A Geospatial Analysis of Climate Change Vulnerability in Ethiopia

A thesis submitted by

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Abstract

The purpose of this thesis was to study spatial relationships among climate change vulnerabilities in Ethiopia to inform policy and planning and to offer a methodology for studying climate change impacts in areas of the world with limited data. Point data with environmental and social vulnerability variables was used for spatial analyses to determine regions of high vulnerability and their intersections. A case study was included for the capital city, Addis Ababa, to highlight the differences in climate change vulnerability in the urban environment. The findings of this thesis indicate that high social and high environmental vulnerability are most linked in the north central region of the country, and that flood-risk is a driver of environmental vulnerability in Addis, while drought is a driver of environmental vulnerability in agrarian and rural areas. Policy should be tailored on the sub-national level to address these divergent threats and may include strategies like water infrastructure improvements and food assistance.

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A Geospatial Analysis of Climate Change Vulnerability in Ethiopia

Executive Summary

This thesis examines the spatial relationships between climate change vulnerabilities in Ethiopia and the insights these relationships can offer to policy and planning for climate change in Ethiopia. Ethiopia is a large sub-Saharan African country with a varied landscape that faces threats from a wide variety of climate change phenomena. As a developing country, Ethiopia has limited access to resources that enable robust study of climate change vulnerability to inform mitigation and adaptation policies. Climate change impacts are already being felt within the nation, making studying and acting on the issue an immediate as well as long term concern.

This thesis uses GPS point data and survey data from the United States Agency for International Development (USAID) to explore climate change vulnerability. Environmental and social vulnerability variables were selected and constructed. With these variables, principal components analyses, and hot spot analyses were performed to identify regions of high and low environmental and social vulnerability in Ethiopia, and a regression analysis was conducted to assess the relationship between environmental and social vulnerability. An additional environmental variables principial components analysis was performed for a case study in Addis Ababa, the capital city of Ethiopia, and analyzed with the other national analysis outputs to identify vulnerabilities and trends specific to the urban case study. The urban case study results were also studied in relation to elevation and informal settlements that can offer additional insight into the vulnerabilities of the urban environment.

The results of this thesis indicate several regions of high vulnerability in Ethiopia. Notably, the northern central region shows a significant relationship between high social and high environmental vulnerability, making this an area of concern. Nationwide, environmental vulnerability showed a stronger spatial pattern than social vulnerability, with a concentration of high environmental vulnerability in the rural, arid areas of Ethiopia's southeast. In the Addis case study, the variables making up environmental vulnerability differed, particularly in that lack of rainfall poses a problem for much of the country creating drought risks, whereas the city appears to be at greater risk for flooding, making high rainfall a threat.

The findings of this study offer some guidance to Ethiopian policy makers, such as emphasizing the need for localized planning efforts tailored to the needs of different areas, such as urban and rural. Infrastructural improvements are recommended across the board, as is food assistance as agrarian output is threatened. As the Fletcher/UEP Climate Migration Research Team and Woodwell Climate Research Center continue their work on this issue, the results of this study should be validated against their findings. The methodology of this study may also offer an avenue for studying climate change vulnerability in other countries with limited data availability and accessibility.

Chapter 1: Background & Introduction

Climate Change in the Developing World

For many countries and cities across the globe, climate change has become the defining challenge of the 21st century with its far-reaching implications for weather, health, safety, food, economy, and virtually all aspects of human society. As developed nations and supranational bodies discuss how to address climate change, its impacts are often felt first not by those global leaders, but by the nations who have contributed the least to the changing climate. Developing countries face unique challenges from climate change, often with less resources to address them than their developed counterparts responsible for these changes.[1]

Many developing countries are part of the Global South, defined by post-colonial scholars in the journal *Contexts* as "regions outside Europe and North America, mostly (though not all) low-income and often politically or culturally marginalized."[2] The countries included in the Global South are, definitionally, politically and economically marginalized in ways that ultimately make them less adept at managing climate change mitigation and adaptation. By nature of its geography, the Global South is particularly vulnerable to certain climate change impacts, such as raising temperatures, that are magnified closer to the Equator. In Africa in particular, climate change impacts are felt through the exacerbation of the dry and wet seasons, interfering with the largely agricultural economies of many countries through drought and increasing temperatures.[3]

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[1] Raworth, "Adapting to Climate Change: What's Needed in Poor Countries, and Who Should Pay."
[2] Dados and Connell, "The Global South."
[3] Serdeczny et al., "Climate Change Impacts in Sub-Saharan Africa."

Colonial legacies have left many countries of the Global South unequipped to deal with these and other issues occurring due to a changing climate that is attributable to their prior colonizers.[4] Africa has been labeled the most vulnerable continent when it comes to climate change, due to both the nature and severity of climate change impacts as a well as a very limited ability to respond an adapt to such impacts.[5] Post-colonial developing nations in sub-Saharan Africa are typically characterized by relatively new and unstable democratic governments with autocratic influences, widespread poverty and agroeconomic reliance, and quickly growing and urbanizing populations.[6] The sub-Saharan economy's reliance on agriculture brings with it the potential for worsening socio-political conflicts as climate change increasingly disrupts agricultural production and threatens food security.[7]

Urban Africa & Ethiopia Context

Cities in sub-Saharan Africa experience an interesting intersection of the climate change issues generally associated with both sub-Saharan Africa and urban environments. Many African cities have experienced rapid urbanization with limited planning, leading to a pattern of sprawling informal settlements with very limited infrastructure and city services around the more traditionally planned urban centers, with infrastructural vestiges of European colonial establishment.[8] Rural to urban migration has also been increasing in the sub-Saharan African region as heat waves and droughts diminish agricultural livelihoods. , Rural residents are forced to search for other work in the cities, further exacerbating the

[4] Wood, "The Environmental Impacts of Colonialism."
[5] Wilson, "Climate Change and Cities in Africa: Current Dilemmas and Future Challenges."
[6] Wilson.
[7] Serdeczny et al., "Climate Change Impacts in Sub-Saharan Africa."
[8] Wilson, "Climate Change and Cities in Africa: Current Dilemmas and Future Challenges."

expansion of impoverished informal settlements.[9] Dense urban environments also come with their own host of climate-related problems, such as the Urban Heat Island Effect, flooding from rainfall and sea level rise, and increased disease prevalence and transmission. These problems are often exacerbated by the overwhelming presence of informal settlements found in nearly all of sub-Saharan Africa's major urban centers.[10]

Cities have often not been the focus of climate change studies and intervention in largely agricultural sub-Saharan Africa. However as many of the nations in sub-Saharan Africa experience increased rural to urban migration, population growth, and urbanization, cities are becoming a greater part of the conversation around climate change in sub-Saharan Africa.[11,12] As a result, migration, climate change, and urbanization have become inextricably linked forces in the region.

One nation that exemplifies this relationship is Ethiopia. Ethiopia is a country with varied geographies, landscapes, and climates. Ethiopia has a largely agricultural and pastoral economy, and a mix of arid grasslands, deserts, and forested mountainous regions. The country has experienced rapid urbanization in the past several decades, and now hosts some of the largest cities in sub-Saharan Africa. While rural populations currently make up a larger percentage of Ethiopia's populace, there has been a steady decline in the percent of the country's population residing in rural areas and an increase in both the precent and total number of Ethiopian's residing in cities.[13] The United Nations World Urbanization projects that urban population will continue to increase and that the rural population will

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[9] Serdeczny et al., "Climate Change Impacts in Sub-Saharan Africa."
[10] Wilson, "Climate Change and Cities in Africa: Current Dilemmas and Future Challenges."
[11] Wilson.
[12] Serdeczny et al., "Climate Change Impacts in Sub-Saharan Africa."
[13] "World Urbanization Prospects - Population Division - United Nations."

continue to decline at an increasing rate in the coming decades in Ethiopia.[14] This trend is generally associated with internal migration of Ethiopians moving from rural to urban areas.[15]

Addis Ababa as a Case Study

Addis Ababa, also referred to as Addis, is the capital city and largest urban area of Ethiopia. The city is a major economic center for the country, and at an estimated population of around 4 million, Addis is home to one-third of Ethiopia's urban population.[16] The city has experienced rapid expansion and urbanization in the past several decades.[17] The limited existing literature on urban impacts of climate change in Ethiopia tend to focus on Addis. Addis serves as a good urban case study for Ethiopia as the country's main urban center and its varying characteristics that set it apart from the rest of the country geographically and socially.

As a city that has experienced rapid expansion in conjunction with high levels of poverty and poor central planning oversight, it is estimated that up to 80% of Addis' residents live in slums, or informal settlements.[18] With such a high percentage of residents living in these settlements, the distinction between the "proper" and "informal" city is often not obvious nor geographically distinct.[19] Many areas of the city are indeed highly developed and

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[14] "World Urbanization Prospects - Population Division - United Nations."
[15] "Slum Housing in Ethiopia."
[16] "Ethiopia: Addis Ababa Urban Profile | UN-Habitat."
[17] Birhanu et al., "Flood Risk and Vulnerability of Addis Ababa City Due to Climate Change and Urbanization."
[18] "Slum Housing in Ethiopia."
[19] Hoeltl et al., "The Interactions of Sustainable Development Goals: The Case of Urban Informal Settlements in Ethiopia."

westernized, but this is not an accurate representation of how the vast majority of the city functions and lives.[20] Issues facing informal settlements are inherently issues that Addis as a city faces, so problems of informal settlements are problems of the whole city.

Policy & Regulation

Informal settlements, and thus the cities of Ethiopia, are by nature difficult to regulate. What few regulations do exist for environmental and health protections in the city can be nearly impossible to enforce in informal settlements, and few services are provided to residents in these settlements to meet city guidelines and regulations.[21] The governing bodies in Ethiopia at large and in the city of Addis have been accused of corruption, though Addis's more recent decentralized governing structure has seen some improvements and is addressing the city's infrastructure and housing problems.[22] While still suffering from a lack of sufficient funding and the overwhelming scope of the problem, it is encouraging for the future of the city and interested external partners like non-governmental organizations (NGOs) that the city is prioritizing such improvements.

Environmental and climate change policy in Ethiopia exist but has struggled to take center stage or instigate meaningful changes in the country. In the past few decades Ethiopia has set forth several national goals and policies for addressing climate change and environmental problems, and has signed several multinational agreements, such as the Paris Climate Accords. However, capacity for studying environmental challenges, planning

[20] Dubbale, Tsutsumi, and Bendewald, "Urban Environmental Challenges in Developing Cities: The Case of Ethiopian Capital Addis Ababa."
[21] Dubbale, Tsutsumi, and Bendewald.
[22] Dubbale, Tsutsumi, and Bendewald.

and implementing solutions, and enacting and enforcing regulatory policy remains low at national and local levels, impeded by several factors including funding and administration.[23]

Conflicts in Ethiopia

Since late 2020, Ethiopia has been engaged in a highly disruptive civil conflict in the northern Tigray region. The dominant political party of Tigray lost power in the national ruling coalition in 2018 and has been at odds with the current administration since. Tensions escalated in 2020 when the Tigray region held their own local elections in defiance of a delay of federal elections due to the Coronavirus pandemic, and military escalation has ensued between the two forces.[24] Little detail is known about the procession of the conflict throughout 2021, as international press and communications access has been shut down in Tigray.[25] Current reports, coming largely from the hundreds of thousands of refugees fleeing the region, paint a disturbing picture of state-sanctioned violence, famine, and humanitarian crisis.[26]

Ethiopia has long been a stabilizing force in eastern Sub-Saharan Africa, where neighbors like Sudan and Somalia have relied on diplomatic interventions from Ethiopia to alleviate some of their own geopolitical struggles. The Tigrayan conflict has destabilized the image, and possibly the power, that the Ethiopian national government holds, and thus threatens

[23] César and Ekbom, “Ethiopia Environmental and Climate Change Policy Brief.”
[24] Gavin, “The Conflict in Ethiopia’s Tigray Region:”
[25] Gavin.
[26] Gavin.

the wider region.[27] The continued conflict and press blackout have also hampered research efforts, making it difficult to obtain new data and advocate for policy changes that may be distant from the conflict that occupies many of the resources of those in power. The coronavirus pandemic has further compounded these difficulties, while also highlighting many of the same vulnerabilities that Ethiopians will face from climate change. The emergence of COVID-19 itself as a zoonotic spillover event is indicative of the increased potential for disease spread in a warming and urbanizing world.[28]

Research Questions & Outline

This study proposes the following research questions:

1. What spatial variation or spatial relationships exist among climate change vulnerability variables in Ethiopia and in Addis Ababa?
2. What are the policy implications of any spatial variation and association among climate change vulnerability variables?

To answer these questions, this study begins with a literature review of existing climate change vulnerability research in cities and countries in sub-Saharan Africa and Ethiopia and geospatial methodologies for assessing these vulnerabilities. The literature review is followed by a description of the data collected and the preparation of this data for analysis. The data analysis and its findings are then presented, and the study concludes with a

[27] Gavin.
[28] Rodó et al., "Changing Climate and the COVID-19 Pandemic: More than Just Heads or Tails."

discussion of the limitations of the study and the implications that these findings have for Climate change policy and planning in Ethiopia.

