SIMPLE SCALED CLIMATE PROJECTIONS AND THEIR POTENTIAL IMPLICATIONS FOR JIJIGA, ETHIOPIA

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Simple Scaled Climate Projections & Their Potential Implications for Jijiga, Ethiopia

ABSTRACT

The purpose of this project is to understand and analyze the degree to which the city of Jijiga, Ethiopia is prepared to receive expected climate change impacts. One of the fastest growing cities in the Somali region, Jijiga currently faces a number of critical developments and ecosystem management challenges that impact the lives and livelihoods of its citizens. Changes in precipitation, temperature, and other climate conditions as a result of climate change have the potential to severely and negatively affect specific populations and the ecosystems they rely on unless different development pathways are chosen that build Ethiopia's resilience to a variety of future challenges, not just climate change. Jijiga's ability to adapt to forthcoming climate impacts will depend, to a great extent, on the understanding of current climate patterns and future projections. Such awareness will hopefully lead to the creation of an informed adaptation plan where institutions, systems, and people will understand their vulnerabilities and take action towards building resilience to future climate shocks, including the ability to receive a large number of climate migrants in upcoming years.

LIST OF ACRONYMS

CORDEX	Coordinated Regional Downscaling Experiment
CSAG	Climate Systems Analysis Group [University of Cape Town]
ENSO	El Niño Southern Oscillation
GCM	General Circulation Model
GHCN	Global Historical Climatology Network
ITCZ	Inter-tropical Convergence Zone
NMA	National Meteorological Agency [Gov. Ethiopia]
RCM	Regional Circulation Model
SST	Sea surface temperatures

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Cover Image: iStockPhoto.com, FrankvandenBergh: Addis Ababa, July 29, 2009: Ethiopian people at the main market (the Merkato) in downtown Addis Ababa.

Simple Scaled Climate Projections & Their Potential Implications for Jijiga, Ethiopia

INTRODUCTION

As with many developing countries, Ethiopia currently faces a number of critical development and ecosystem management challenges that impact the lives and livelihoods of its citizens. Current climate variability, especially the cycles of drought and intense rainfall events in the Highlands, in which the city of Jijiga is located, exacerbates socioeconomic and environmental issues and often creates a feedback mechanism under which the average person has few options other than the ones they are already choosing. Changes in precipitation, temperature, and other climate conditions as a result of climate change have the potential to severely and negatively affect specific populations and the ecosystems on which they depend unless different development pathways are chosen that build Ethiopia's resilience to a variety of future challenges, not just climate change.

The city of Jijiga, the focus of this study, is located in the eastern Highlands in the Somali region of Ethiopia. Jijiga is located on a plateau, at an elevation of 1600m above mean sea level. The city is ringed on three sides by mountains, with only the north open to the plateau top.

FIGURE 1

LOCATION OF THE CITY OF JIJIGA. SOURCE: WIKIPEDIA 2012

The local topography and climate have greatly influenced ecosystem type and water resources in and around the city. Two seasonal rivers flow through the city, contributing to flooding during the rainy seasons and providing recharge zones for groundwater supplies. Vegetation is minimal—primarily of scrub-brush type, due to the cool, semi-arid climate of the plateau and extensive de-vegetation for livestock and firewood fuel needs.

A number of factors have combined to make Jijiga one of the fastest growing cities in the Somali region:

- The city lies along a major trade route and is connected to Degehabur via a concrete and asphalt road facilitating the movement of people and goods.
- Drought and rainfall variability leading to crop and livestock losses prompt some families to migrate on a permanent or cyclical basis to the city.
- Desire to augment family incomes, particularly by those households living on the peri-urban fringe that send one or more family members to the city to earn a living and send remittances (DDPA 2004).
- Conflict in Somalia and some areas of the Somali Region, driving families to cities.

As the city continues to expand and transportation networks improve, more people will be drawn to the city in order to avail themselves of the social and economic opportunities that the city offers. During the horn of Africa droughts of 2011, Jijiga city, the capital of the Somali Region, experienced an unprecedented influx of climate migrants. A number of informal peri-urban settlements have sprung up and they continue to rise. Migrants with far, and sometimes unknown, relatives in Jijiga usually settled within their lands. The demand on basic services and common goods grew considerably; drinking water, grassland or fodder, and food and charcoal, imposing an extra financial burden on already impoverished host families. Usually lacking formal education and often illiterate, the ability of rural climate migrants to integrate into urban life, access basic services, maintain steady employment, and establish themselves in the city, is limited at best. Jijiga, while enjoying economic growth, is overwhelmed by the rapid influx of migrants and is unprepared to provide basic services to this large group.

Current climate variability is one of the known drivers contributing to the city's burgeoning population. Lack of coherent land use planning, thus leading to the construction of informal settlements in flood zones, and loss of impervious surface and deforestation, is leading to an increase in the frequency of flooding and gully formation/erosion events in the city and surrounding areas. These behaviors have increased the local population's vulnerability and exposure to suffering harm during weather events. Among some of the recent climate related disasters are the flash floods of 2010 that killed approximately 30 people, injured dozens, and created physical asset and property loss for people living along the rivers. Jijiga's future climate risk will increase—due not only to changes in the area's climate regime because of climate change, but primarily due to the urbanization and development pathways that the city might take in the next 5–30 years.

Jijiga's ability to adapt to forthcoming climate impacts will depend, to a great extent, on the understanding of current climate patterns and future projections. Such awareness will hopefully lead to the creation of an informed adaptation plan where institutions, systems, and people will understand their vulnerabilities and take action towards building resilience to future climate shocks, including the ability to receive a large number of climate migrants in upcoming years.

The purpose of this project is to understand and analyze the degree to which the city of Jijiga is prepared to receive expected climate change impacts, by using scientific projections for temperature and precipitation, work with the local administration in the creation of a city resilience strategy and adaptation projects that serve the urban poor, and expose findings to relevant institutions at the various levels of government, as well as donor organizations, for the possible inclusion of urban climate change adaptation action plans in other vulnerable cities in Ethiopia.

METHODOLOGY

In order to produce a basic set of climate projections for Jijiga, in which the direction of possible changes to precipitation and temperature for the mid-future (2046–2065) are characterized, we employed the following techniques:

1. Review of existing, historical climate datasets for Jijiga and nearby population centers available online.
2. Review of literature characterizing Jijiga's historical climate and trends.
3. Seasonal Mann-Kendall trend analysis of Jijiga's and Dire Dawa's monthly precipitation totals, and mean monthly minimum and maximum temperatures over the historical record.
4. Determination of each variable's scaling factor between Jijiga and Dire Dawa.
5. Literature search and review of climate projection data for the Horn of Africa, the Somali Region, and areas close to Jijiga. Downscaled climate projections could only be found for Dire Dawa.
6. Applying the scaling factors in step 4 to the climate projections for Dire Dawa to produce very simple, pattern-scaled climate projections for Jijiga.

JIJIGA'S CURRENT CLIMATE

In order to analyze Jijiga's current climate variability, we conducted a search for station datasets of three basic climate variables—precipitation, mean maximum, and mean minimum monthly temperature—for Jijiga and nearest cities or towns. Available datasets were tested for homogeneity before conducting a trend analysis.

