USGS
science for a changing world

USAID
FROM THE AMERICAN PEOPLE

Famine Early Warning Systems Network—Informing Climate Change Adaptation Series

FEWS NET
FAMINE EARLY WARNING SYSTEMS NETWORK

A Climate Trend Analysis of Chad

Conclusions

- *Summer rains have decreased in eastern Chad during the past 25 years.*
- *Temperatures have increased by 0.8° Celsius since 1975, amplifying the effect of droughts.*
- *Crop yields are very low and stagnant.*
- *The amount of farmland per person is low, and declining rapidly.*
- *Population growth combined with stagnating yields could lead to a 30 percent reduction in per capita cereal production by 2025.*
- *In many cases, areas with changing climate are coincident with zones of substantial conflict, indicating some degree of association; however, the contribution of climate change to these conflicts is not currently understood.*

Food Security Context: Drying Trends in Food Insecure Areas in Eastern Chad

Chad is a landlocked country (area: 1,284,000 km^2) with a population estimated at 10.8 million people; it has an annual growth rate of 2.0 percent (CIA, 2011). The agriculture sector engages more than 70 percent of the active population. The main crops are millet and sorghum in the northern part of the agricultural zone, with increased crop diversification around Lake Chad and areas further south. Annual rainfall totals vary from 1,000 millimeters (mm) in the south to 300 mm at the northern limit of the agricultural zone. Variability increases with latitude, resulting in a higher risk of production shortfalls in the northern part of the agricultural zone. In spite of considerable revenues from oil exports, the country remains one of the world's poorest, with limited access to adequate food, health facilities, potable water, and education for a large part of the population.

In Chad, refugees, internally displaced persons (IDPs), and host communities in the east are chronically food insecure, and poor populations in the Sahelian zone experience major acute food insecurity one year in three (FEWS NET, 2010). Human and animal pressures on a degraded ecosystem, combined with limited agricultural development, have led to low levels of national food production. In-migration from Sudan has placed increasing pressures on the eastern part of the country; in this region, the population has doubled, and competition among IDPs, refugees, and host populations has limited access to resources and employment.

This brief report, drawing from a multi-year effort by the U.S. Agency for International Development (USAID) Famine Early Warning Systems Network (FEWS NET), identifies significant decreases in rainfall and increases in air temperature across Chad, especially in the eastern part of the country. These analyses are based on quality-controlled station observations.

Rainfall Declines in the 2000s

Rainfall in Chad declined rapidly between 1950 and the mid-1980s, recovered in the 1990s, and declined again in the 2000s. Between 2000 and 2009, the average rainfall in Chad's crop growing regions was about 13 percent lower than the 1920–1969 mean average, which is more than 1.3 standard deviations below this mean. These changes can be visualized in three ways: as a contraction of the region receiving adequate rainfall for viable agricultural livelihoods, as maps of anticipated changes in rainfall, and as time series plots.

Chad receives most of its rain between June and September, and rainfall totals of more than 500 mm during this season typically provide enough water for farming and livestock. Between 1960 and 1989 the region receiving (on average) this much rain during June–September is shown in light brown in the left panel of figure 1 and should be understood to lie beneath the dark brown and orange areas. During the past 25 years, this region has contracted (dark brown polygon), exposing populations in the eastern parts of the country to increased rainfall deficits. If present rainfall trends continue, by 2025 the drying impacts will likely lead to a further, more substantial, contraction.

Rainfall reductions and temperature increases can be visualized by combining the observed 1960–2009 changes with predicted 2010–2039 changes, based on persistence of the observed trends (fig. 2, top panels). Rainfall declines range from -150 to -50 mm across the eastern parts of the country, and could impact already chronically insecure IDPs, refugees, and host communities. Observed changes (those between 1960 and 2009) account for 63 percent of these estimated change magnitudes.