Chapter 2: Literature Review

The literature review has two main focuses: 1) climate changed related impacts and vulnerabilities that have already been observed in sub-Saharan Africa, Ethiopia, and urban centers within both; and 2) methods and findings of previous studies on these topics. Through these themes, the literature review explores the vulnerability variables for consideration, difficulties of data availability, and access that frame both the need and the potential for answering the research questions of this study.

Existing research on climate change impacts on the global scale as well as those specific to sub-Saharan Africa has established that the severity of impacts may vary widely depending on the degree of warming the Earth experiences.[29] Climate change impacts are being felt in Ethiopia in many ways, from increasing temperatures to the exacerbation of both the dry and wet seasons, interfering with the largely agricultural economies of countries like Ethiopia.[30] Cities are particularly susceptible to floods, as they tend to be located near riverbanks or other bodies of water and their impervious surfaces and informal settlements make it difficult to deal with rainwater runoff and proper water sanitation.[31] Figure 1 shows a land cover map generated by a comprehensive remote sensing study of Ethiopia's landscape that shows some insight about the underlying geographic factors impacting vulnerability.[32] Cultivated land and savannahs cover most of the country, in line with the agricultural and pastoral nature of Ethiopia's economy. These areas combined

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[29] Serdeczny et al., "Climate Change Impacts in Sub-Saharan Africa."
[30] Serdeczny et al.
[31] Birhanu et al., "Flood Risk and Vulnerability of Addis Ababa City Due to Climate Change and Urbanization."
[32] Khatami et al., "Operational Large-Area Land-Cover Mapping: An Ethiopia Case Study."

with the northern section of bare soil show a large area at risk for drought and crop failure from climate change disruptions.

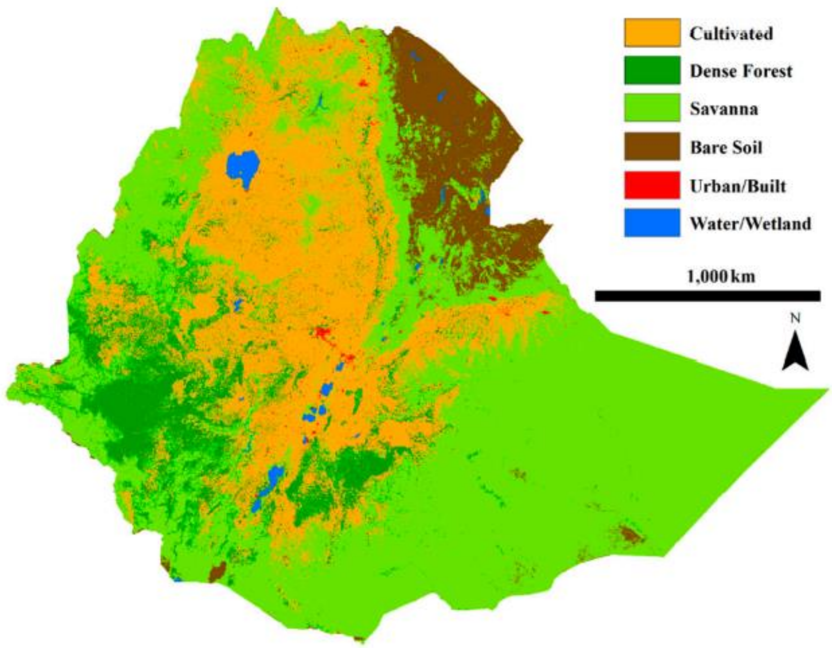

Figure 1: Land cover map of Ethiopia, 2017, 30 m resolution (Data Source: Khatami et al.)

Because cities in Ethiopia like Addis are characterized by such a high prevalence of informal settlements, the vulnerabilities of these settlements shape the vulnerabilities of the city. These settlements face increased threats from climate change and environmental degradation. Due to the inherent nature of informal settlements, they tend to lack central city services for things like waste and water management. This leads to unregulated use of available resources, such as rivers, that can quickly become polluted to levels unsafe for human consumption, in addition to disrupting wildlife and natural systems.[33] Burning

[33] Dubbale, Tsutsumi, and Bendewald, “Urban Environmental Challenges in Developing Cities: The Case of Ethiopian Capital Addis Ababa.”

trash, which can damage human and environmental health, is also a common practice in informal settlements with limited means for waste disposal.[34]

Previous climate change vulnerability models of Addis incorporate other factors beyond environmental indexing. This could include socioeconomic factors such as income that may make certain communities less adept at dealing with climate change, or existing infrastructure, like green spaces, that may provide potential mitigation benefits.[35] Social vulnerabilities can compound with environmental vulnerabilities and are thus important to consider in a vulnerability analysis. The ability to adapt to the harsh conditions of a changing climate is key to understanding the vulnerability of people in both urban and rural areas.

A great deal of local environmental degradation comes from deforestation surrounding the city. Trees have been cut down at a rapid pace for several decades to accommodate both the spatial and resource needs of city residents, particularly those in informal settlements that have sprawled at the city's edges.[36] A large swath of environmental issues has accompanied this deforestation, including soil erosion and the loss of environmental services such as flood protection and temperature regulation.[37] In addition, ambient air quality is impacted by the burning of this deforested wood for fuel and increasing vehicle

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[34] Dubbale, Tsutsumi, and Bendewald.
[35] Feyissa et al., "GIS Based Quantification and Mapping of Climate Change Vulnerability Hotspots in Addis Ababa."
[36] Dubbale, Tsutsumi, and Bendewald, "Urban Environmental Challenges in Developing Cities: The Case of Ethiopian Capital Addis Ababa."
[37] Dubbale, Tsutsumi, and Bendewald.

usage as the city urbanizes.[38] Meanwhile, indoor air quality is threatened by the use kerosene as a primary fuel source for poor residents.[39]

Flooding also poses a major problem for Addis and other cities in Ethiopia. Analyses of the past several decades show that the average annual rainfall has been steadily increasing, and climate change models predict that this trend with continue for the region of east Africa that Ethiopia is located in.[40] However, this rainfall pattern can drastically differ by season, as droughts have also occurred during this time period, severely impacting the agricultural seasons and the highly-agriculturally dependent economy.[41] While the agricultural economy may not typically be viewed as an urban issue, it can have crippling effects on food supply that will impact urban populations. Food insecurity will exacerbate the internal rural to urban migration patterns already observed in Ethiopia, and thus continue the sprawl of informal settlements. Rapid urbanization in Addis has led to an increase in impervious surfaces and a decrease in green spaces, leaving the urban environment unable to handle water influxes. These drainage problems are particularly pertinent in informal settlements that lack water and sewage infrastructure and are often built in some of the most flood prone areas, such as riverbanks.[42] Flood risks are expected to be a vulnerability variable specific to the urban case study of this thesis, as agricultural and rural areas of the nation are already subject to drought and famine.

[38] Dubbale, Tsutsumi, and Bendewald.
[39] Dubbale, Tsutsumi, and Bendewald.
[40] Birhanu et al., "Flood Risk and Vulnerability of Addis Ababa City Due to Climate change and Urbanization."
[41] Conway and Schipper, "Adaptation to Climate change in Africa: Challenges and Opportunities Identified from Ethiopia."
[42] Birhanu et al., "Flood Risk and Vulnerability of Addis Ababa City Due to Climate change and Urbanization."

Addis Ababa sits at a very high elevation (7,700 feet on average), making it more complex to model flood risks. Previous research combines multiple different data layers to determine a flood risk layer, including land cover maps, slope, drainage density, and soil composition.[43] This process in a sense creates an "index within an index" for flood risk to be used for greater environmental risk assessment. However, the availability of these complex data layers seen in other studies is not very transparent, so it is difficult to incorporate their methods and findings into this study. Figure 2 shows a flood risk analysis generated by a previous study on climate change impacts in Addis Ababa.[44] This map serves as a key reference point for confirming flood risk as a component of environmental vulnerability in the analyses of this study.

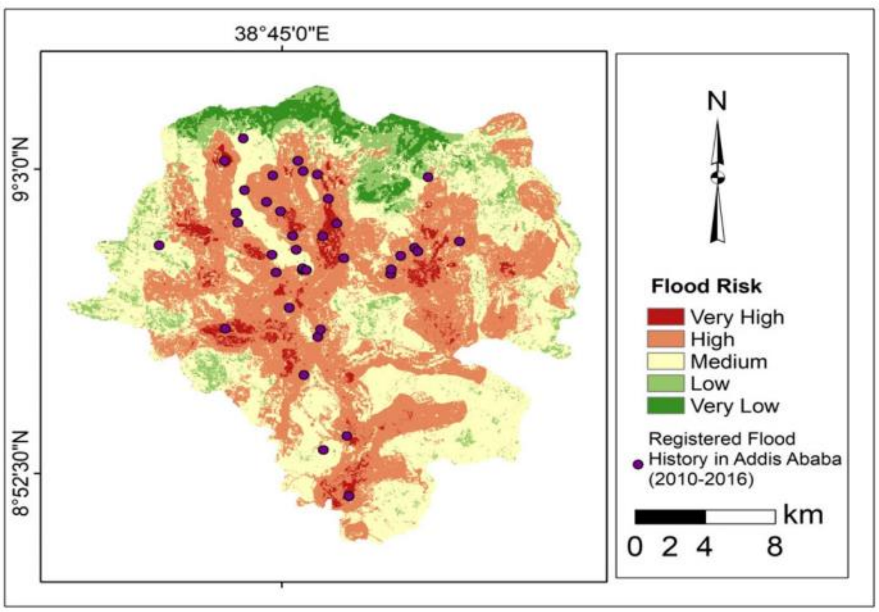


Figure 2: Map of flood risk zones in Addis Ababa, overlaid with historical flood locations (Data Source: Feyissa et al)

[43] Feyissa et al., "GIS Based Quantification and Mapping of Climate change Vulnerability Hotspots in Addis Ababa."
[44] Feyissa et al.

Like the rest of the world, Ethiopia has been subject to anthropogenic warming and will continue to be for the foreseeable future. Rising temperatures can exacerbate drought conditions and worsen the agricultural situation.[45] Heat is also a city-specific problem via the Urban Heat Island Effect. Addis has traditionally had a somewhat stable climate due to its high elevation, but studies show it is not immune to the changing global climate of the past few decades.[46] The same rapid urbanization and deforestation events that have degraded air quality and increased flood risks have also contributed to increased urban temperatures. In addition to the loss of tree cover shade, the high prevalence of impervious surfaces and lack of green spaces that prevents water management means naturally cooling transpiration processes cannot be performed. Imperious surfaces and buildings with low albedo reflectiveness also absorb heat that raises a city's air temperatures.[47] The frequency and intensity of heat waves continues to increase and pose a threat to the health of city residents and the environment.[48]

Social vulnerability is an important factor to consider in assessing climate change risk and preparedness, on the national and the city level. Social risk factors, such as lower socioeconomic status and access to critical services and infrastructure make it much harder for certain groups or regions to deal with environmental challenges and instability. It is therefore important to include social indicators and variables in climate change

[45] Conway and Schipper, "Adaptation to Climate change in Africa: Challenges and Opportunities Identified from Ethiopia."
[46] Conway and Schipper.
[47] Taha, "Urban Climates and Heat Islands: Albedo, Evapotranspiration, and Anthropogenic Heat."
[48] Conway and Schipper, "Adaptation to Climate Change in Africa: Challenges and Opportunities Identified from Ethiopia."

vulnerability analyses. Previous studies in Addis have considered factors that corresponded to things like urban overcrowding, wealth, and healthcare access.[49]

Health and climate change impacts and vulnerability are often closely intertwined, especially in developing regions where many people may already suffer from poor social and environmental determinants of health and insufficient care.[50] Therefore, in addition to social vulnerability factors, health and disease related indicators can be helpful in evaluating climate change vulnerability. The World Health Organization (WHO) highlights several climate-sensitive health risks and outcomes and their relationship to various vulnerabilities and exposures in figure 3. Many of the risks and variables mentioned in the chart fall within aforementioned social and environmental vulnerability, such as heat-related illness. Heat-related illness is connected to rising temperatures and food security, which is in turn connected to drought and famine. It is beyond the scope of this study to incorporate every risk and impact reported by the WHO but incorporating an array of factors from across these broad categories based on data availability and feasibility is a key strategy for creating a holistic analysis of vulnerability.

[49] Feyissa et al., "GIS Based Quantification and Mapping of Climate Change Vulnerability Hotspots in Addis Ababa."
[50] World Health Organization, "Climate Change and Health."