HOMOGENEITY

Not all changes in a station's dataset are due to shifts in the climate. Changes in instrumentation, urbanization around the station, or relocating it can introduce artificial trends into a dataset. These artificial trends are detected and removed by comparing the station with neighboring stations. They must be removed first before doing trend analysis to make sure that actual climate trends are being captured.

DATA AVAILABILITY AND GAPS

A variety of Internet sources were searched for station data for Jijiga and surrounding locations, like Dire Dawa and Harar. We did request data from the National Meteorological Agency (NMA, Gov. of Ethiopia), but the request could not be fulfilled given time constraints. Monthly summary data for precipitation totals and mean minimum and maximum temperature spanning the period of 1952–1987 for Jijiga and Dire Dawa were downloaded from the Global Historical Climatology Network (GHCN - http://www.ncdc.noaa.gov/oa/climate/climatedata.html) maintained by the National Oceanic and Atmospheric Administration (Government of United States). Many countries send records, sometimes only partial, to the GHCN or the World Meteorological Organization, which then homogenize the records as much as possible and make them available online for the global community to access. Ethiopia has made station records available through the GHCN for a select number of stations, although the period of record included for each station and the set of climate variables (precipitation, wind speed, temperature, etc.) varies for each. More recent data up to the present were not available for Dire Dawa (only available to 1999) or Jijiga (only up to 1987) in an easily accessible format, though both stations are active. The NMA should be able to provide more complete records for these two stations. Additional stations have been installed in the Somali Region, most after 2000, which will enhance future efforts to describe climate trends, characterized extreme weather events, and assist in climate adaptation initiatives. See—http://www.ethiomet.gov.et/stations/regional_information/7—for a map of the Somali Region station network.

Likewise, when searching for climate projection data for Jijiga or the surrounding areas, very little information could be found other than literature pertaining to climate modeling exercises for the Horn of Africa. The only group with publically available climate projection data for locations throughout Africa, including some in Ethiopia, is the Climate Systems Analysis Group (CSAG at the University of Cape Town). CSAG's projection data are available through the Climate Information Explorer tool—http://cip.csag.uct.ac.za/webclient/introduction—after user registration.

NOTE: We strongly urge users of CSAG's data portal to read ALL of the information CSAG offers on statistical downscaling and the interpretation of climate projection information BEFORE downloading and using the data. Misapplication of climate projection data can lead to dangerous mal-adaptation.

CURRENT CLIMATE AND TRENDS IN JIJIGA

Approximately 5% of the monthly precipitation totals, and nearly 10% of the mean monthly temperature datasets were missing for Jijiga over the period of 1952–1987. The missing data were extrapolated using a simple scaling (a Type II regression) with Dire Dawa's data before trend analysis.

Precipitation

Both Jijiga and Dire Dawa have bimodal precipitation distributions, with much of their annual precipitation occurring during Kiremt (~July–September) and Belg (~February–May). Little precipitation is contributed during Bega (~October–January). Jijiga's annual average rainfall total during 1952–1987 was around 670mm, with roughly 50% occurring during Kiremt and approximately 40% falling during Belg. There is significant inter- and intra-annual variability in precipitation as evidenced in Figure 2. The bars on the plots represent the inter-quartile range (25th to 75th percentiles) of the historical monthly rainfall totals for each location. A large inter-quartile range is indicative of significant inter-annual variability. The lines represent the median monthly rainfall total, which is a more stable statistic than the mean.

Kiremt rainfall amounts, onset, and withdrawal in any given year are strongly conditioned by a number of large-scale climate features, although local land-use, topography and vegetation influence Jijiga's local climate as well. A number of studies (Block and Rajagopalan 2006; Endalew et al. 2007; Diro et al. 2011a,b; Korecha and Barnston 2007; Williams and Funk 2011; Ummenhofer et al. 2009; Segele et al. 2009) have documented that the inter-annual and inter-seasonal (monsoon active and break periods, intense rainfall events, etc.) are modulated to some degree by the El Niño Southern Oscillation (ENSO) and the migration of the Inter-tropical Convergence Zone (ITCZ), sea surface temperatures in the Indian and Pacific Oceans, the strength and location of the Somali Jet, African and East African Jets, and some pressure centers, such as the Mascarenas pressure ridge, see Figure 3.

FIGURE 2

JIJIGA (LEFT) AND DIRE DAWA (RIGHT) ANNUAL PRECIPITATION STATISTICS

The bars represent the inter-quartile range of that month's historical data, which is a representation of inter-annual variability. The lines represent the median rainfall behavior.

Data sourced from the GHCN (Jijiga and Dire Dawa: 1952–1987) and CSAG (Dire Dawa: 1988–1999).

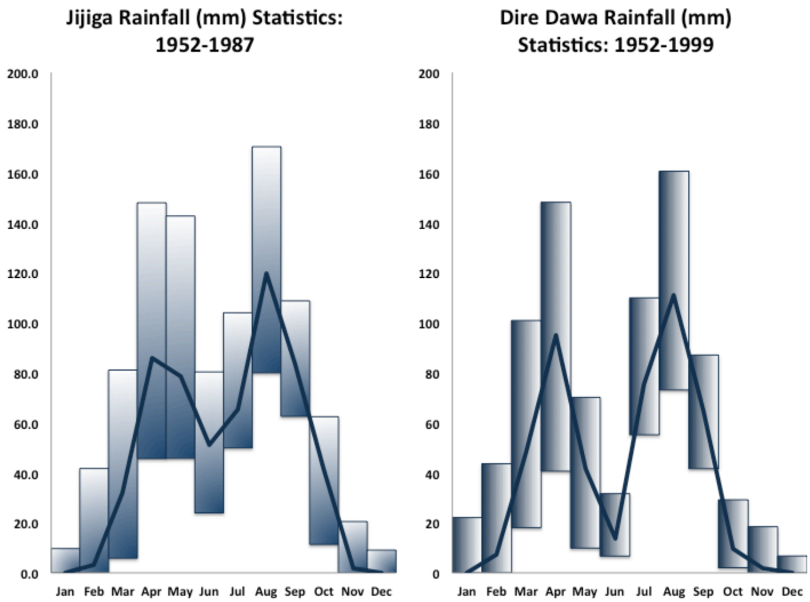
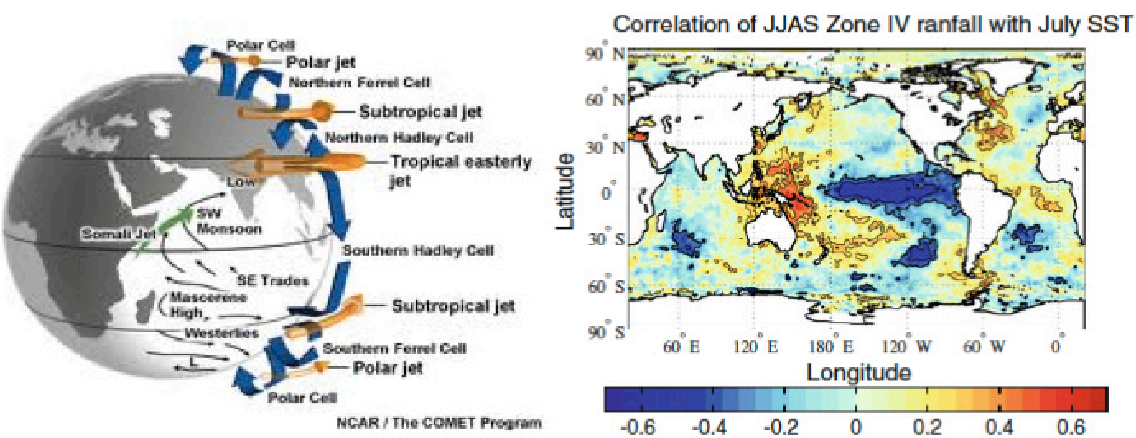


FIGURE 3

LARGE-SCALE CLIMATE FEATURES AFFECTING KIREMT

Some key large-scale climate features that influence the strength, onset and withdrawal of Kiremt rains across the Horn of Africa. The SST correlation map is sourced from Diro et al. (2011a: 108).