A smoothed time series (fig. 2, lower panel, 10-year running means) of 1990–2009 rainfall, extracted for crop growing regions in Chad, indicate that 2000–2009 rainfall has been, on average, about 13 percent lower (-1.3 standard deviations) than rainfall between 1920 and 1969. These time series were based on crop growing regions in northeastern and southwestern Chad

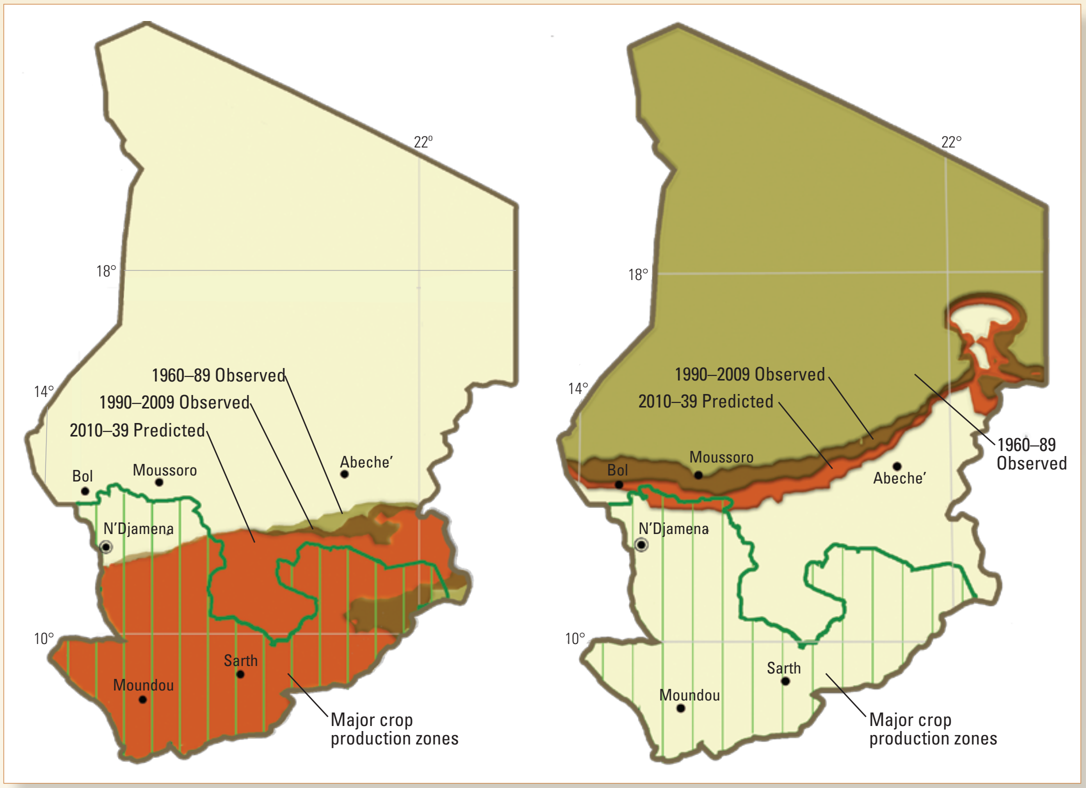

Figure 1. Climate change in Chad: The left map shows the average location of the June–September 500 millimeter rainfall isohyets for 1960–1989 (light brown), 1990–2009 (dark brown), and 2010–2039 (predicted, orange). The green polygons in the foreground show the major crop production areas. The right map shows analogous changes for the June–September 30 °Celsius air temperature isotherms.

(see Objectives and Methods section for details). Although the June–September rainfall has partially recovered in both northeastern and southwestern Chad since the mid-1970s, it has decreased again during the past decade, and remains substantially below its long-term mean.

Much Warmer Air Temperatures

Since 1975, temperatures have increased by more than 0.8° Celsius (°C) across much of Chad, with typical rates of warming greater than 0.2°C per decade. Assuming the observed trends persist, a composite of observed and anticipated air temperature changes can be created (fig. 2, top panel); most of the country will soon have warmed by almost 1.0°C. Again, observed changes alone account for 63 percent of these change magnitudes. Chad is becoming both drier and hotter, which is consistent with an increase in atmospheric circulation bringing dry subsiding air during the June–September rainy seasons (Williams and others, 2011).