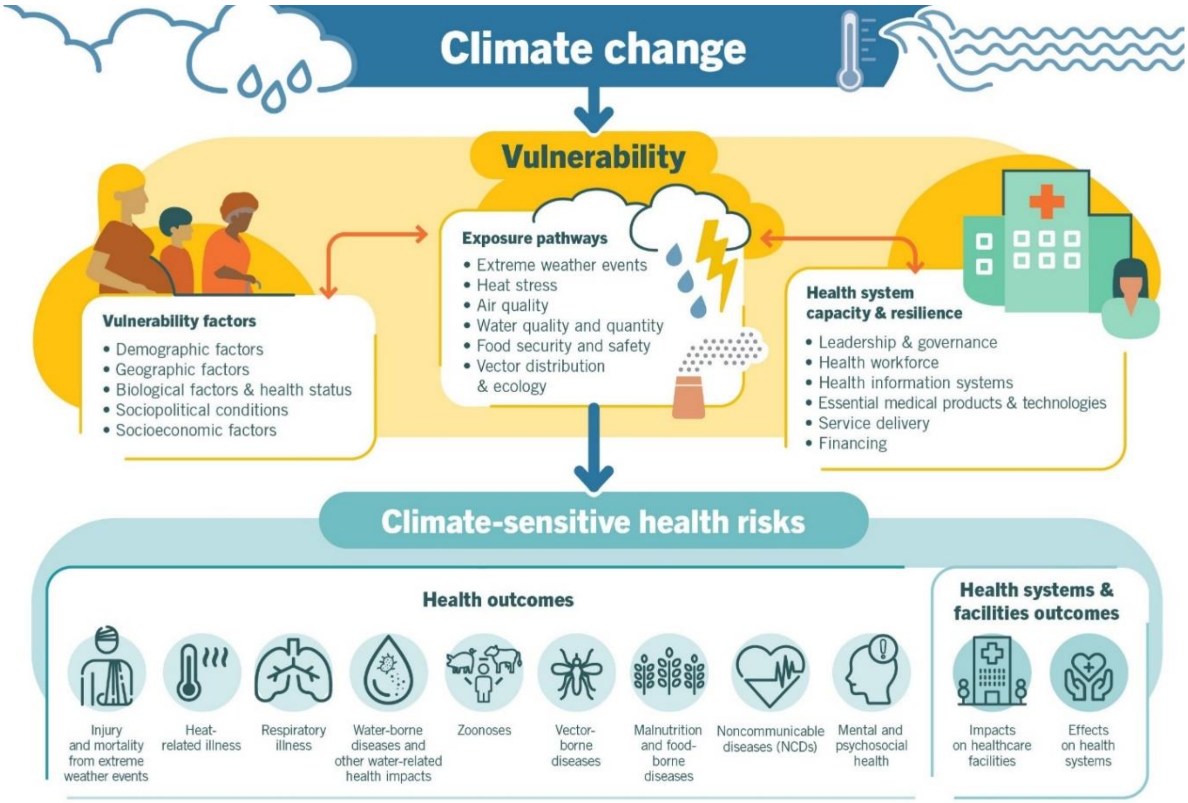


Figure 3: World Health Organization climate change health impacts graphic (Data Source: Word Health Organization)

Gaps in the Literature

The vast majority of the articles reviewed here do not share their data sources, either publicly or by request, making many of their methodologies and results impossible to confirm, replicate, or extrapolate from. Data availability and access is an issue this thesis hopes to address. By utilizing data sources that are accessible and sharable, the methods that this study uses can be recreated by others to confirm results or explore new variables and new geographic areas, such as other countries and cities in sub-Saharan Africa and the Global South.

Environmental vulnerabilities in Ethiopia have largely been studied as isolated phenomena. In this literature review, only one study incorporated social vulnerability variables, and that study only focused on Addis Ababa. This thesis seeks to offer a greater integration of social and environmental vulnerabilities to climate change in its analysis.

Many studies of climate change risks and potential mitigation strategies in sub-Saharan African nations often forgo highlighting the unique landscapes and vulnerabilities that are present in cities that may differ or even contradict what is observed and concluded about countries or regions more broadly. This thesis will offer a holistic view of Ethiopia's climate change vulnerabilities as a country in addition to an urban case study of Addis Ababa, the capital city. This will offer a unique opportunity for comparison and differentiation within one analysis. Policy recommendations for cities like Addis are contingent upon both their national context and their urban context, so offering insights to both will inform policy that is both most feasible and most necessary.

Chapter 3: Data & Analysis

The methodology and analyses of this study employs the following steps: research design; data search and collection; data cleaning; descriptive statistics; geospatial analysis; and regression analysis. The questions being considered here are inherently of a geospatial nature, so determining geospatial methods and collecting geospatial data were key to beginning to answer them. As touched on in the literature review, high resolution spatial data can be hard to come by in countries of the Global South like Ethiopia, so research design and data collection were conducted in an iterative process: as data sources were explored, the methods that could be utilized to analyze them in ways to answer the research questions were dually considered.

The data source that was ultimately deemed the most usable, based on geographic spread, granularity, time series, and accessibility, was a collection of GPS data points and related survey data. Thus, the subsequent steps in the methodology were tailored to what could be accomplished and would be best practice for working with point data. For descriptive statistics, the variables for each point were broken down by their attributed dates to show patterns in variables over time. For the initial geospatial analysis, the most recent time series available in the point data were utilized and variables were aggregated to show series averages by point and to create proxy variables for social factors contained in the survey data by point. Then, a principal components analysis was performed to determine relationships between variables, and a hot spot analysis and geographically weighted regression were performed to further examine variable relationships and offer insights to zones of highest vulnerability.

Data Sources

The majority of the data for this thesis come from the United States Agency for International Development (USAID) demographic and health surveys (DHS). The most recent DHS survey and GPS data available is from 2019. However, this data was challenging to work with because of its formatting and the long waiting periods for requesting and receiving the data. IPUMS, the Integrated Public Use Microdata Series generated by the Institute for Social Research and Data Innovation at the University of Minnesota, offers some more user-friendly formats for accessing this data, where users can view survey variables, read descriptions about each variable, and selected a set of their preferences for immediate download. The limiting factor of the IPUMS option is that at the time of this analysis, their most recent survey offering is from 2016. However, the time and computation saving benefits made the use of the 2016 data justifiable. GPS point data is only available through DHS directly, so IPUMS survey data was joined to the 2016 DHS points.

IPUMs additionally offers larger time series data on its contextual variables, or those variables collected with DHS GPS points but not directly tied to survey responses. According to the IPUMS-DHS website, “Contextual variables describe features of the physical and social environment of a small geographic area (5-10 kilometer radius) surrounding the location where a DHS respondent was interviewed.”[51] In this study, malaria prevalence, maximum temperature, normalized difference vegetation index (NDVI), and precipitation are contextual variables. Contextual variable tables were downloaded for all available survey years on IPUMS: 2000, 2005, 2010, and 2016. For each

[51] “IPUMS-DHS.”

survey year, data is available for 11 months after the survey collection date and 60 months prior. There are some overlaps between the dates for each survey, but the values may vary because the GPS points change each survey year, meaning that DHS IDs for household respondents are not compatible across survey years.

NDVI was chosen to assess drought and deforestation impacts, and malaria prevalence was chosen to assess disease spread and treatment access. The malaria variable had the potential to be included in either the environmental or social group, as it has strong ties to both, but was ultimately put in the environmental group because of its status as a contextual variable in the DHS data set. Thus, all the environmental variables are contextual, and all of the social variables are survey derived. Malaria prevalence as an environmental risk variable is related to the nature of disease spread. Hotter, wetter climates foster an ideal environment for mosquito-vector diseases like Malaria, and climate change has the potential to expand the mosquito habitation zone and, consequently, disease spread.[52]

Some supplemental data was obtained for additional sources to support this study. This includes a digital terrain elevation model in the city of Addis that was generated by and obtained from the Ethiopian national government through the Fletcher/UEP Climate Migration Research Team in partnership with the Woodwell Climate Research Center. The digital terrain model, or DTM, is at a 10-meter resolution level, which is relatively high resolution and an appropriate scale for use in a city. Other supplemental data includes digital maps of informal settlements in Addis Ababa. These maps were created by researchers at Tufts University using Google Earth Satellite imagery to identify and trace

[52] Fernando, "Climate Change and Malaria - A Complex Relationship."

approximate areas suspected to be informal settlements based on imagery features derived from previous literature on the subject.

Data Preparation

Initial data cleaning was conducted using Python in Jupyter Notebook. Scripts used for data preparation can be found in the GitHub repository included in the appendix of this paper.

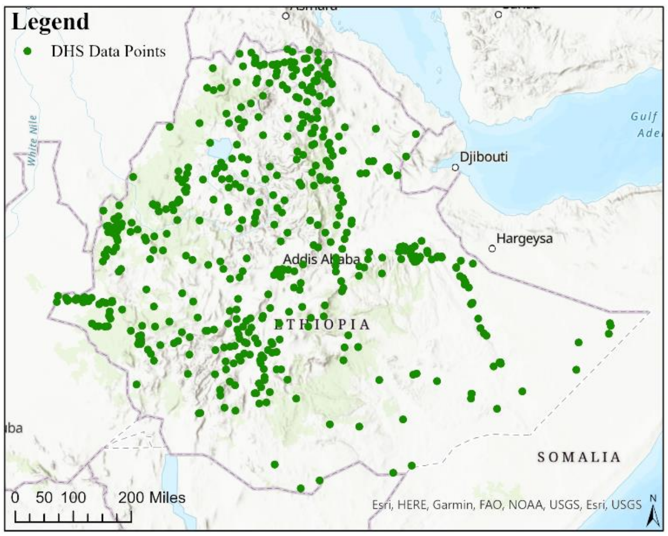


Figure 4: 2016 DHS data points used for Principal Components Analysis (Data Source: USAID)

The DHS data is organized by responses from household members where surveys were collected, while the GPS points correspond to geographic points of household clusters where surveys were administered. For environmental variables that are not contingent on individual responses, like temperature, one data point exists for each cluster. In order to use household members responses in a spatial analysis with environmental variables, household member responses were aggregated up to the cluster level. Pivot tables in Microsoft Excel were used for this aggregation, after which a comma separated values file

(CSV) for the geographic points was exported to ArcGIS Pro and joined to the GPS point data shapefile from the DHS data portal. The final output of the geographic points with attached aggregated survey and environmental data included 601 points. These points are show in figure 4.

Contextual variables were downloaded as CSV and joined to a supplemental CSV with precise survey start dates in ArcGIS. The resulting CSVs were processed in Microsoft Excel. These files contained columns for each of the 72 months for each variable (11 months after the collection month, the collection month, and 60 months prior to the collection month). Since contextual variables are all based on the survey collection start date, the dates for each survey year are the same. For example, survey contextual variables from the year 2000 all share the same start date of February 2000, and thus the first month of data collection for the 2000 dataset is February 1995, and the last month of data collection is January 2001. The full extent of the contextual variables covers from February 1995 to December 2016.

Descriptive Statistics

Overall, temperature has been increasing and precipitation has been decreasing in Ethiopia. The same trends hold true for Addis Ababa, the capital city. NDVI in both cases does not show a discernable pattern, likely due to the fragmentation of the data. The national temperature averages were generally higher than those of Addis Ababa, and the national precipitation averages lower. Given the geographic context of Addis, located at a high elevation in a more sylvan region of the country, these baseline differences in meteorological observations make sense. Table 1 shows the average values for Ethiopia and Addis Ababa for these three variables throughout the time scale of the dataset.

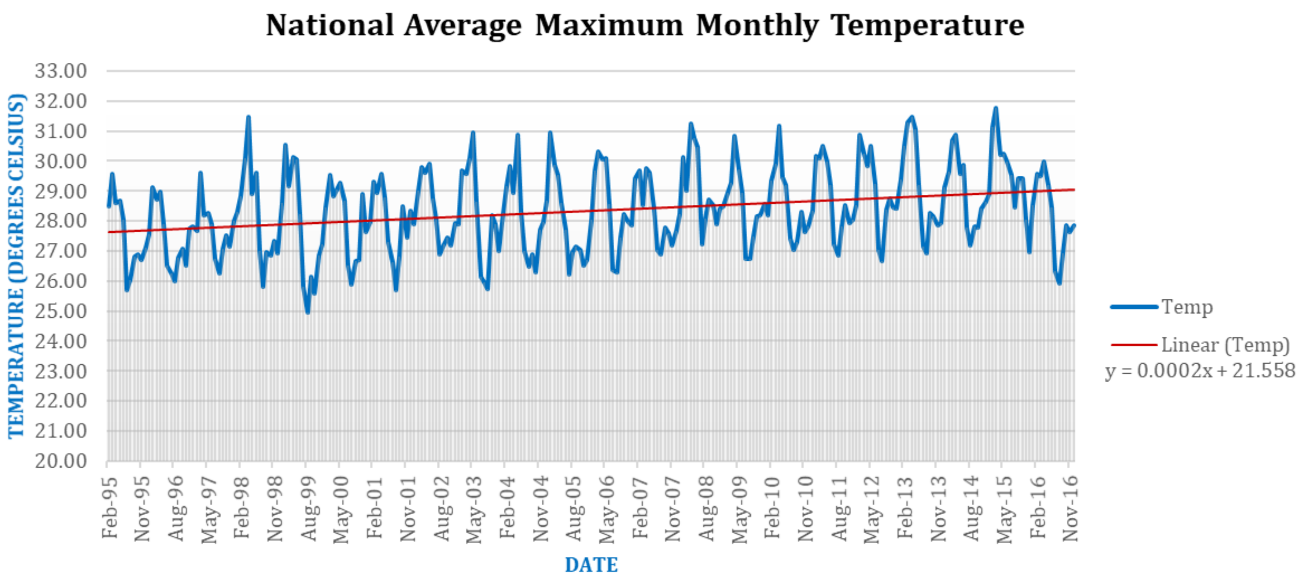
The DHS NDVI data is broken up due to large gaps in the data reporting; unlike other contextual variables, historic data does not appear to be available, so NDVI data is only available for the month of the beginning of survey collection and the 11 subsequent months.