Our Mann-Kendall seasonal trend analysis did not show any significant increasing or decreasing precipitation trends for Jijiga during the period of 1952–1987. However, the trend analysis for Dire Dawa, for which precipitation data were available out to 1999, indicates a statistically significant decreasing trend in Kiremt rainfall. Seleshi and Zanke (2004), with access to data for Jijiga out to 2000, found a significant decrease in Kiremt rainfall for Jijiga during the period of 1982–2000, which would not be reflected in our analysis for Jijiga due to our shorter records. We, therefore, defer to Seleshi and Zanke's findings, as well as point to the decreasing Kiremt rainfall at Dire Dawa, to indicate that Jijiga's rainfall has decreased significantly since the mid- to late-1980s. *According to Seleshi and Zanke, Jijiga's mean annual rainfall has decreased by nearly 130mm since 1982, due to a 40% decrease in Kiremt rainfall. Ethiopia has experienced four major droughts (1998-2000, 2006, 2008, and 2011), resulting in famine conditions in some areas of the Somali region (EM–DAT 2012). These drought incidences are evidence of increasing rainfall variability in the region around Jijiga.*

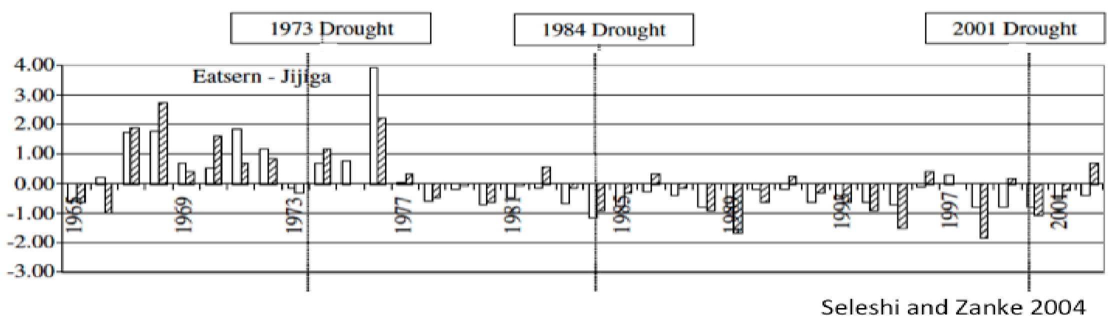
Daily rainfall analysis by Seleshi and Zanke (2004) revealed that the number of annual and June–September mean rainy days at Jijiga have undergone a statistically significant decrease in the annual (June–September) rainy days from 75 days (41 days) over the period 1965–83 to 63 days (32 days) over the period 1984–2002, i.e. a reduction in the number of rainy days by 16% (22%). At the same time, Tilahun (2006) characterized storm events at Jijiga and noted that 97% of storms produce less than 20mm of rainfall, yet only account for 55% of total rainfall. One percent of the storms produce 40 mm of rainfall or more, and account for 17% of the annual rainfall total, indicating extreme rainfall events at Jijiga. Unfortunately, Tilahun did not present a trend analysis of extreme rainfall events, so we cannot extrapolate an increase or decrease in the frequency of such events over the recent period of record.

FIGURE 4

ANNUAL RAINFALL CHARACTERISTICS FOR EASTERN ETHIOPIA

Standardized plots of annual rainfall totals (white bars) and annual rainy days (hatch bars).

Source: Seleshi and Zanke 2004: 979.



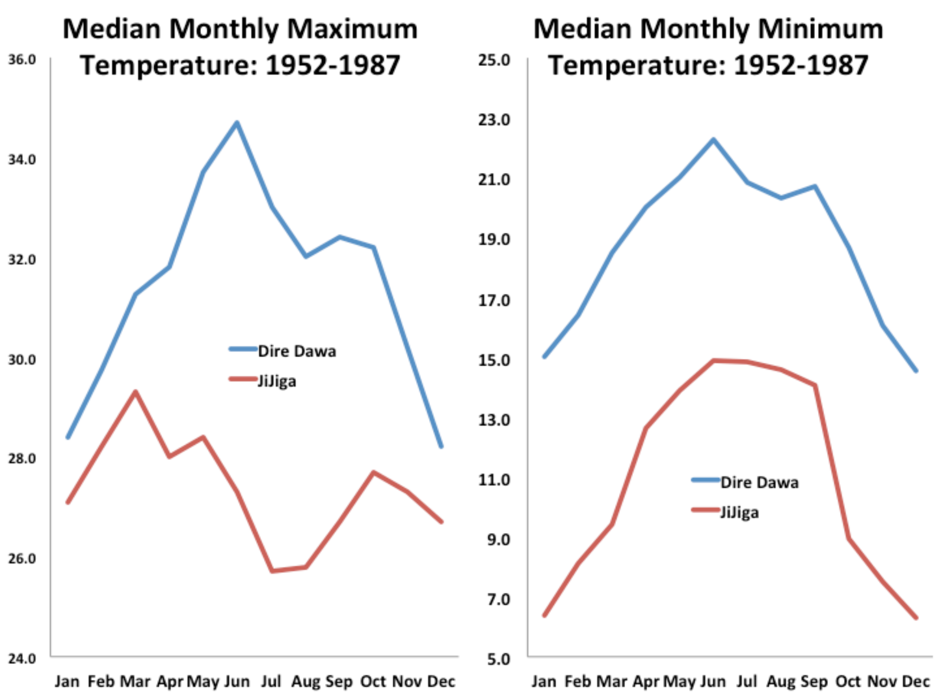
Temperature

Few studies were found during the literature review that examined seasonal temperature characteristics or trends for Jijiga or Dire Dawa. Therefore, all findings presented here are reliant upon analysis of the datasets for these two locations compiled from GHCN and CSAG. Due to its location on a plateau, Jijiga's median monthly maximum and minimum temperatures are quite temperate compared to Dire Dawa. Jijiga's hottest period is during February–May, with maximum daytime temperatures rarely exceeding 30°C, see Figure 5. Median maximum temperatures are around 28.3°C during this period, with a small inter-quartile spread of around 2°C, indicating that inter-annual variability is small for this variable. During Kiremt, maximum temperatures cool to approximately 26°C. Median monthly minimum temperatures are quite cool compared to Dire Dawa, again due to Jijiga's higher elevation, and range from roughly 6.5°C (December) to 15°C (June). Nighttime temperatures, from which the monthly values are compiled, are coolest during December–February and rise steadily until the onset of Kiremt. Dire Dawa's minimum and maximum monthly temperatures are nearly double those of Jijiga's.