A time series of air temperature data (fig. 2, lower panel) indicates that the magnitude of recent warming is large and unprecedented within the past 110 years. Given that the standard deviation of annual air temperatures in these regions is low (approximately 0.5°C), these increases represent a extremely large (approximately 2.0 standard deviation) change from the climatic norm. This transition to an even warmer climate could decrease crop harvests and pasture availability, amplifying the impact of droughts. This seems particularly problematic in the east, where warming has coincided with rainfall declines and an influx of displaced persons from neighboring Sudan.

Population Pressure and Stagnating Agricultural Growth

In 2011, Chad had a population of 10.8 million people, with an annual growth rate of 2.0 percent, producing a doubling of the population every 35 years (CIA, 2011). Between 1990 and 2010, Chad's population increased by 87 percent (CIESIN, 2010). Given that Chad is a landlocked country that depends on agricultural, agro-pastoral, and pastoral livelihoods, this population expansion will place increasing stress on limited natural resources, especially in the east, where immigration from the Darfur region of Sudan increases competition for resources. Although 27 percent of Chad receives more than 500 mm of precipitation during June–September (fig. 1, left panel), per capita cereal production is low compared to other Sahelian countries (166 kilograms per person per year; FAO, 2011). An examination of crop statistics from the Food and Agriculture Organization of the United Nations (FAO, 2011) reveals that this low level of cereal production arises from low yields (729 kilograms per hectare) and a small amount of farmland per person (0.22 hectares per person). Examining the temporal evolution of these crop and population statistics, it is evident that low frequency (decadal) variations in yields show no trend, whereas the decline in farmland per person is continuing at a steady rate. If this decline persists, per capita cereal production will decline by 30 percent by 2025 as the population expands faster than the amount of farmland.

A Convergence of Evidence

The results presented here point to a convergence of evidence among the rainfall and temperature data evaluated. The analyses of rainfall and temperature based upon station data show large departures from normal. Further corroboration for these observed changes comes from southwestern Ethiopia, South Sudan, and Uganda. FEWS NET has analyzed observations from these countries as well, and these studies reveal similar trends (see Objectives and Methods section). Although recent research indicates that warming in the northern Atlantic Ocean has led to increased rainfall across much of the Sahel since the early 1990s (Hoerling and others, 2006), FEWS NET research indicates that recent (post-1980) drying in eastern Chad, South Sudan, northern Uganda, Ethiopia, and Kenya is likely to be associated with warming in the Indian and Western Pacific Oceans (Funk and others, 2008; Williams and Funk,