	Ethiopia	**Addis Ababa**
Temperature (degrees Celsius)	28.33	23.76
Precipitation (inches)	4.25	9.64
NDVI	0.73	0.81

Table 1: Environmental and meteorological variable averages, national and city-level based on DHS data, February 1995- December 2016 (Data Source: USAID)

Figure 5 shows trends in temperature and precipitation as national averages over the time periods available in the DHS surveys. Averages were taken by aggregating all the points in each survey for the month and variable of collection, with cross-survey tabulations for repeated time periods. Maximum temperatures appear to be rising over time, while precipitation appears to be decreasing.

Figure 6 shows the national trend in NDVI, or the normalized difference vegetation index. NDVI measures chlorophyll presence through infrared radiation to assess vegetation presence and health. The index is recorded on a scale from -1 to 1, with higher scores indicate denser and healthier vegetation, and lower scores indicating deserts or drought.[53] Averages were again taken by aggregating all the points in each survey for the month and variable of collection, with cross-survey tabulations for repeated time periods.



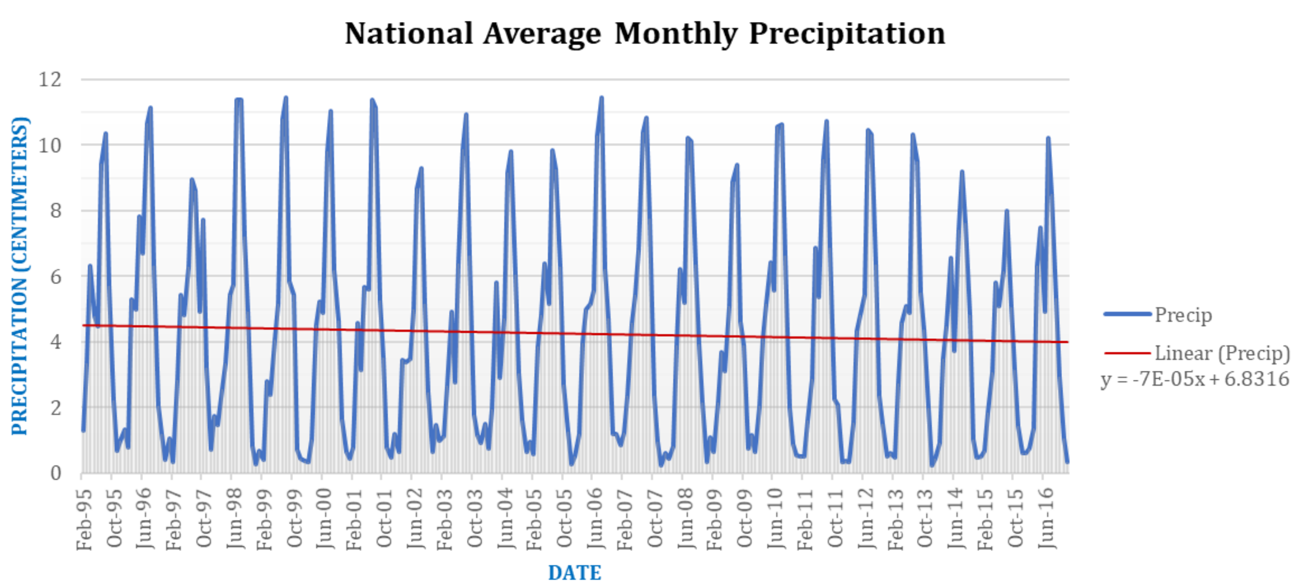


Figure 5: National average graphs for monthly maximum temperature (degrees Celsius) and average monthly total precipitation (centimeters), February 1995- December 2016 (Data Source: USAID)

[53] GISGeography, "What Is NDVI (Normalized Difference Vegetation Index)?"

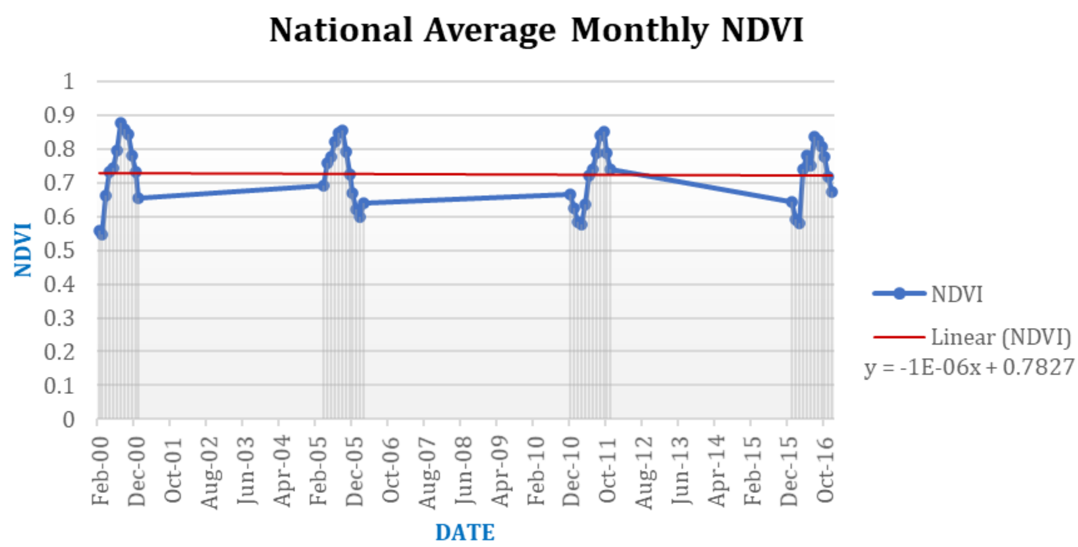
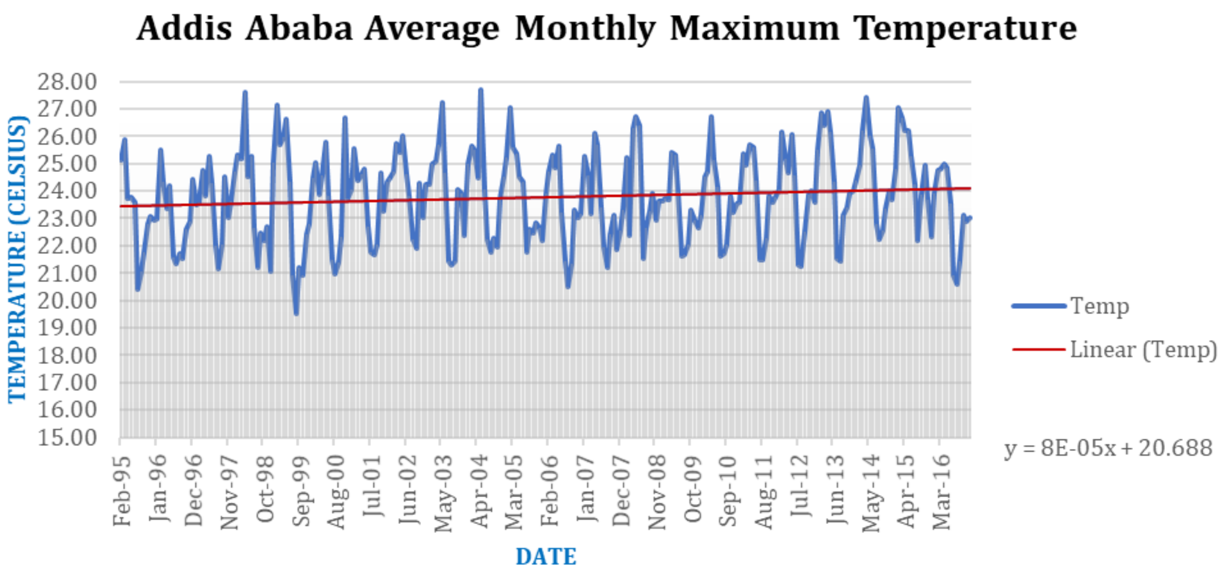


Figure 6: National average monthly NDVI scores, reported for February 2000 – January 2001, April 2005 – March 2006, December 2010 – November 2011, and January 2016 – December 2016 (Data Source: USAID)

Figure 7 shows the trends in temperature and precipitation averages for Addis Ababa, as a subset of the national data set. The trend lines align with those of the national data, with temperature increasing and precipitation decreasing. However, the slopes for both are much less pronounced for Addis. The average temperatures in Addis are lower than the national average, likely due to the temperate mountainous climate of the city. Precipitation is much higher in Addis than the national average, also likely due to the climate. Average precipitation in Addis is decreasing at a faster rate in Addis than the national average, though very slightly so that it is likely an insignificant difference. Average maximum temperature is increasing at slower rate than the national average as well, with a slight but more pronounced difference in slopes.

Figure 8 shows the NDVI trend for Addis. There is a very slight, but likely insignificant, upward trend in NDVI. The NDVI values are generally similar and slightly higher than the national averages. NDVI is difficult to measure in cities, as it is designed for vegetation and not manmade surfaces.



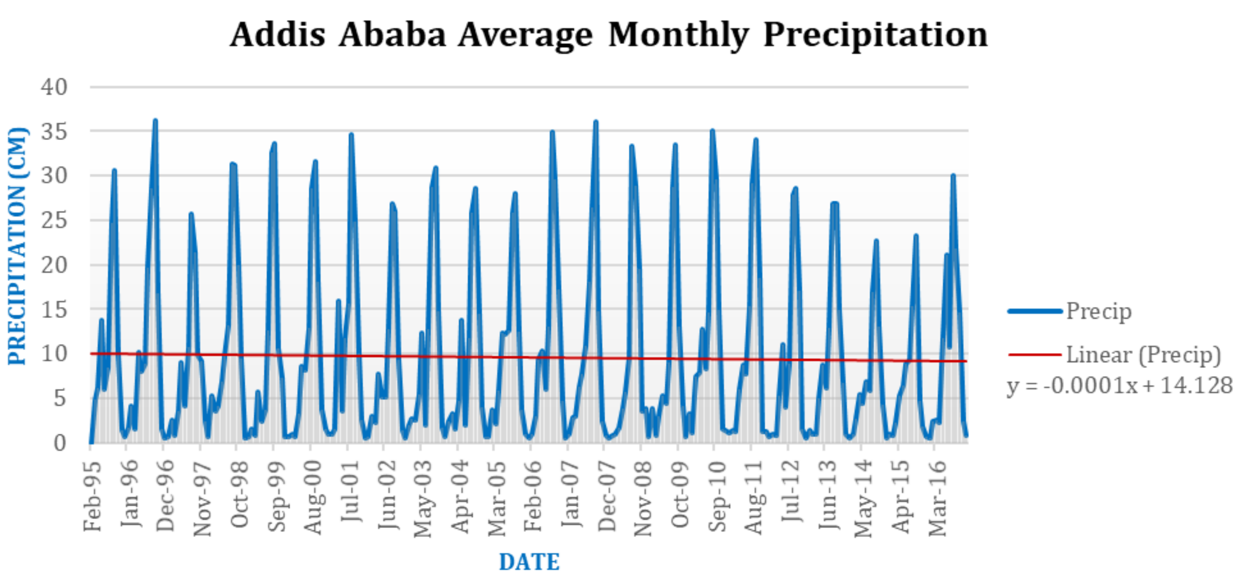


Figure 7: Addis average graphs for monthly maximum temperature (degrees Celsius) and average monthly total precipitation (centimeters), February 1995- December 2016 (Data Source: USAID)