Due to the lack of available literature studies investigating temperature trends around Jijiga or for the Somali Region, we can only describe temperature trends for Jijiga over the period of 1953–1987, and extrapolate trends from Dire Dawa's data out to 1999. According to seasonal Mann-

FIGURE 5

MEDIAN MONTHLY MAXIMUM (LEFT FIGURE) AND MINIMUM (RIGHT FIGURE) HISTORICAL TEMPERATURES FOR JIJIGA AND DIRE DAWA BETWEEN 1952–1987.

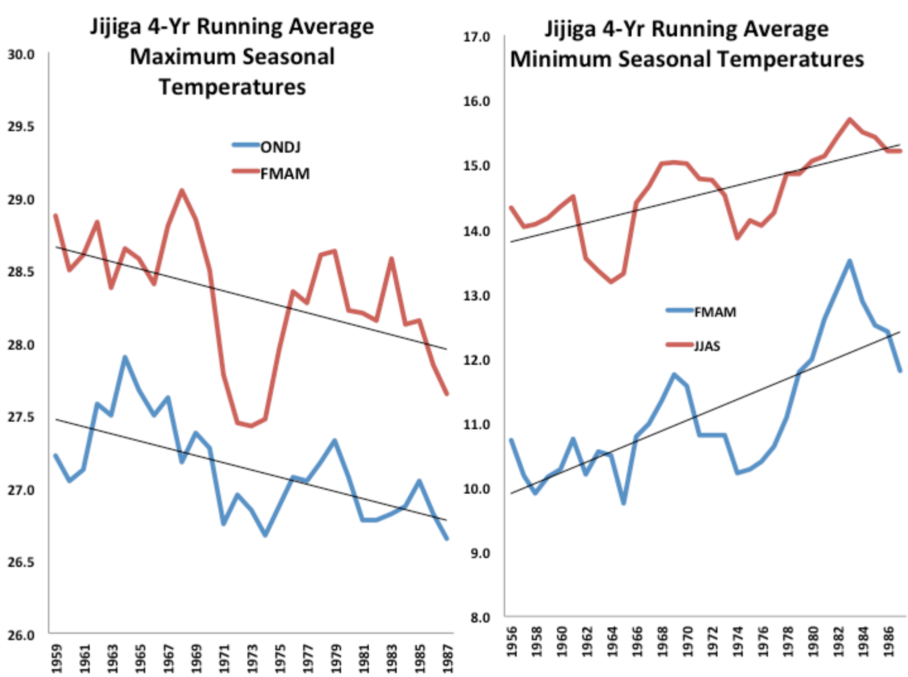


Kendall trend analysis, adjusted for auto-correlation (trend test run using the "Kendall" package in R 2.15.1 Roasted Marshmallows), Jijiga has experienced (Figure 6):

- A statistically significant warming of minimum temperatures during both Belg (2-sided p-value of 0.004) and Kiremt (2-sided p-value of 0.001). Temperatures in the decade of 1977–1987 were an average of 1.9°C (Belg) and 1.3°C (Kiremt) warmer than the first decade of the records 1953–1963.
- A statistically significant cooling of maximum temperatures during Bega (2-sided p-value of 0.007) and Belg (2-sided p-value of 0.012). Temperatures in the decade of 1977-1987 were on average -0.7°C (Bega) and -0.9°C (Belg) cooler than the first decade of records.
- Dire Dawa experienced statistically significant cooling of maximum Belg temperatures over its entire record of 1953–1999, and statistically significant warming of minimum Belg and Kiremt temperatures over the same period. Given the correlation between Jijiga's and Dire Dawa's temperature datasets, we may cautiously extrapolate that the temperature trends seen at Jijiga likely continued until at least 1999.

FIGURE 6

JIJIGA STATISTICALLY SIGNIFICANT SEASONAL MAXIMUM AND MINIMUM TEMPERATURE TRENDS



CLIMATE CHANGE PROJECTIONS FOR JIJIGA

No climate change projections appear to exist specifically for Jijiga, at least as were easily accessible online in either scientific or grey literature. CSAG has generated statistically downscaled monthly precipitation, maximum and minimum temperatures for Dire Dawa, driven by future large-scale atmospheric processes modeled by 9 general circulation models (GCMs) using 2 SRES emission scenarios A2 and B1, for two future time periods 2046–2065 and 2081–2100. Hewitson and Crane (2006) document the statistical downscaling method employed by CSAG. Only 9 models out of the 21 utilized in the IPCC AR4 review (2007) could be downscaled by CSAG because their method requires simulated daily large-scale climate fields (winds, atmospheric pressure, etc.) which were not available for all models. The 9 models employed offer a plausible range of potential future changes to precipitation and temperature under different emission scenarios (see Table 1).

TABLE 1

GENERAL CIRCULATION MODELS

The following are used for empirical downscaling of precipitation and temperature for stations throughout Africa, including Dire Dawa, by the Climate Systems Analysis Group of the University of Cape Town. Therefore, it is critical that a user select projections, either directly from GCMs or downscaled for their location and application, from multiple models and emission scenarios. This will help the user to ascertain the likely range and trend of changes to variables like precipitation or temperature from a historical, baseline period.

Agency	Model Name	Model Acronym
Canadian Centre for Climate Modelling Analysis (CCCMa)	Coupled Global Climate Model	CGCM3
Centre National de Recherches Meteorologiques, Meteo France, France	CNRM-CM3	CNRM-CM3
CSIRO, Australia	CSIRO Mark 3.0	CSIRO
Geophysical Fluid Dynamics Laboratory, NOAA	CM2.0 – AOGCM	GFDL
Institut Pierre Simon Laplace (IPSL), France	AOM 4x3	GISS
Meteorological Institute of the University of Bonn (Germany), Institute of KMA (Korea), and Model and Data Group	IPSL-CM4	IPSL
Max Planck Institute for Meteorology, Germany	ECHO-G = ECHAM4 + HOPE-G	MIUB
Meteorological Research Institute, Japan	ECHAM5/MPI-OM	MPI
Meteorological Agency, Japan	MRI-CGCM2.3.2	MRI

Empirical downscaling relies on the fact that local climate is dependent on large-scale climate features, like the Somali Jet, and local features like terrain and vegetation. GCM projections are of too coarse a spatial resolution (~50–100km per grid) to be used in adaptation processes. Empirical downscaling finds a relationship between a variable (e.g. precipitation) and large-scale climate fields (wind, atmospheric pressure, etc.) to produce local-scale climate change projections of that variable.

We produced scaled mean monthly total precipitation and mean monthly minimum and maximum temperature for Jijiga using the empirically downscaled projections for Dire Dawa, produced by CSAG. We focused only on the nearer-term projections of 2046–2065, as the distant projections (2081–2100) do not represent a future for which Jijiga can currently prepare. A scaling factor was found between the two stations over their common historical period for precipitation (ratios of the long-term monthly median values) and temperature (differences between the long-term monthly median values). This scaling factor was then applied to the Dire Dawa precipitation (multiplied) and temperature (subtracted) projections, to produce simple, broad climate projections for Jijiga. Due to the simplicity of this scaling method, and to the fact that the scaling factors were calculated over a historical base period that does not match the base period used by CSAG (1979–2000) for Dire Dawa, one should NOT take the ranges of projected precipitation and temperature as the ABSOLUTE ranges likely to occur under climate change. Instead, the ranges should be interpreted as indicative of the likely direction of change for precipitation, minimum and maximum temperatures for Jijiga between 2046–2065.