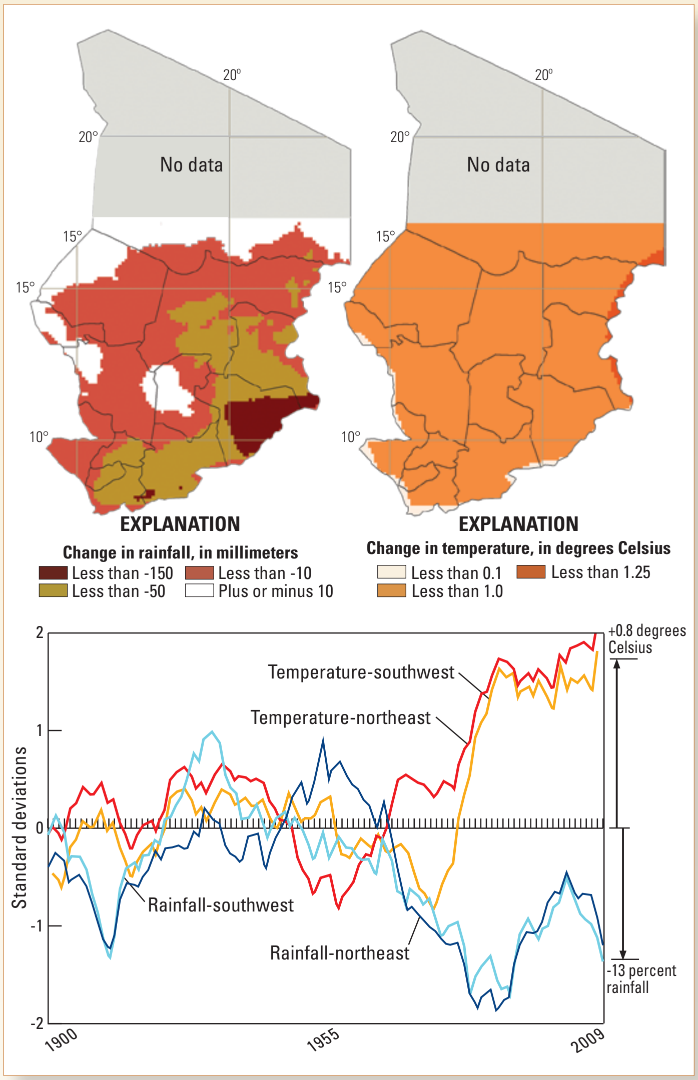

Figure 2. Observed and projected change in June–September rainfall and temperature for 1960–2039 (top), together with smoothed rainfall and air temperature time series for northeastern and southwestern Chad (see Objectives and Methods section for definitions of these regions). Mean rainfall and temperature are based on the 1920–1969 time period.

2011; Williams and others, 2011). The climate for Chad is, therefore, different than the other Sahelian countries. Chad is substantially more likely to see persistent rainfall declines.

Some Implications for Food Security and Adaptations

Although the results presented here do not depict a massive drying trend, they are large enough to affect the insecure IDPs, agro-pastoralists, and pastoralists in Chad; the strongest increases in aridity coincide with the eastern parts of the country, where food security conditions are currently the worst. The drying during June–September is consistent with previous FEWS NET studies (see Objectives and Methods section) identifying large declines in June–September rainfall in southern Ethiopia, South Sudan, and northern Uganda. The 1.3 standard deviation decline in rainfall (close to -13 percent) is sufficient to increase the number of poor harvests that can be expected (FEWS NET, 2010). Since 1990, decreasing rainfall has been accompanied by rapid increases in air temperature on the order of 0.8°C. This warming, which is two times greater than the rate of global warming, exacerbates water shortages. In the past, Chad has experienced large, natural variations in mean rainfall on decadal time scales. If another natural rainfall decline occurs, the impact of this dryness could be augmented by the effects of warmer air temperatures, and the effect of warming western Pacific and Indian Oceans.

Given the rainfall declines, raising yields in wetter areas may be a more viable option than extending agriculture into more marginal areas. Rapid population growth, however, may make it difficult to slow the process of agricultural extension into marginal areas. Increasingly frequent droughts might be offset by improved water and agricultural management practices, and raising yields could lead to improved food availability. Infrastructure development may provide irrigation opportunities to improve agricultural potential. Chad has two long rivers, and several permanent lakes, that could be used to support irrigated crops. Our analysis of crop statistics indicates that without investments in agriculture, stagnant yields combined with decreases in the amount of farmland per person will lead to a 30 percent decline in per capita cereal production by 2025.

Objectives and Methods

The FEWS NET *Informing Climate Change Adaptation* series seeks to guide adaptation efforts by providing subnational detail on the patterns of climate trends already observed in an appropriately documented record. Whether or not these observed trends are related to natural climate variations, global warming, or some combination of the two is less important than knowing now where to focus adaptation efforts.

These FEWS NET reports rely on rigorous analysis of station data, combined with attribution studies using observed climate data. This brief report examines Chad rainfall and temperature trends for the last 110 years (1900–2009) using observations from 117 rainfall gauges and 13 air temperature stations for the primary rainy period, June–September. The data were quality controlled, and the mean 1960–1989 and mean 1990–2009 station values calculated. The difference between these means was converted into 1960–2009 trend observations and interpolated using a rigorous geo-statistical technique (kriging). Kriging produces standard error estimates, and these can be used to assess the relative spatial accuracy of the identified trends. Dividing the trends by the associated errors allows us to identify the relative certainty of our estimates (Funk and others, 2005; Verdin and others, 2005; Brown and Funk, 2008; Funk and Brown, 2009; Funk and Verdin, 2009; Funk and others, 2012). The location of climate changes should be considered in conjunction with population (fig. 3, ORNL, 2010) and other factors affecting food security.