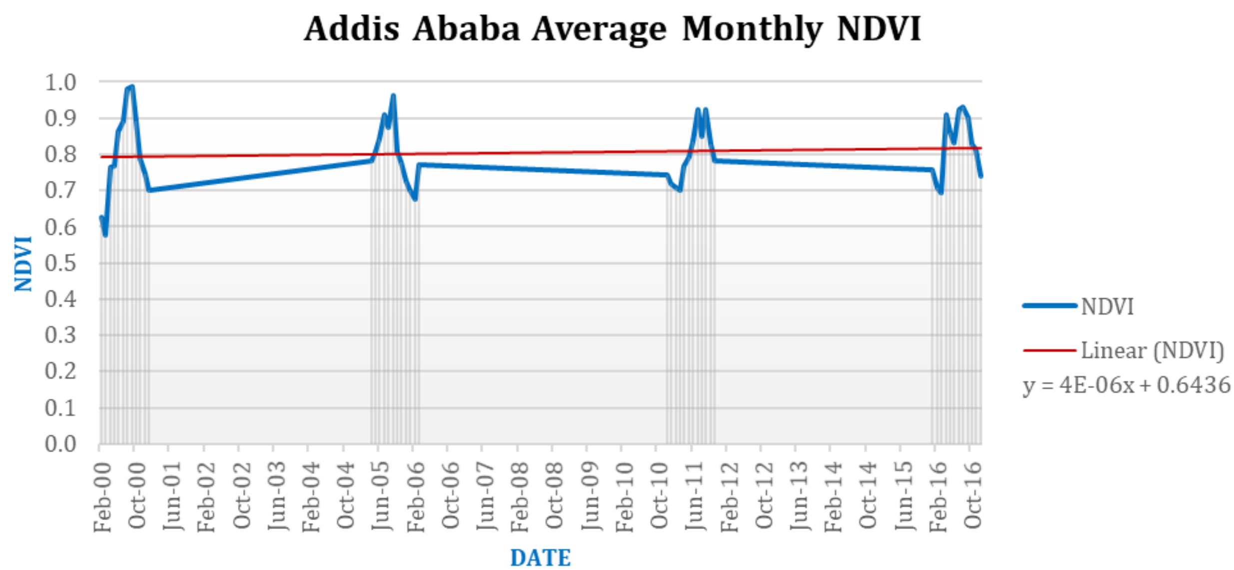


Figure 8: Addis average monthly NDVI scores, reported for February 2000 – January 2001, April 2005 – March 2006, December 2010 – November 2011, and January 2016 – December 2016 (Data Source: USAID)

Data Analysis

A principal components analysis (PCA) was conducted on the DHS point data to determine trends amongst different variable categories for environmental and social vulnerability factors. The PCAs were initially done in GeoDa and exported to ArcGIS Pro for display and further analyses. Table 2 shows the definitions of the variables derived from the DHS point data for the PCAs. The environmental PCA was made up of four variables: MALARIA, NDVI, PRECIP, MAXTEMP; and the social PCA was made up of three variables: WEALTHQHH, COMMS, EDYEARS. The loading tables for the PCAs can be found in the appendix.

Variable	**Definition**
COMMS	Compilation of variables to serve as a proxy for communications availability; sum of landline phone, mobile phone, personal computer, radio, and television ownership (1 for owning an item and 0 for not owning one) by individual, averaged for geographic points
EDYEARS	Number of years of education for individual, averaged by geographic points
MALARIA	2015 mean Malaria prevalence (fraction of cases per person)
MAXTEMP	Maximum monthly temperatures averaged for the 72-month data set, originally reported in degrees Kelvin, and converted to degrees Celsius in data preparation
NDVI	Index value describing greenness as a proxy for vegetation health and coverage (higher values are better, on a scale for 0 to 1), averaged over the 72 months available
PRECIP	Totals for monthly rainfall averaged for the 72-month data set in millimeters
WEALTHQHH	Wealth Index Score in quantiles

Table 2: Definitions of PCA input variables

The social variables were constructed using DHS survey data to serve as proxies for different aspects of social vulnerability. Wealth index level relates most directly to vulnerability, as lack of financial resources is tied to both individual and community ability to respond to economic volatility and climate change preparedness efforts.[54] The communications variable is meant to serve as a representation of resident's ability to receive and share information that impacts their adaptation ability, particularly in climate change-driven extreme weather events. The education variable is a more general variable

[54] Raworth, "Adapting to Climate Change: What's Needed in Poor Countries, and Who Should Pay."

of social vulnerability, as higher educational attainment has generally been associated with higher economic status as well as knowledge and life skills in areas such as nutrition, health, and agricultural techniques.[55] Therefore, higher educational attainment may make people more aware of climate change and more motivated and able to respond to it or pressure their governments and communities to respond.

The environmental PCA showed a strong inverse relationship between NDVI and PRECIP and MALARIA and MAXTEMP, with an eigenvalue of 2.02179. Eigenvalues above 1 are generally considered significant, so this is a very strong score for these relationships. Figure 5 shows the geographic spread and pattern of the environmental PCA results, where darker colors represent higher scores, and lighter colors represent lower scores. Higher PCA scores indicate lower environmental vulnerability, as they represent higher vegetation and precipitation (NDVI and PRECIP) and lower Malaria prevalence and mean maximum temperatures (MALARIA and MAXTEMP).

Clusters of environmental vulnerability can thus be seen in the southeast and parts of the central/northeast. This pattern aligns quite well with the geographic landscape of the country, as can be seen in Figure 8. These regions are more arid and desert-like, with forested areas and plains concentrated on the west side of the country. The southeastern region is also more sparsely populated, rural, and difficult to access, which may be contributing to its higher Malaria prevalence more so than geological and environmental causes.

[55] Glewwe and Kremer, "Chapter 16 Schools, Teachers, and Education Outcomes in Developing Countries."

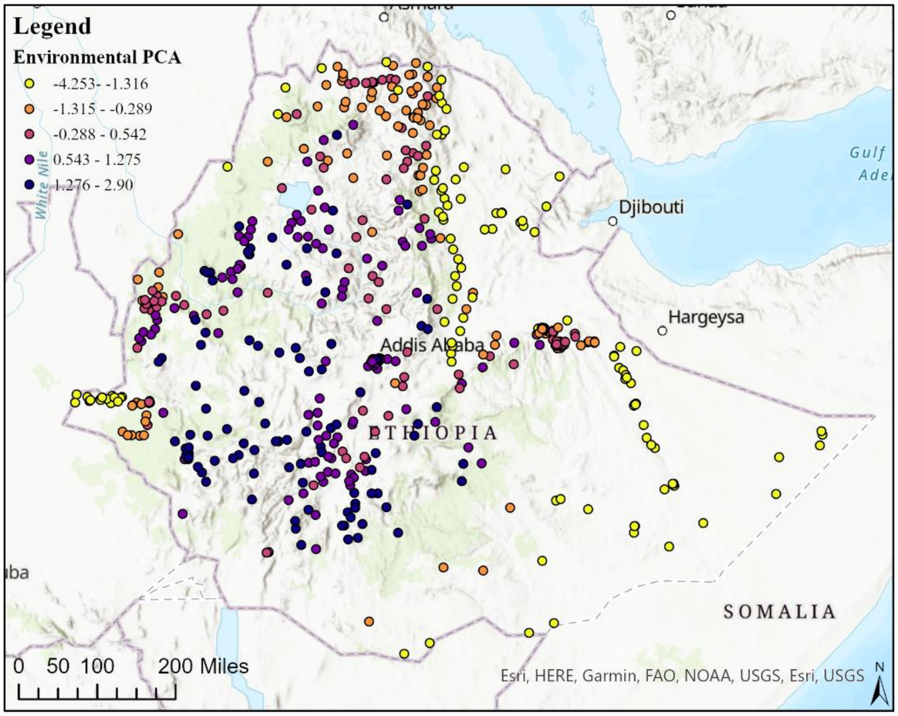


Figure 7: Principal Components Analysis results for environmental variables, with darker colors indicating lower environmental vulnerability and lighter colors indicating greater environmental vulnerability (Data Source: USAID)

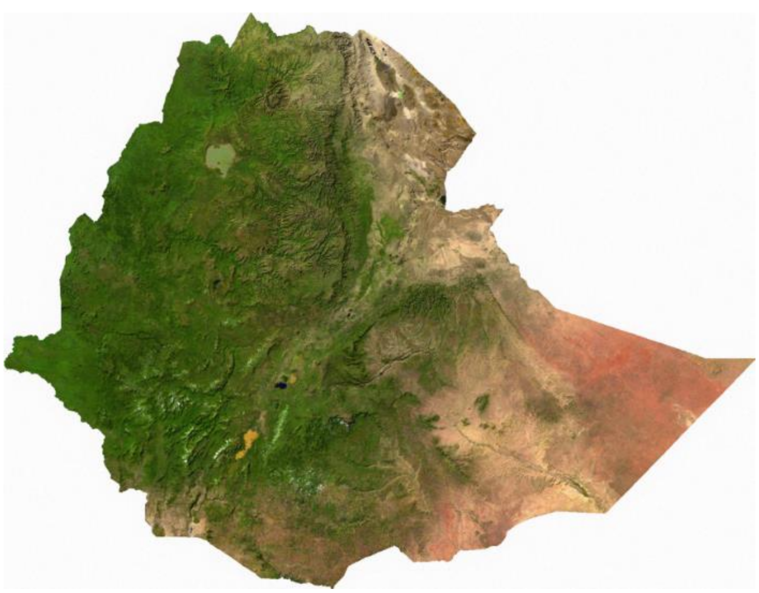


Figure 8: Satellite imagery of Ethiopia (Data Source: Wikimedia Commons)

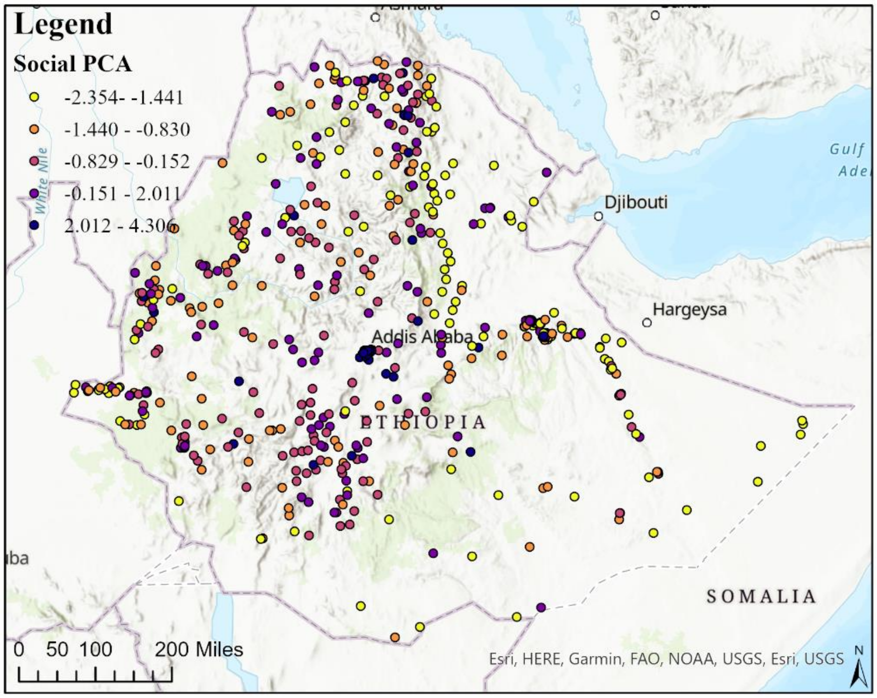


Figure 9: Principal Components Analysis results for social variables, with darker colors indicating lower social vulnerability (Data Source: USAID)

While greater precipitation and vegetation are largely considered as positives, precipitation can pose its own hazards. Too much rainfall, particularly if it occurs in short period of time in an urban area, can lead to flooding. It is possible that high precipitation and low Malaria and heat scores may be masking the impact of low vegetation scores in urban areas, that also contributes to flood risk. This is important to keep in mind when observing the environmental PCA results, as many urban areas appear less vulnerable, but may actually be susceptible to this different vulnerability. Case study analysis on Addis Ababa is therefore useful to gauge how urban areas face different types of vulnerability than the nation as whole.

Figure 9 shows the results for the social PCA. All the variables in this PCA were positively correlated. Higher scores in the social PCA indicate lower social vulnerability, since they are comprised of higher education levels (EDYEARS), higher communication device access, (COMMS), and higher wealth (WEALTHQHH). Darker colors in figure 7 indicate higher scores and thus lower social vulnerability; lighter colors indicate lower scores and thus higher social vulnerability. The spatial spread of the social PCA does not immediately show a discernable pattern or relation to geography.

To search for spatial patterns in social vulnerability, a Hot Spot analysis was conducted in ArcGIS Pro, the results of which can be seen in figure 10. Hot spots represent areas where high PCA scores are spatially correlated and are therefore hot spots of low social vulnerability. Cold spots represent spatially correlated low PCA scores, or high social vulnerability. From this analysis, some of the lowest concentrations of social vulnerability begin to appear around the capital city, Addis Ababa. This may indicate the relatively higher standards of living that are sometimes found in more urban areas. Much of the northern region of the country is covered by cold spots, as is a portion of the southeast. Although conflict in the northern Tigray region began after data collection for the surveys used in this thesis ended, social vulnerability is interestingly higher in the north, suggesting this vulnerability may influence political instability. Unfortunately, a substantial portion of the points remain outside of either cold or hot spots, particularly in the west.