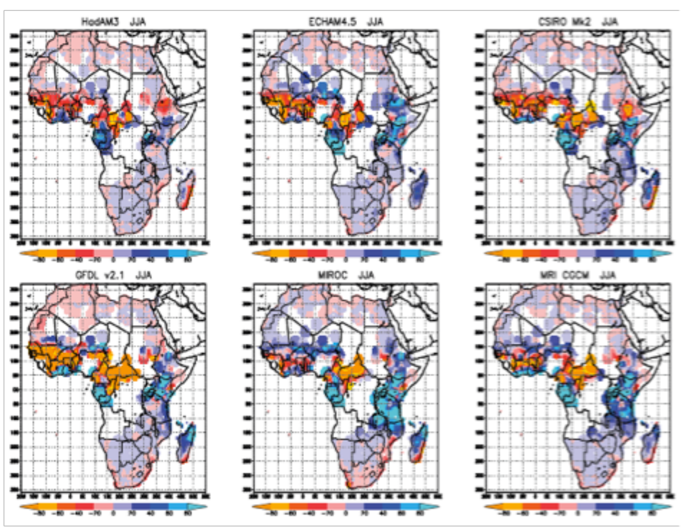
WHICH CLIMATE MODEL IS BEST FOR MY REGION?

When searching for climate change projection information for the first time, some users want to know which model out of the myriad available they should use for their region. The short answer is, as many as possible. Why?

Simulations of future climate are estimations of how the world's climate might change if certain greenhouse gas emission levels are reached, which are contingent upon scenarios of future population growth, energy use type and demand, and land-use change that must be estimated. Thus, no single model can exactly predict the future climate. Furthermore, each GCM or regional circulation model (RCM) represent climate processes—the interactions between the land, oceans, and atmosphere—in slightly different manners, and are able to replicate historical climate features differently in different regions of the world. Even if a model is not able to accurately replicate key statistics of a local region's historical climate, such as a bi-modal precipitation peak, it does not mean that that model's projection of future precipitation will turn out to be inaccurate in the future (30+ years from now).

FIGURE 7

MEAN MONTHLY PRECIPITATION ANOMALIES PROJECTED FOR AFRICA BY 6 GCMS FOR THE A2 EMISSION SCENARIO, EMPIRICALLY DOWNSCALED BY HEWITSON AND CRANE (2006).



Precipitation Projections

As stated earlier, the precipitation projections for Jijiga should not be taken as the ABSOLUTE range of possible values of future monthly precipitation; they should only be interpreted as an approximation of the potential range of change and possible trend direction.

In general, this simple set of projections for Jijiga indicates:

- Possible increasing precipitation trends during Belg, with potential decreases in Kiremt precipitation.
- Perceived shifts in the onset and withdrawal of Belg and Kiremt should NOT be extrapolated from Figure 8. This extrapolation should not be made as it is an artifact of the projections for Dire Dawa, in which none of the GCMs were able to successfully replicate the timing of the two rainfall periods over the historical record for Dire Dawa, see Figure 9. It is possible that the above shifts will occur, but not as likely.

FIGURE 8

MULTI-MODEL MONTHLY PRECIPITATION PROJECTIONS SCALED FOR JIJIGA FOR THE PERIOD OF 2046–2065.

The bars on the plot represent the 10th to 90th percentile range of the projections. The solid line represents the median historical rainfall for Jijiga, and the dashed lines represent the 10th to 90th percentile historical precipitation values.

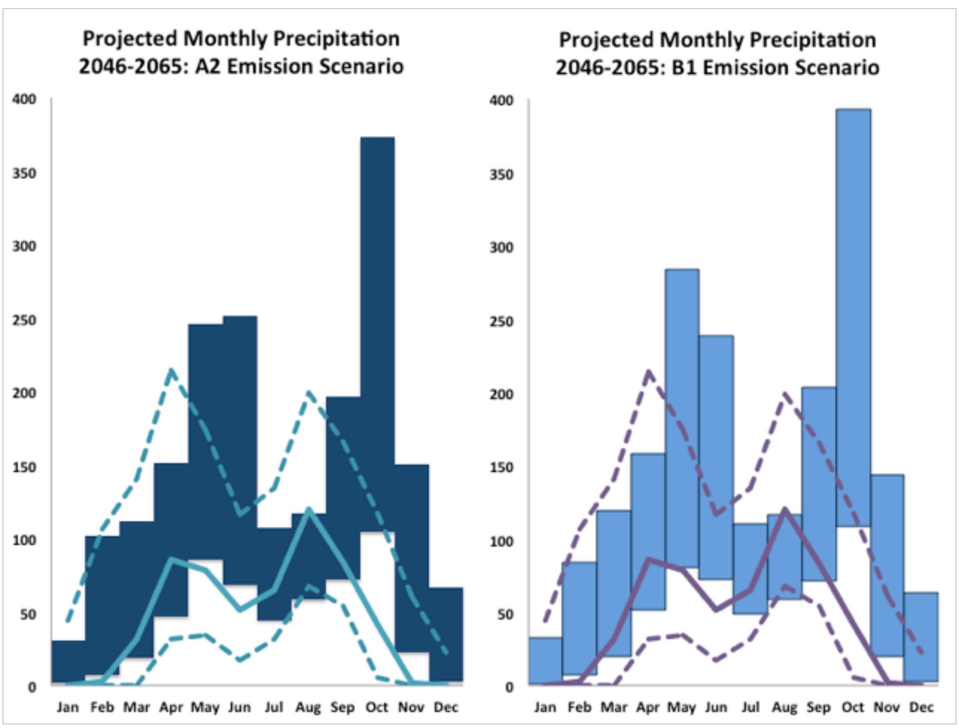
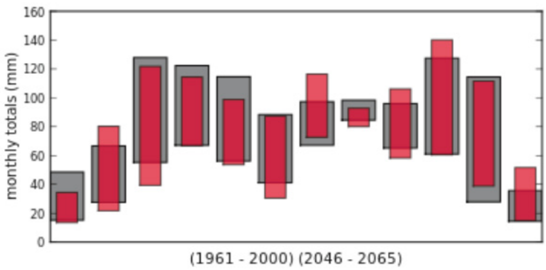


FIGURE 9

DIRE DAWA'S A2 PRECIPITATION PROJECTIONS

The grey bars represent the 10th to 90th percentile model simulations of Jijiga's climatology over the period 1961–2000, while the red bars represent 10th to 90th the multi-model projections for 2046–2065. Source: CSAG 2012.



The following table presents the differences between the 10th and 90th percentile projected precipitation values with Jijiga's historical median monthly rainfall from 1952–1987. Again, these values should be interpreted only as a very simple approximation of the potential range of changes that might be seen at Jijiga, while remembering the potentially erroneous seasonal shifts from the Dire Dawa projections. Each projection value must be considered equally probable for that month, and it is not possible to yet say which emission scenario is the most likely, although globally, we are following the A2 (higher) emission scenario. Precipitation is a particularly difficult climate variable to downscale and project because of its naturally higher variability, dependent on variability in large-scale climate features and local-scale features.