The observed warming trends are more likely to continue in the same direction and rate of change than the rainfall trends. Recent declines in rainfall appear linked to a warming of the Indian and Western Pacific Oceans and are, therefore, likely to persist for at least the next decade. Readers interested in more information can see the reference links below. These publications are available at *http://earlywarning.usgs.gov/fews/reports.php*.

The time series in figure 2 were based on crop growing regions in north and eastern Chad (Batha Ouest, Batha Est,

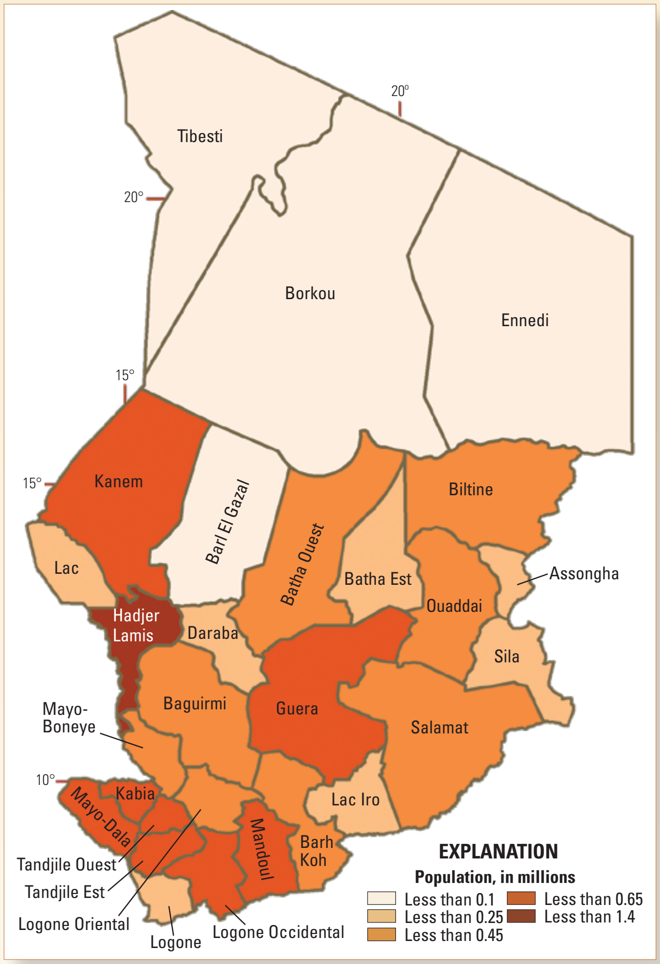

Figure 3. Landscan 2008 population for Chad (ORNL, 2010).

Ouaddai, Assongha, Hadjer Lamis, Daraba, Guera, Sila, Baguirmi, Salamat) and south and western Chad (Mayo-Boneye, Lac Iro, Barh Koh, Tandjile Est, Mayo-Dala, Kabia, Tandjile Ouest, Mandoul, Logone Occidental, Logone Oriental, Mont De Lam). These regions, along with Landscan 2008 population totals, are shown in figure 3.

This report was written by Chris Funk and Jim Rowland (both USGS), Alkhalil Adoum (UCSB), Gary Eilerts (USAID), and Libby White (UCSB). It builds upon a multi-year research project (see references below) carried out under a USAID-funded FEWS NET agreement with USGS.

References

Brown, M.E., and Funk, C.C., 2008, Food security under climate change: Science, v. 319, p. 580–581. (Also available at *http://earlywarning.usgs.gov/fews/pubs/Science_2008.pdf*.)