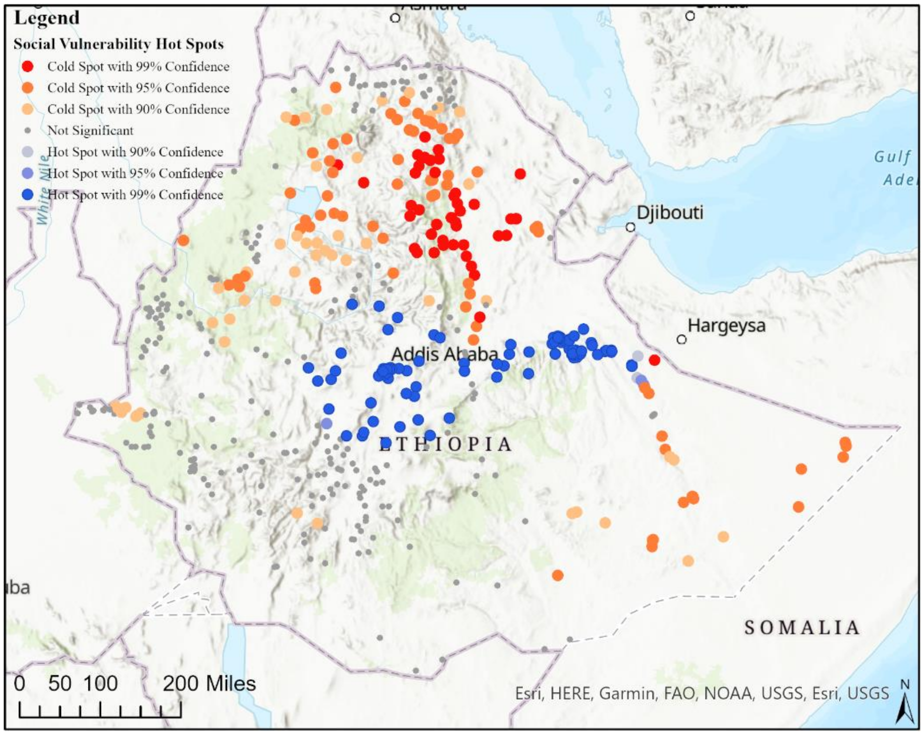


Figure 10: Hot Spot analysis for the social PCA. Cold spots are show in red hues and represent lower social vulnerability. Hot spots are show in blue hues and represent higher social vulnerability (Data Source: USAID)

The PCA analyses do not tell the whole story for cities, however, because urban environmental vulnerabilities can differ from those seen in the country as a whole, which is largely pastoral and agricultural. One variable of concern, precipitation, presents perhaps the most divergent risk between urban and rural settings in Ethiopia. Low precipitation is a major problem for large swaths of the country, as it indicates drought and damage to the agricultural communities and economy. The pastoral areas in the south of the country are some of the most vulnerable to low precipitation and are also low-lying in terms of elevation, missing out on the benefits of cooler and moister climates seen in higher in the higher, forested and mountainous areas of Ethiopia. Addis Ababa is located at a very high elevation, amongst the mountainous region in the center of Ethiopia, indicating potential for greater rainfall. As a city, this poses risks, since the urban environment is much less equipped to deal with high precipitation, as discussed in the literature review. High precipitation in the city may be artificially deflating urban vulnerability when looking at the nation-wide PCA. Figure 12 shows a map of the 2016 DHS points average monthly precipitation in Addis. The central areas of the city, which contain the greatest density impervious surfaces that contribute to flood risk, have a concentration of relatively high precipitation averages.

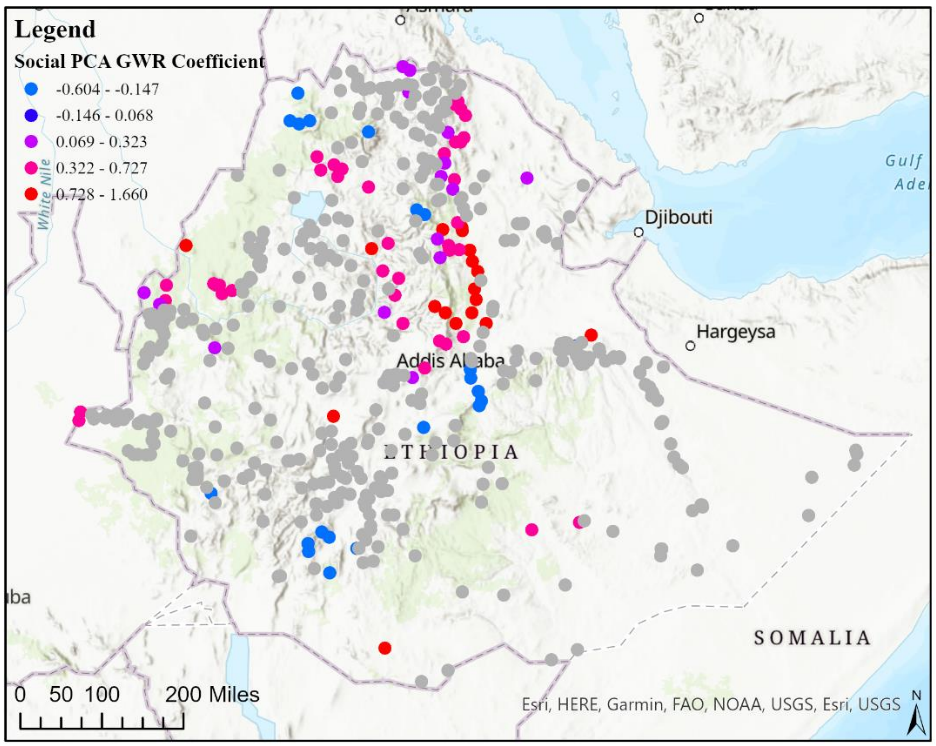


Figure 11: Geographically weighted regression map for environmental and social PCAs in Ethiopia displaying coefficients for the independent variable, the social PCA. Red points show high social and environmental vulnerability, purple points show less significantly correlated social and environmental vulnerability, and blue points show high social vulnerability and low environmental vulnerability. Grey points indicate no significant relationship. (Data Source: USAID).

Interestingly, some of the cold spots begin to correlate with the areas of higher environmental vulnerability (figure 7), suggesting that these areas face quite high overall vulnerability. To assess the relationship between the two PCA analyses, a geographically weighted regression (GWR) was conducted (figure 11). High positive coefficients (red points) indicate high social and high environmental vulnerability while low negative coefficients (blue points) indicate high social vulnerability and low environmental vulnerability. The points were filtered for significance of the regression relationship, so grey points represent points without a significant relationship between the PCAs. Much of the country is covered by insignificant points, likely due in part to the sporadic spread of the social PCA. The areas of insignificance in the social PCA hot spot analysis and the geographically weighted regression analysis have plenty of overlap. However, there are still some areas where relationships are apparent. The cluster of high positive coefficient points the creates a path between Addis and the northern border highlights an area of high association between vulnerabilities. This area borders on some of the politically unstable and more arid regions of the country. The positive coefficients skew higher than the negative ones, suggesting a more significant relationship.

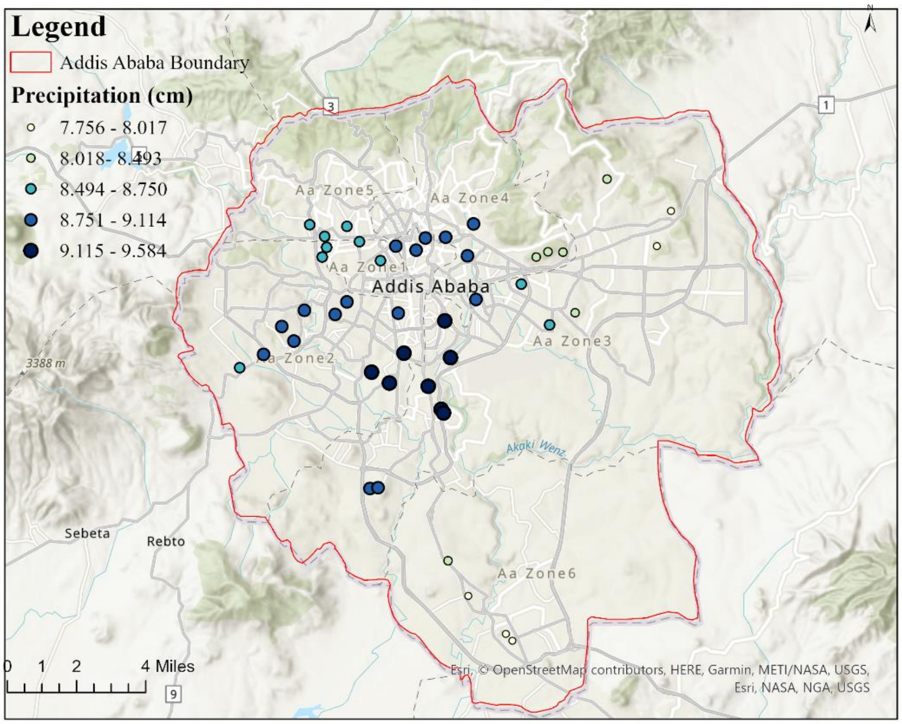


Figure 12: Average monthly precipitation in Addis Ababa measured in centimeters (Data Source: USAID)

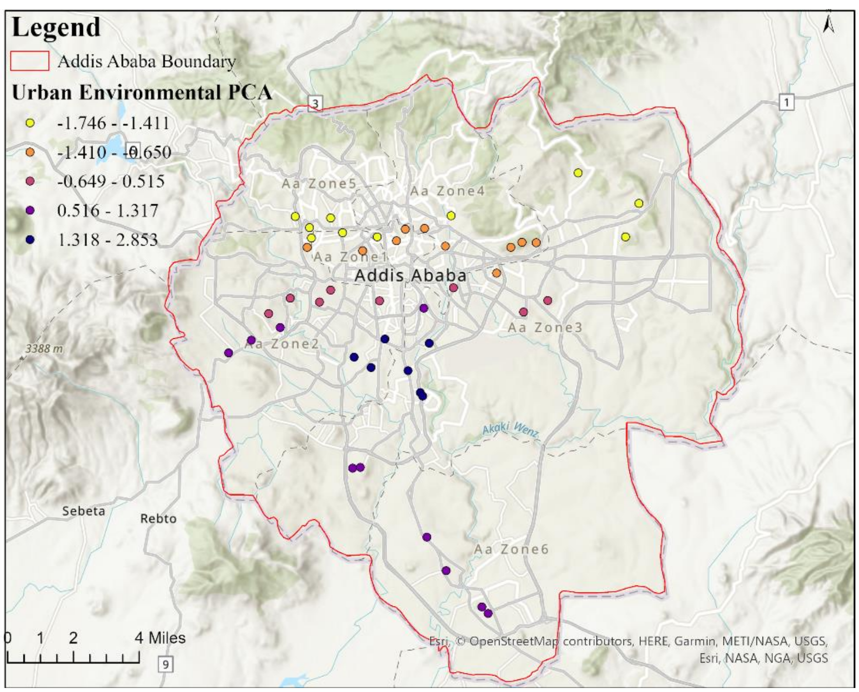


Figure 13: Urban Environmental PCA for Addis Ababa case study, with darker colors indicating greater vulnerability (Data Source: USAID)

An Addis-specific PCA analysis was performed with three environmental variables: NDVI, PRECIP, and MAXTEMP, the results of which can be seen in figure 13. This PCA result was quite significant, with a 2.04705 eigenvalue. NDVI loaded negative and PRECIP and MAXTEMP loaded positive, with -0.665181, 0.382998, and 0.640974 respectively. This trend indicates higher temperatures and greater precipitation are associated with lower NDVI, and thus higher PCA scores indicate greater vulnerability. As expected, precipitation has moved from a positive to a negative indicator from the national to urban sample PCA analyses. This is seen most prominently in the southern center cluster of the city, which also lays downhill/downstream from the northern mountainous boundary of the city, as seen in figure 12's elevation map, indicating an even greater capacity for flood risk. The flood risk map included in the review of literature (figure 2) offers some support to this finding, with the northern mountains having the lowest risk, and the central and southern sections of the city generally experiencing high and medium risk.[56]

The variables used in the nationwide social PCA all tended to have higher values in Addis, as seen in figure 15. This is likely because the urban setting is generally where communications, education, and wealth are concentrated in developing countries like Ethiopia. However, some stratification can be seen when re-classifying the points within Addis (figure 16). While there is not a very clear spatial pattern here, the most outlying areas of the city show some of the lowest scores and thus highest vulnerability.

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[56] Feyissa et al., "GIS Based Quantification and Mapping of Climate Change Vulnerability Hotspots in Addis Ababa."