TABLE 2

RAW DIFFERENCES (MM) BETWEEN THE SCALED LOWER/UPPER (10TH/90TH) MULTI-MODEL PROJECTION (2046–2065) MEMBER AND JIJIGA HISTORICAL (1952–1987) MEDIAN MONTHLY RAINFALL VALUES FOR TWO EMISSION SCENARIOS.

These values represent one potential set of range changes in Jijiga's future precipitation, notwithstanding the "shifts" in Kiremt onset and withdrawal, which may or may not happen.

EMISSION SCENARIO	RANGE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
A2	10TH	2	3.9	-13.2	-38.9	7.1	17.2	-20.5	-61.4	-11.5	62.9	21	2.9
	90TH	30.7	98.4	80	65.3	167.3	200.6	42.4	-2.3	112.7	331.2	149	66.6
B1	10TH	0.9	3.7	-12	-34.4	1.7	21	-16.2	-61.5	-12.1	66.8	18.1	3
	90TH	32.7	80.7	87.4	72.4	205.2	187.7	44.7	-3.3	119.4	351.7	142.1	63.1

Temperature Projections

The same cautions apply to interpreting the scaled monthly maximum and minimum temperature projections for Jijiga as were mentioned for the precipitation projections. In general, Jijiga is likely to experience warming of both minimum and maximum monthly temperatures, in all seasons (Figure 10, Figure 11, Table 3, and Table 4), with warming more pronounced in minimum monthly temperatures. The spread of temperature change for any given month is much smaller than that seen for precipitation, reflecting the fact that temperature generally displays far less intra-seasonal variability.

FIGURE 10

MULTI-MODEL MONTHLY MAXIMUM TEMPERATURE PROJECTIONS SCALED FOR JIJIGA FOR THE PERIOD OF 2046–2065.

The bars on the plot represent the 10th to 90th percentile range of the projections. The solid line represents the median historical monthly maximum temperature for Jijiga, and the dashed lines represent the 10th to 90th percentile historical tmax values.

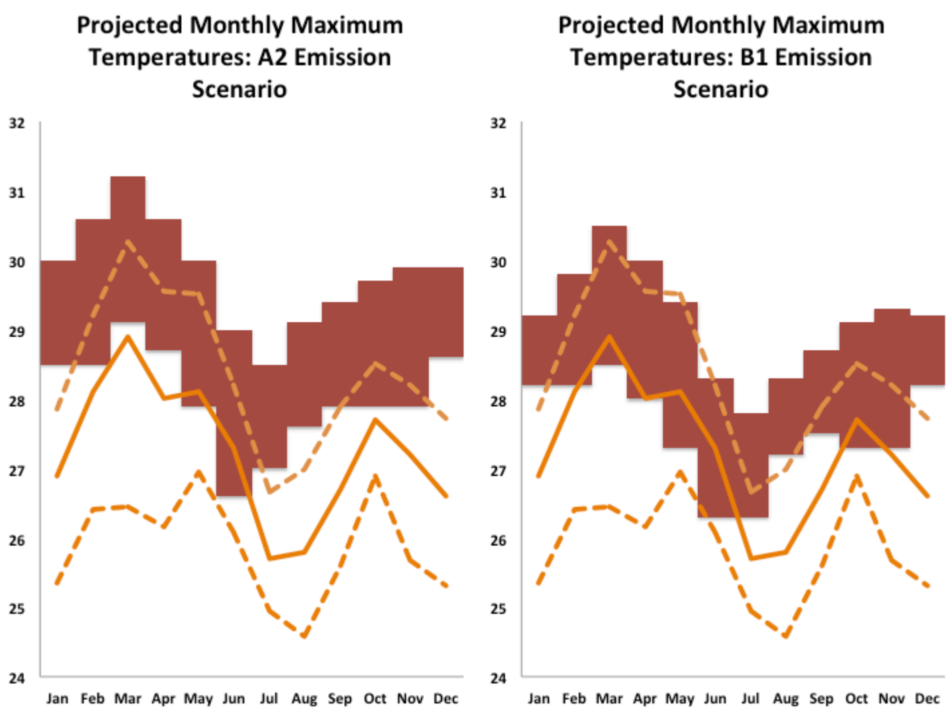


TABLE 3

RAW DIFFERENCES (°C) BETWEEN SCALED MONTHLY MULTI-MODEL MAXIMUM TEMPERATURES (2046–2065) AND JIJIGA'S MEDIAN HISTORICAL MONTHLY MAXIMUM TEMPERATURES (1953–1987).

EMISSION SCENARIO	RANGE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
A2	10TH	1.6	0.4	0.2	0.7	-0.2	-0.7	1.3	1.8	1.2	0.2	0.7	2
	90TH	3.1	2.5	2.3	2.6	1.9	1.7	2.8	3.3	2.7	2	2.7	3.3
B1	10TH	1.3	0.1	-0.4	0	-0.8	-1	0.6	1.4	0.8	-0.4	0.1	1.6
	90TH	2.3	1.7	1.6	2	1.3	1	2.1	2.5	2	1.4	2.1	2.6

FIGURE 11

MULTI-MODEL MONTHLY MINIMUM TEMPERATURE PROJECTIONS SCALED FOR JIJIGA FOR THE PERIOD OF 2046–2065.

The bars on the plot represent the 10th to 90th percentile range of the projections. The solid line represents the median historical monthly minimum temperature for Jijiga, and the dashed lines represent the 10th to 90th percentile historical tmin values.

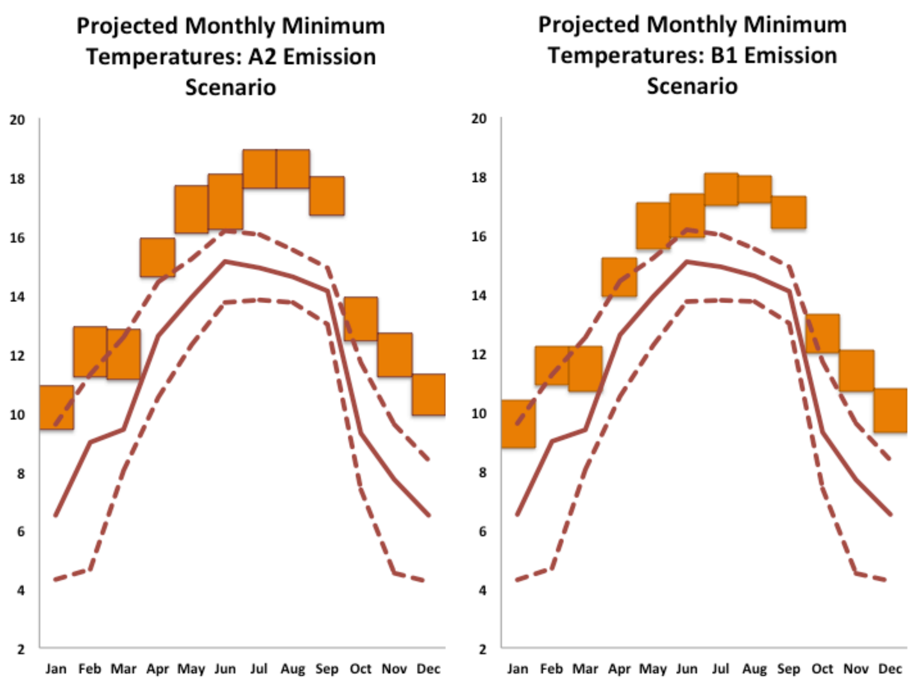


TABLE 4

RAW DIFFERENCES (°C) BETWEEN SCALED MONTHLY MULTI-MODEL MINIMUM TEMPERATURES (2046–2065) AND JIJIGA'S MEDIAN HISTORICAL MONTHLY MINIMUM TEMPERATURES (1953–1987).

