and Johan Lindéh who patiently helped me with the technical difficulties I encountered. I also want to thank my friends “Bullarna” and “Snickarna” for their support and encouragement, and my sister Johanna Hänninen for comments on language and grammars, and for being there for me whenever I need her. Lastly, I want to thank my mum, Kristina Börjesson, and my partner, Niclas Wallin, for their encouragement, patience and never-ending support over the length of my studies.

REFERENCES

Atlas of Humanity. (2022, 06 07). *The Hottest Place on Earth.* Retrieved from Atlas of Humanity: https://www.atlasofhumanity.com/danakil

Betts, R. A., Alfieri, L., Bradshaw, C., Caesar, J., Feyen, L., Friedlingstein, P., . . . Wyser, K. (2018, 05 13). Changes in climate extremes, fresh water availability and vulnerability to food insecurity projected at 1.5°C and 2°C global warming with a higher-resolution global climate model. *Philosophical Transactions of the Royal Society A, 376*(2119), p. 20160452. doi:https://doi.org/10.1098/rsta.2016.0452

Cattaneo, C., Beine, M., Fröhlich, C. J., Kniveton, D., Martinez-Zarzoso, I., Mastrorillo, M., . . . Schraven, B. (2019, 06 25). Human Migration in the Era of Change. *Review of Environmental Economics and Policy, 13*, pp. 189-206. doi:https://doi.org/10.1093/reep/rez008

Centre for Research on the Epidemiology of Disasters. (2022). *Data.* Retrieved from EM-DAT Public: http://www.public.emdat.be

Déqué, M., Clamanti, S., Bøssing-Christensen, O., Dell Aquila, A., Fox-Maule, C., Haensler, A., . . . Teichmann, C. (2016, 06 18). A multi-model climate response over tropical Africa at +2 °C. *Climate Services*, pp. 87-95. doi:https://doi.org/10.1016/j.cliser.2016.06.002

Gleick, P. H. (1989). Climate Change and International Politics: Problems Facing Developing Countries. *Ambio, 18*(6), pp. 333-339.

Gröschl, J., & Steinwachs, T. (2017). Do Natural Hazards Cause International Migration? *SESifo Economic Studies, 63*(4), pp. 445-480. doi:https://doi.org/10.1093/cesifo/ifx005

Gutiérrez, J. M., Jones, R. G., Narisma, G. T., Alves, L. M., Amjad, M., Gorodetskaya, I. V., . . . Yoon, J. -H. (2021). *Atlas.* Retrieved from Climate Change 2021: The Physical Science Basis: http://interactive-atlas.ipcc.ch/

IPCC. (2013). Climate Change 2013: The Physical Science Basis. In T. F. Stocker, D. Qin, G. -K. Plattner, M. Tignor, S. K. Allen, J. Boschung, . . . P. M. Midgley, *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 1535). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC. (2014). Annex II: Glossary. In K. J. Mach, S. Planton, & C. von Stechow, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 117-130). Geneva, Switzerland: IPCC.

IPCC. (2021). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, . . . B. Zhou, *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 3-23). United Kingdom and New York, NY, USA: Cambridge University Press, Cambridge,. doi:10.1017/9781009157896.001

Jones, B., & O'Neill, B. O. (2016, 07 29). Spatially explicit global population scenarios consistent with the shared socioeconomic pathways. *Environmental Research Letters, 11*(8), p. 084003. doi:10.1088/1748-9326/11/8/084003

Kharin, V. V., Flato, G. M., Zhang, X., Gillett, N. P., Zwiers, F., & Anderson, K. J. (2018, 04 20). Risks from climate extremes change differently from 1.5°C to 2.0°C depending on rarity. *Earth's Future, 6*(5), pp. 704–715. doi:https://doi.org/10.1002/2018EF000813

Mège, D., Purcell, P., Pochat, S., & Guidat, T. (2015). The Landscape and Landforms of the Ogaden, Southeast Ethiopia. In P. Billi, *Landscapes and Landforms of Ethiopia. World Geomorphological Landscapes* (pp. 323-348). Dordrecht: Springer.

Natural Earth. (2012, 12 15). *1:10 Physical Vectors.* Retrieved from Natural Earth Data: https://www.naturalearthdata.com/downloads/10m-physical-vectors/

Norwegian Refugee Council/Internal Displacement Monitoring Centre. (2019). *Global report on internal displacement - 2019.* Norwegian Refugee Council.

Rubel, F., & Kottek, M. (2010, 02 2). Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification. *Meteorol, 19*(2), pp. 135-141. doi:DOI: 10.1127/0941-2948/2010/0430

Sandvik, B. (2022, 05 13). *World Borders Dataset.* Retrieved from Thematic Mapping: http://thematicmapping.org/downloads/world_borders.php

Seneviratne, S. I., Corti, T., Davin, E. L., Hirschi, M., Jaeger, E. B., Lehner, I., . . . Teuling, A. J. (2010, 05). Investigating soil moisture–climate interactions in a changing climate: A review. *Earth-Science Reviews, 99*(3), pp. 125-161. doi:https://doi.org/10.1016/j.earscirev.2010.02.00

The Africa Research in Sustainable Intensification for the Next Generation. (2022, 05 27). *Ethiopian Highlands*. Retrieved from https://africa-rising.net/ethiopian-highlands/

The World Bank Group. (2022a, 05 05). *Climate Change Knowledge Portal*. Retrieved from Ethiopia - Climatology: https://climateknowledgeportal.worldbank.org/country/ethiopia/climate-data-historical

The World Bank Group. (2022b, 04 08). *Population, total - Ethiopia*. Retrieved from The World Bank: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ET

The World Bank Group. (2022c, 05 28). *Food exports (% of merchandise exports - Ethiopia*. Retrieved from The World Bank: https://data.worldbank.org/indicator/TX.VAL.FOOD.ZS.UN?locations=ET

Worldmark Encyclopedia of Cultures and Daily Life. (2022, 05 20). *Afar*. Retrieved from Encyclopedia.com: https://www.encyclopedia.com/places/africa/ethiopia-political-geography/afar

Zhao, Y., Weng, Z., Chen, H., & Yang, J. (2020, 07 12). Analysis of the Evolution of Drought, Flood, and Drought-Flood Abrupt Alteration Events under Climate Change Using the Daily SWAP Index. *Water, 12*(7), p. 1969. doi:https://doi.org/10.3390/w12071969