CIA (Central Intelligence Agency), 2011, The World Factbook: Accessed December 15, 2011, available at *https://www.cia.gov/library/publications/the-world-factbook/geos/cd.html*.

CIESIN (Center for International Earth Science Information Network), 2010, Gridded population of the world, version 3: Accessed May 5, 2010, available at *http://sedac.ciesin.columbia.edu/gpw/*.

FAO, 2011 (Food and Agriculture Organization of the United Nations), FAOSTAT: Accessed December 15, 2011, at *faostat.fao.org*.

FEWS NET, 2010, Food Security Framework: Accessed December 15, 2011, available at *http://www.fews.net/ml/en/info/Pages/fmwkfactors.aspx?gb=td&l=en&fmwk=factor*.

Funk, C., Senay, G., Asfaw, A., Verdin, J., Rowland, J., Korecha, D., Eilerts, G., Michaelsen, J., Amer, S., and Choularton, R., 2005, Recent drought tendencies in Ethiopia and equatorial-subtropical eastern Africa: Washington, D.C., U.S. Agency for International Development. (Also available at *http://earlywarning.usgs.gov/fews/pubs/FEWSNET_2005.pdf*.)

Funk, C., Dettinger, M.D., Michaelsen, J.C., Verdin, J.P., Brown, M.E., Barlow, M., and Hoell, A., 2008, Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development: Proceedings of the National Academy of Sciences of the United States of America, v. 105, no. 32, p. 11,081–11,086. (Also available at *http://earlywarning.usgs.gov/fews/pubs/PNAS_2008.pdf*.)

Funk, C.C., and Brown, M.E., 2009, Declining global per capita agricultural production and warming oceans threaten food security: Food Security, v. 1, no. 3, p. 271–289. (Also available at *ftp://chg.geog.ucsb.edu/pub/pubs/FoodSecurity_2009.pdf*.)

Funk, C., and Verdin, J.P., 2009, Real-time decision support systems—The famine early warning system network *in* Satellite rainfall applications for surface hydrology: Netherlands, Springer, p. 295–320. (Also available at *http://earlywarning.usgs.gov/fews/pubs/SatelliteRainfallApplications_2010.pdf*.)

Funk, C, Michaelsen, J., and Marshall, M., 2012, Mapping recent decadal climate variations in precipitation and temperature across eastern Africa and the Sahel, chap. 14 *of* Remote Sensing of Drought: Innovative Monitoring Approaches, *ftp://chg.geog.ucsb.edu/pub/pubs/mapping_decadal_variations.pdf*.

Hoerling, M., Hurrell J., Eischeid, J., and Phillips A., 2006, Detection and attribution of twentieth-century northern and southern African rainfall change: Journal of Climate, v. 19, p. 3,989–4,008.

ORNL (Oak Ridge National Laboratory), 2010, Landscan 2008 population: Accessed May 5, 2010, at *http://www.ornl.gov/sci/landscan/*.

Verdin, J.P., Funk, C.C., Senay, G.B., and Choularton, R., 2005, Climate science and famine early warning: Philosophical Transactions of the Royal Society B—Biological Sciences, v. 360, no. 1463, p. 2,155–2,168. (Also at *http://earlywarning.usgs.gov/fews/pubs/RoyalSociety.pdf*.)

Williams, A.P., and Funk, C.C., 2011, A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa: Climate Dynamics, v. 37, no. 11–12, p. 2,417–2,435. (Also available at *http://www.springerlink.com/content/u0352236x6n868n2/*.)

Williams, A.P., Funk, C., Michaelsen, J., Rauscher, S.A., Robertson, I., Wils, T.H.G., Koprowski, M., Eshetu, Z., and Loader, N.J., 2011, Recent summer precipitation trends in the Greater Horn of Africa and the emerging role of Indian Ocean sea surface temperature: Climate Dynamics, 22 p. (Also available at *http://www.springerlink.com/content/d3h8738018410q74/*.)

Publishing support provided by the Rolla Publishing Service Center