EMISSION SCENARIO	RANGE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
A2	10TH	2.9	2.2	1.7	2	2.2	1.1	2.7	3	2.6	3.1	3.5	3.4
	90TH	4.4	3.9	3.4	3.3	3.8	3	4	4.3	3.9	4.6	5	4.8
B1	10TH	2.3	1.9	1.3	1.3	1.6	0.8	2.1	2.5	2.1	2.7	3	2.8
	90TH	3.9	3.2	2.8	2.6	3.2	2.3	3.2	3.4	3.2	4	4.4	4.3

JIJIGA'S CURRENT VULNERABILITY PROFILE

The severity of damages and harm caused by current climate events, such as flooding and drought, is determined largely by the underlying factors causing vulnerability for a particular group of people, livelihoods, or a location. Jijiga is facing a unique set of socio-economic, environmental, and urbanization conditions that combine as a vulnerability profile to make particular populations and city systems suffer harm from drought and flood events. Broad vulnerability profiles, highlighting vulnerability factors for Jijiga's population at large and certain city systems, are presented below. These vulnerability profiles provide a snap-shot of the dynamic processes that are likely to continue shaping Jijiga's current vulnerability and climate risk for the next five years, and will influence the city's future development pathway that will either lead to greater resilience to potential climate changes or prove maladaptive.

Jijiga has experienced significant population growth in the past 5–10 years due to a number of factors: such as sporadic conflict and competition over natural resources in the neighboring country of Somali and within the Somali region (Milas and Latif 2000; Bogale and Korf 2007); livelihood and food insecurity, which are both partially influenced by rainfall variability, conflict, and environmental degradation (Burg 2008); and burgeoning trade opportunities given Jijiga's location along major transportation and trade routes. Jijiga's permanent population has grown steadily since 1997, in which the population was counted at approximately 66,000 and grew to 97,000 in the census count of 2005. The most recent count (2011) places the city's population at approximately 148,000 (all statistics from the Central Statistical Agency, Gov. of Ethiopia). Women in the rural areas of Jijiga zone and the Somali Region have significantly less access to contraception and education, leading to birth rates that are roughly three times higher than those in Addis Abba (CSA and ORC Marco 2006). A burgeoning population in rural areas is placing greater strain on ecosystem resources and services, likely contributing to a portion of the migration to Jijiga.

Migration to the city is occurring both on a cyclical and permanent basis, as agropastoralists and sedentary

FIGURE 12

GOOGLE MAP OF ETHIOPIA

The map below shows settlement locations on the south-side of the city right in the floodplains. The mountains in the blue highlighted area route flood waters into the city. Settlements are literally springing up in harm's way at the base of the mountains. The highlighted areas below are illustrative.

Source: Google Earth 2013.

farmers in Jijiga Zone and the larger region seek perceived better economic conditions and amenities in the city. Subsistence agriculture and pastoralism form a significant part of the Somali Region's economy, constituting nearly 80% of the economy (DDPA 2004). Given the lack of permanent surface water bodies and low access to irrigation technologies or the economic means necessary to purchase them, most households must rely on rainfed agriculture. Only families with land usage rights in seasonal riverbeds can dig borewells to supplement their crops' water demands. This situation is common throughout the rest of Ethiopia, with chronic food shortages among poorer households who must partially meet their food needs through food assistance (Conway and Schipper 2011). Within Jijiga Zone, households can be divided as engaging in agropastoralism (maize, sorghum, cattle) or sedentary farming (sorghum, maize, wheat, cattle). Due to the lack of permanent surface water sources in the zone, small- to medium-agropastoralists/ farmers are particularly vulnerable to rainfall variability. Pastoralists will migrate within their home zones during years of adequate rainfall, but must migrate to neighboring regions or even into neighboring countries in search of fodder. Households may send one or more family members to the city in search of supplemental economic activities, though actual remittances may not be significant after living expenses are subtracted from wages (DDPA 2004).

Migration to Jijiga, internal population growth and the resultant urbanization processes are contributing greatly to the population's vulnerability profile, exposure to floods and gully emergence, and ecosystem degradation on the peri-urban fringes. Once in the city, few have access to basic services like electricity, domestic water supply and sewage, or solid waste management services. Less than 7% of Jijiga's households have access to the electricity grid (World Bank 2004). As a result, many rely on fuel-wood or charcoal sourced from the peri-urban areas. The subsequent loss of vegetation leads to soil destabilization and increased erosion/gully formation in and around the city.

Multiple settlements are developing and expanding in the southern areas of the city, which also happen to be flood zones due to the convergence of seasonal rivers out of the surrounding hills (Google Earth 2012). These settlements, and the resultant loss of pervious surfaces for absorbing rainfall, channelize river flows emerging from the mountains during Belg and Kiremt. This channelization, in combination with the lack of solid waste management—Mercy Corps estimates that nearly 65% of solid waste is uncollected—can create flooding situations and gully formation even during medium rainfall events. An investigation into the causes of urban flooding in the Rawalpindi-Islamabad conurbation in Pakistan, which shares similar topographic challenges as it is surrounded by hills, found that settlement in the floodplain and lack of solid waste management were the principle causes of flooding. The severity and frequency of flood events increased with settlement growth in Pakistan, even though there were no observable increasing trends in extreme precipitation events (Khan et al. 2008). Similarly, the flood profile of Jijiga could be changing simply because of land-use, vegetation destruction and lack of solid waste management. Much of the recent settlements in Jijiga are developing in highly exposed flood areas.

Lack of adequate water supply places a considerable burden on household incomes and health. Families may or may not be able to meet their domestic need via withdrawals from borewells; those without access to borewells must purchase water from tankers or private borewells. Water quality is likely to be a significant challenge, due to the lack of solid waste and sewage management, leading to the contamination of shallow groundwater tables. Very little publically available data exist on domestic water supply, water quality, and quantity of groundwater resources in and around Jijiga. Recent migrants or poorer households in the city that suffer from malnutrition as a result of food insecurity, may find themselves prone to infection due to water-borne diseases from low-quality drinking water. Finally, malnourished and formerly-malnourished migrants to Jijiga, particularly children, suffer high rates of pneumonia. In many equatorial countries, the number of pneumonia infections tends to increase during the rainy season (Paynter et al. 2010), which matches observations of infection rates in the city.