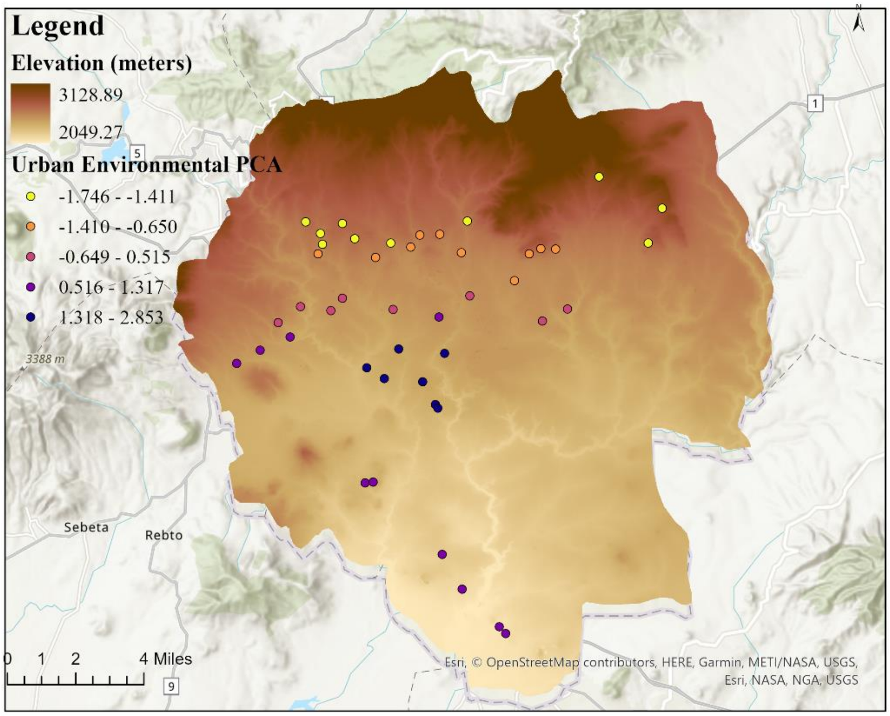

Figure 14: Digital elevation model (DEM) raster for Addis Ababa, overlain with Urban Environmental PCA points (Data Sources: Fletcher/UEP Climate Migration Research Team, USAID)

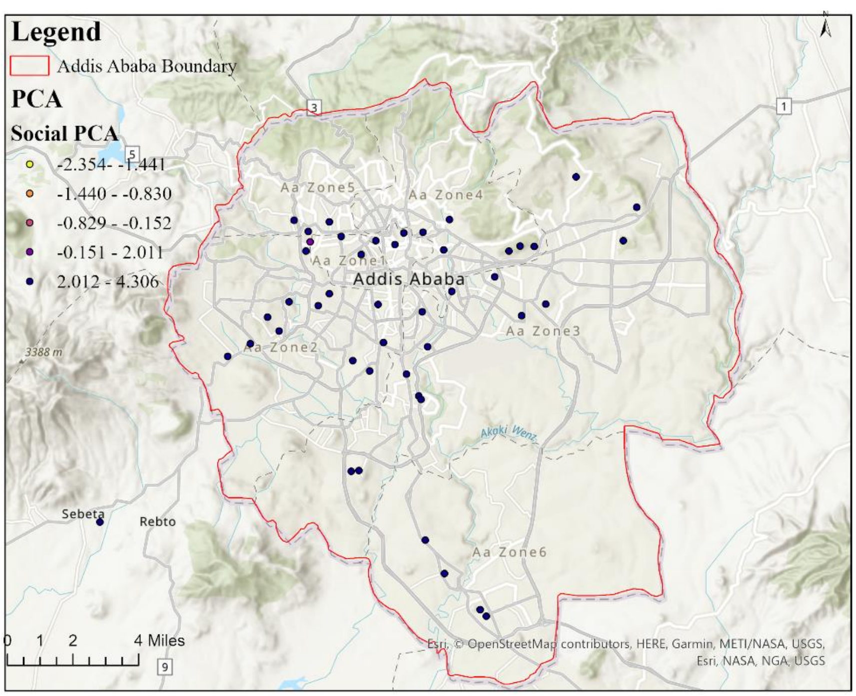

Figure 15: Social PCA (nation-wide scale) in Addis (Data Source: USAID)

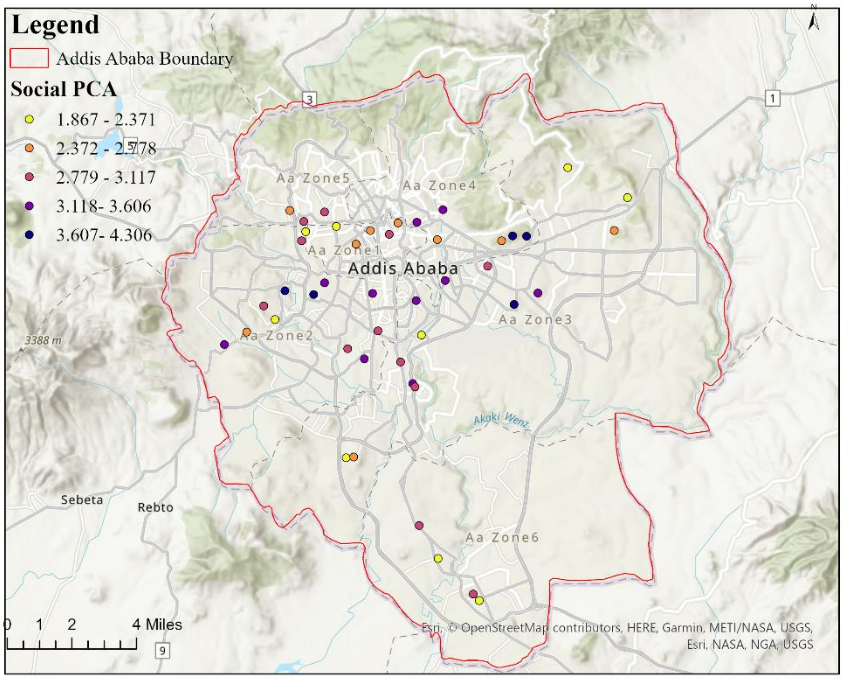

Figure 16: Reclassified nation-wide PCA for bounds of Addis, with darker colors indicating lower social vulnerability (Data Source: USAID)

Figure 17 shows a map of informal settlements in Addis. This is overlain with the social PCA points in figure 18 and environmental PCA points in figure 19. Again, a clear spatial relationship is not apparent, but it is worth noting that where potential overlaps occur in the social PCA, they often show high vulnerability. These potential overlaps are highlighted by red circles in figures 18. DHS GPS points have an approximate range for representing actual locations of collected survey data, in order to ensure privacy of participants. The DHS website indicates a margin of error range of 0 to 2 km. However, they note that the average for all data is 15 meters, making the precision of the points in correlation to proximity to or location within the informal settlements a reasonable assumption for observational analysis.[57]

[57] USAID Demographic and Health Surveys, "The DHS Program - GPS Data Collection."

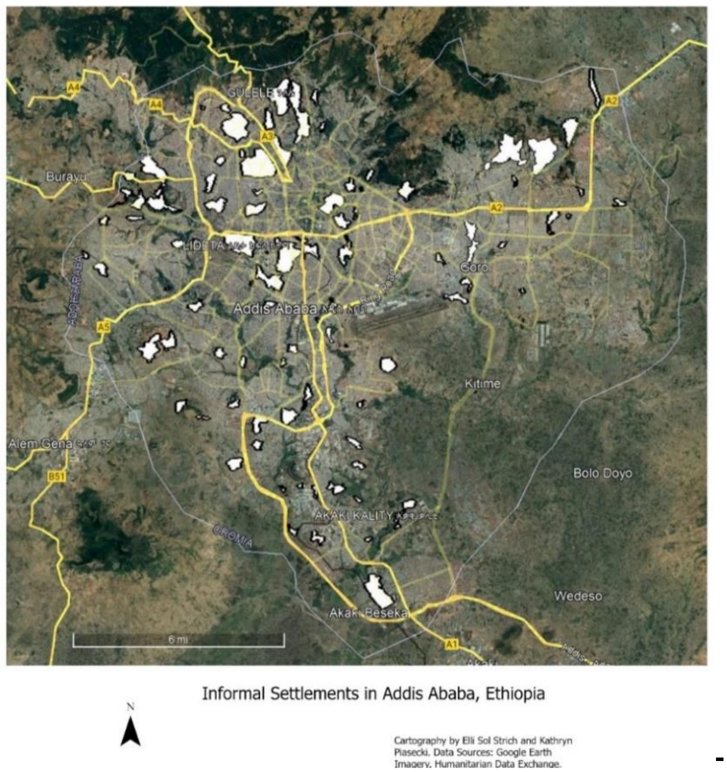

Figure 17: Satellite imagery map of informal settlements within Addis (Data Sources: Fletcher/UEP Climate Migration Research Team, USAID)

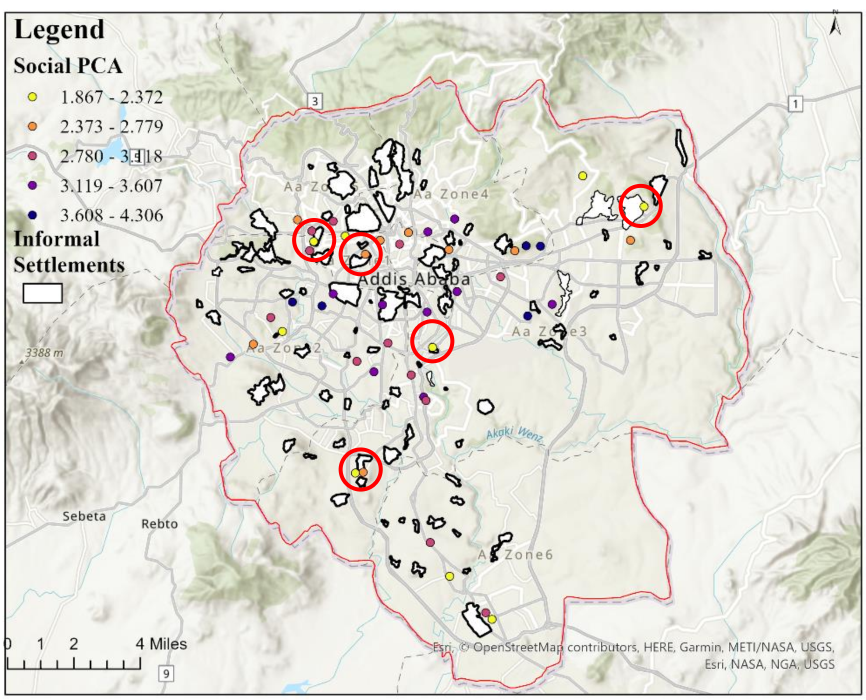

Figure 18: Social PCA points in Addis overlain on informal settlements. Red circles highlight overlaps between low social PCA scores that indicate high vulnerability and the informal settlements. (Data Sources: Fletcher/UEP Climate Migration Research Team, USAID).

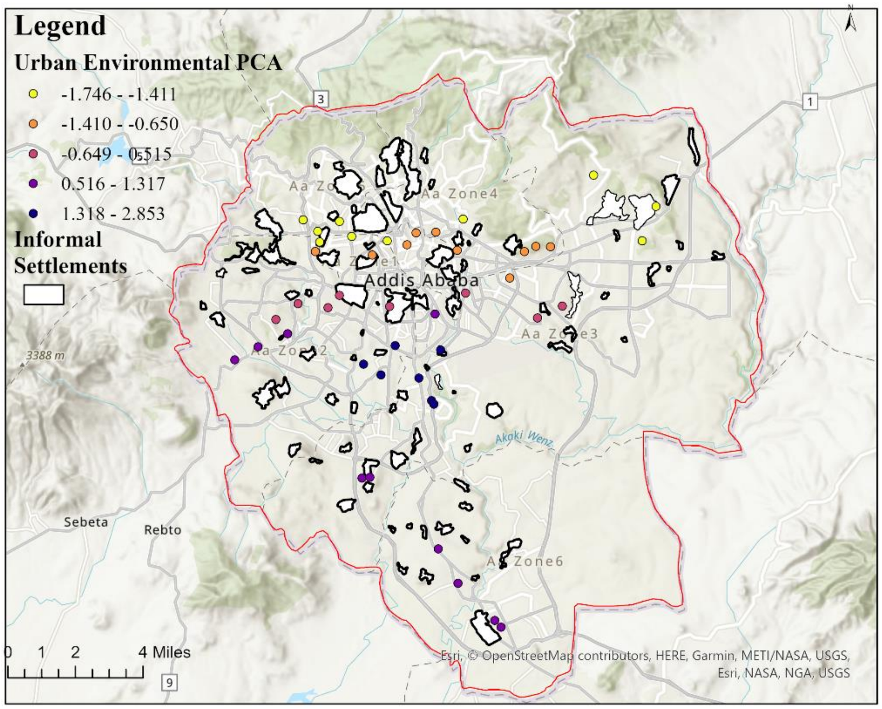

Figure 19: Urban Environmental PCA points in Addis overlain on informal settlements (Data Sources: Fletcher/UEP Climate Migration Research Team, USAID)

Chapter 4: Discussion & Implications

Key Findings

This study began with the following research questions:

1. What spatial variation or spatial relationships exist among Climate change vulnerability variables in Ethiopia and in the Addis Ababa urban case study?
2. What can we do with the knowledge this study generates on spatial variation and association among Climate change vulnerability variables?