JIJIGA'S POSSIBLE CLIMATE CHANGE RISKS

Generally, climate change projection studies focus on Ethiopia as a whole, or the Horn of Africa. No studies were readily available that focus specifically upon Jijiga or the Somali Region. The available studies are in broad agreement that maximum and minimum monthly temperatures are likely to increase for Ethiopia; precipitation projections indicate only a slight increase or no change (Conway and Schipper 2011; IPCC AR4 2007; Williams et al. 2011; Patricola and Cook 2011). Thus, our study's simple scaled projections are in broad agreement with projections produced for a larger region. Our precipitation projections are high in comparison to the other studies, but we do wish to caution that the projection values should not be taken as the absolute change values, especially as no bias correction was conducted.

Simple, scale precipitation projections generated for this study indicated the possibility of a reduction in Kiremt rainfall amounts, and possibly, a delay in its onset. An overall reduction in precipitation amounts during Kiremt might not necessarily be offset by increases in precipitation in the other seasons, leading to an overall reduction in annual precipitation. *The recent decreases in Jijiga's Kiremt precipitation and multiple droughts might be more indicative of potential near-term (2015–2040) climate change impacts than are suggested by the scaled precipitation projections. Even though this study was unable to access daily or sub-daily historical precipitation data for Jijiga, recent drought and flood events, as well as an investigation* *by Tilahun (2006), indicate increasing rainfall variability. Precipitation variability is likely to continue to increase, both in Jijiga and globally, until a new climate regime is achieved in the very distant future.*

These potential future precipitation changes are likely to alter Jijiga's climate change risks—assuming the city maintains its current vulnerability profile and development trajectory. Should the city begin implementing land-use planning and zoning, building codes, solid waste and sewage management, as well as an extension of basic services to more households, the city will be able to reduce its climate change risk. Without adequate resilience building processes, the following climate change impacts are likely to occur in Jijiga and surrounding peri-urban areas:

- Less rainfall during Kiremt, in addition to a delay in its onset, could have potentially harmful impacts on agriculture and livestock for populations surrounding Jijiga. Livelihood failure and resulting food insecurity might induce increased migration to Jijiga due to these climate changes.
- Pneumonia and diarrheal diseases cause significant mortality and morbidity for children in the city, and other malnourished populations. These types of diseases tend to be more prevalent during the rainy seasons. Shifts in rainfall amount and timing will influence shifts in the timing and severity of various disease outbreaks in the city.
- Water Supply – At the same time, increased temperatures and reduced precipitation will lead to greater evapotranspiration and lower recharge rates of groundwater supplies for Jijiga. Given the fragile state of existing supply—high contamination with sewage and solid waste byproducts, and lack of regulation or enforcement of borehole pumping amounts, population growth, and potential urban growth demand for things like trade, industry, and so forth—Jijiga's water supply is not very resilient to any range of current climate variability or future change.
- Given the fairly significant projected increase in temperatures, both mean monthly minimum and maximum, and the expected increase in days exceeding 32°C at Dire Dawa, it is fairly safe to say that the number of extreme maximum daily temperature events is likely to increase. Nighttime temperatures are also likely to increase for Jijiga. The threat of frost events, particularly during October harvest times is likely to be reduced, improving harvest totals.
- Ecosystem Implications – Vegetation around Jijiga is already being denuded to meet energy demand for the city's residents. If the city does not manage to provide its citizens with alternative energy sources (such as connection to the national grid) by 2046, according to these simple projections:
    - The warmer temperatures and possible shifts in the timing and amount of precipitation in each season will cause a shift in vegetation type and possibly augment human-induced vegetation loss. This loss of vegetation can increase ambient temperatures further in the city (urban-heat island).
    - Loss of vegetation and impervious surface will further destabilize soils in and around the city, leading to an increase in gully/erosion events. This will happen even without ANY changes in climate.
    - Loss of vegetation and impervious surfaces will channelize rainwater, leading to lower flooding thresholds in the city. The lower flooding thresholds will occur REGARDLESS of any changes in precipitation or temperature.

RECOMMENDATIONS FOR FURTHER STUDY

This study can only be considered a preliminary scoping study of current precipitation and temperature trends in Jijiga and its peri-urban area, as well as a broad assessment of the city's current vulnerability profile. Publically available datasets covering basic information such as demographics, socio-economic trends, percentage of population with access to city services, land-use and urbanization footprint trends, among others, are not easily found. This lack of data makes it difficult to contextualize Jijiga's current vulnerability profile and extrapolate, except in the broadest sense, as to how the nature of Jijiga's climate risks might change in the future.

We, therefore, make the following recommendations, as steps that should be conducted as part of an urban climate resilience building process in Jijiga:

- Survey of Jijiga's water supply, with particular attention to characterization of groundwater tables, withdrawal, and recharge rates.
- Conduct a labor and migration survey to ascertain migrants' stated reasons for coming to the city, how long they plan to stay, and what sorts of barriers and opportunities they face. A sub-portion of that survey should be on the neighborhoods within the city to which migrants are attracted, their reasons for moving to such locations, and their risk perceptions related to flooding and gully formation.
- Try to determine how many gullies are forming after each rainfall event, and characterize each rainfall event within the historical record. This will help determine whether the principle cause of erosion and gully formation is due to vegetation loss for firewood, or an increase in the frequency of extreme rainfall events. Either way, better land-use management and alternative energy sources, coupled with re-vegetation efforts should help stabilize soils in and around the city and reduce erosion.

Daily historical precipitation and temperature data do exist for Jijiga, but are only available upon request from the National Meteorological Agency (NMA) of Ethiopia. These datasets should be compiled and augmented with data from recently installed, neighboring stations, and trend analysis repeated to capture recent trends. Had more time been allotted for this scoping study and more complete historical datasets been available, additional downscaling (pattern scaling) could have been done for Jijiga. If the NMA is unable to release more complete datasets, the trend analysis can be repeated using the CRU TS3.10 (or most recent version) gridded climate variable sets. The CRU datasets (2012) currently have a 0.5°resolution, which is a scale of approximately 50km x 50km per grid space (Harris et al. 2012).

It will be absolutely critical to acquire the complete record for Jijiga from the Met Agency. Seleshi and Zanke (2004) conducted Mann Kendall seasonal trend analysis for 11 stations throughout Ethiopia, including Jijiga over a period of 1965–2004. It is not apparent from their study if they checked the data for homogeneity first before doing the trend analysis. Their analysis found that Kiremt rainfall in Jijiga decreased over the period 1982–2004. This finding is corroborated with the decline seen in Dire Dawa's Kiremt rainfall. However, their analysis should be deemed incomplete without apparent data homogeneity AND extended to the present to see if the trend continues.

Finally, higher resolution climate projections will soon (~2014) be available for much of Africa through the Coordinate Regional Downscaling Experiment (CORDEX) currently underway. CORDEX is an initiative to produce coherent, high-resolution projections using multiple GCMs for the continuous period of 1951–2100. These downscaled, continuous projections will facilitate investigations into near-term (2015-2040) climate change possibilities for Jijiga that are currently difficult to extrapolate. The CORDEX Africa Analysis campaign is spearheaded by CSAG at the University of Cape Town, the same group whose earlier empirical downscaling efforts produced the projections for Dire

Dawa that we rescaled for Jijiga. More information on the CORDEX initiative can be found via http://www.csag.uct.ac.za/cordex/.

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