The Methods and Findings section offers answers to the first question. Environmental vulnerability variables show an alignment with features of the country's geography, and the variables that define vulnerability are different in the Addis case study. Specifically, precipitation is associated with high vulnerability in the city, but low vulnerability in much of the rest of the country. Environmental and social vulnerability show notable variation within the city of Addis, with environmental vulnerability seen mostly in the north and social vulnerability seen mostly on the city's outskirts. Nationally, arid areas tend to show greater vulnerability and forested areas tend to show lower vulnerability. Social vulnerability shows a less distinct spatial pattern, but some hotspots and cold spots do emerge. Low social vulnerability is concentrated in the center of the country in and around some of the major urban centers, and high social vulnerability is concentrated in the north and southeast regions that are more rural. Combining these two components of climate change vulnerability reveals a relationship between social and environmental vulnerability in the north-central region of the country, along the mountains between Addis and the northern border. This area is thus deemed the most vulnerable to Climate change impacts in Ethiopia.

What can be done with these findings is a broad question. The following subsections offer some suggestions of how the methodology and findings of this study may be used to inform policy and planning in Addis, Ethiopia, and other countries of the Global South.

Limitations

The format of the DHS data necessitated some processing for aggregation to enable a spatial analysis. While the process for this aggregation is outlined in detail here and follows standard best practices, any type of processing increases the potential for the introduction of errors. Some data points were also dropped in the joining process to the GPS points because matches could not be found. This only his represented a small proportion of the data (approximately 20 points out of 620 points).

Perhaps the greatest limitation of this study is the challenge of data availability and scalability. Global and regional data sets, largely coming from satellites in the United States and Europe, produce a very comprehensive selection of climatological data that cover Ethiopia. However, as Africa and Ethiopia are not the focus of these scans, they are only included in the global datasets, which do not contain the level of granularity and specificity to be useful on a national or sub-national scale for Ethiopia. The DHS data points offer a very strong and useful set of variables that can stand-in for some of this data. However, as they exist as points rather than continuous data, it is difficult to truly scale them to whole cities or countries. The DHS points themselves may also be somewhat self-selectively biased for population density, as data is only collected in places where people live.

As mentioned in the introduction, civil conflict in Ethiopia has made getting real-time, on-the-ground data and support from Ethiopia difficult, making it challenging to place the findings of this study in the practical and political context of the country at this time. I am hoping to meet with a student from Ethiopia to attempt to ground some of my findings.

Extrapolating Methodology

My hope is that this study may also serve as a model for assessing climate change vulnerability in developing nations and areas where data quality and accessibility is challenging. DHS data is available for many of these areas where detailed environmental data from satellites or national agencies is not, just as is the case in Ethiopia. The methods used here for identifying vulnerability variables and spatial relationships have the potential to be replicated for other countries, especially those which may struggle with their study of and preparation for climate change impacts.

Policy Recommendations

Ethiopia struggles from a lack of resources and governmental power to study and understand current conditions and best solutions for tackling the challenges of climate change. Generating and understanding data about climate change is a crucial first step in formulating policies to address it, so the products of this study may help do just that and serve as an asset to moving the needle forward on policy and implementation, even if they are not the perfect.

As addressed in the limitations section, Ethiopia is currently dealing with national crises that likely divert resources and attention from longer-term planning and policy, including addressing climate change vulnerability. However, climate change is increasingly being recognized as an underlying driver of political and civil conflicts.[58] Therefore, Ethiopia's crises may be more related than they seem. Components of this study highlight this: the data used in this project stop in 2016, a few years before the Tigrayan conflict came to head, yet they show high social and environmental vulnerability in northern areas of the country that are within and around Tigray. Drought has also been reported as a problem in the region contributing to instability and food shortages and worsening and increasing droughts can be attributed to climate change.[59] Thus, dealing with existing conflicts is crucial to getting policy in Ethiopia to a point where climate change adaptation can be more rigorously considered and developed.

In the urban centers of developing countries like Addis in Ethiopia, where informal settlements that lack most essential services make up major swaths of the city, health and sanitation concerns tend to take the center of attention.[60] Addressing these concerns is the utmost importance. As with political conflicts, health and sanitation issues do not exist in a vacuum separate from climate change issues. The inclusion of malaria prevalence as an environmental vulnerability variable in this study speaks to one of the intersections

[58] Sitati et al., "Climate change Adaptation in Conflict-Affected Countries: A Systematic Assessment of Evidence."
[59] Serdeczny et al., "Climate change Impacts in Sub-Saharan Africa."
[60] Campbell-Lendrum and Corvalan, "Climate change and Developing-Country Cities: Implications for Environmental Health and Equity."

between health and environment, as malaria prevalence appears to show a correlation with increasing temperatures. In this example, more rural areas where healthcare can be harder to access appear to also have higher malaria prevalence, indicating a potential social component to this vulnerability. As discussed in the literature review, the damaging relationship between climate change spans across many ailments and categories as well. Integrating health, social, and environmental policy to holistically address the intersections of these issues could be a key strategy for gathering widest-spread support for potential policy interventions at both the city and national level.

This study shows that key regional and urban-rural differences exist in climate change vulnerability in Ethiopia. Therefore, it would be advantageous for national policies to be tailored to the regional or provincial level, in partnership or with deferment to regional and provincial governments. Agricultural and pastoral regions are high in environmental vulnerability, and droughts in these regions will impact the food supply and economic livelihoods of residents of the region and the entire country. Economic safety net measures may be most appropriate on the regional and provincial level to help the farmers and pastoralists who are affected, while national investment in agricultural resiliency and food staple importation may be better suited to the national jurisdiction. The infrastructural needs of rural areas also differ from those of cities like Addis, with transportation, education, and communications in need of bolstering in rural areas while sanitation and water control infrastructure are more urgent in Addis.

Urban Case Study Recommendations

Addis has already made a commitment to bettering it's housing and infrastructure, but still has much progress to make on strengthening these policies and creating meaningful and lasting implementation.[61] The city also has some ways to go on more specific commitment to climate and environmental issues and their mitigation. However, the city faces many of the same challenges that the country as a whole faces in terms of lack of resources, structure, and administration. The data analysis presented in this study offer insights to planners and policy makers.

Flood risks and social inequity comprise the greatest climate change vulnerability in Addis. On a relative scale, social vulnerability appears low in Addis compared to all of Ethiopia. But on closer examination, notable disparity exists in the city. Given prior reports on the very high proportion of residents living in informal settlements and/or in poverty, this is not surprising.[62] Precipitation is much higher in Addis than the national average, which compounds with factors like impervious surfaces, poor or nonexistent infrastructure, and elevation/slope to create flood risk in the city. Precipitation appears to be decreasing over time in Addis, as it is in all of Ethiopia, but at a very slow rate that is not noticeably different from the national rate. Given the high baseline of precipitation in Addis, this decrease does not seem to pose a threat, and continued higher rates of precipitation coupled with continued urbanization are a greater concern. Overall, the environmental vulnerabilities show some notable differences in the urban setting, but many factors of social vulnerability are the same compared to the rest of the country.

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[61] Dubbale, Tsutsumi, and Bendewald, "Urban Environmental Challenges in Developing Cities: The Case of Ethiopian Capital Addis Ababa."
[62] "Slum Housing in Ethiopia."

Despite what was suggested by previous literature, the results of this study did not find any strong indicators of the Urban Heat Island Effect occurring in Addis. Average maximum temperatures in Addis are increasing at a lower rate than the rate of increase in the country, and baseline temperatures in Addis are markedly lower as well (table 1, figures 5 & 7). It is still possible that small pockets of heat islands exist within the city that weren't captured by the DHS data points, and it is accepted in the scientific community that temperatures worldwide will continue rising with climate change. But overall excess urban heat does not appear to be a leading environmental issue in Addis. In fact, the more stable temperatures of Addis may play a role in making the city a desirable destination for rural-urban migration from other areas of the country suffering much more acutely from heat distress and drought.

Based on these findings, environmental vulnerability seems to be somewhat separate from climate change vulnerability, since the most notable environmental challenges of the city are not necessarily driven by climate change. However, the social vulnerabilities that may be driven more so by climate change serve to exacerbate these existing environmental vulnerabilities. As more severe meteorological impacts of climate change are felt in other parts of the country, people will continue to gravitate towards the city as safe haven and thus exacerbate the urbanization issues that contribute to flood risk and a potential future with a more pronounced Urban Heat Island Effect.

Planners and cities officials may use this information to help prioritize items on the policy agenda in the face of inevitable competition for resources and attention. Flood mitigation and adaptation are more pressing than dealing with heat effects, especially with concern to the lack of infrastructure in informal settlements. Therefore, it would be most beneficial to pursue policies that address those issues and bolster infrastructure, such as replacing impervious surfaces with more green spaces and improving sewers and water drainage capabilities.

Future Research

As the Climate Policy Lab at the Fletcher School continues with to study climate change in Ethiopia in conjunction with the Woodwell Climate Research Center, more robust forms of meteorological data may become available. Comparing this augmented data to the findings of this study would be beneficial to assess their accuracy and usability for other developing countries and future projects. The DHS data sources offer a much wider geographic range of data than more advanced data obtained from satellites and field collections do, so comparing in places where both data sources exist can verify the usability of DHS data in locations where other sources remain difficult or impossible to access. Future geospatial study of DHS data in urban areas may also benefit from the use of buffers around the GPS points to better reflect the distance margin of error associated with the location of the points.

Future research into the urban effects and adaptation to climate change in Ethiopia and throughout the Global South could also benefit from focusing more deeply on informal settlements, since they are inherently at-risk places that comprise very significant proportions of the urban population. This study could be greatly augmented by the addition of more data points within the informal settlements, so these areas should be the focus for possible data collection efforts with limited resources and should be considered by USAID in their future DHS surveys.

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Appendix

Github Repository: REHerman/Thesis-project (github.com)

PCA Loading Tables:

Environmental PCA

```
PCA method: svd

Standard deviation:
1.430751 0.911107 0.350480

Proportion of variance:
0.682349 0.276705 0.040945

Cumulative proportion:
0.682349 0.959055 1.000000

Kaiser criterion: 1.000000

95% threshold criterion: 1.000000

Eigenvalues:
 2.04705
0.830116
0.122836

Variable Loadings:
                    PC1       PC2       PC3
NDVI_AVG      -0.665181 -0.190868  0.721875
PRECIP_AVG     0.382998 -0.917125  0.110425
max_TEMP       0.640974   0.34993  0.683156
```

Squared correlations:

	PC1	PC2	PC3
NDVI_AVG	0.905748	0.0302415	0.0640103
PRECIP_AVG	0.300276	0.698226	0.00149785
max_TEMP	0.841024	0.101648	0.0573279

Social PCA

PCA method: svd

Standard deviation:

1.645652 0.430625 0.326184

Proportion of variance:

0.902722 0.061813 0.035465

Cumulative proportion:

0.902722 0.964535 1.000000

Kaiser criterion: 1.000000

95% threshold criterion: 1.000000

Eigenvalues:

2.70817

0.185438

0.106396

Variable Loadings:

	PC1	PC2	PC3
WEALTHQHH	0.568883	0.80796	0.153537
comms	0.584223	-0.265617	-0.766897
EDYEARS	0.57884	-0.525974	0.623133

Squared correlations:

	PC1	PC2	PC3
WEALTHQHH	0.876438	0.121054	0.00250805
comms	0.924342	0.0130828	0.062575
EDYEARS	0.907386	0.0513006	0.0413126

Urban Environmental PCA

PCA method: svd

Standard deviation:

1.430751 0.911107 0.350480

Proportion of variance:

0.682349 0.276705 0.040945

Cumulative proportion:

0.682349 0.959055 1.000000

Kaiser criterion: 1.000000

95% threshold criterion: 1.000000

Eigenvalues:

2.04705

0.830116

0.122836

Variable Loadings:

	PC1	PC2	PC3
NDVI_AVG	-0.665181	-0.190868	0.721875
PRECIP_AVG	0.382998	-0.917125	0.110425
max_TEMP	0.640974	0.34993	0.683156

Squared correlations:

	PC1	PC2	PC3
NDVI_AVG	0.905748	0.0302415	0.0640103
PRECIP_AVG	0.300276	0.698226	0.00149785
max_TEMP	0.841024	0.101648	0.0573279