Applications of the African Flood and Drought Monitor to Vector- and Water-borne Disease, and to Human Well-being

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PCA PRINCETON CLIMATE ANALYTICS

UNESCO United Nations Educational, Scientific and Cultural Organization · ICIWaRM International Center for Integrated Water Resources Management under the auspices of UNESCO

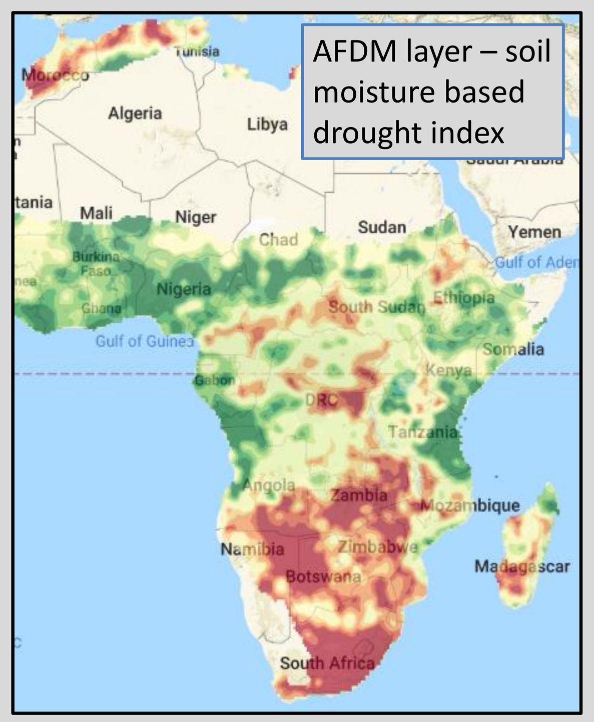
Plain Language Summary:

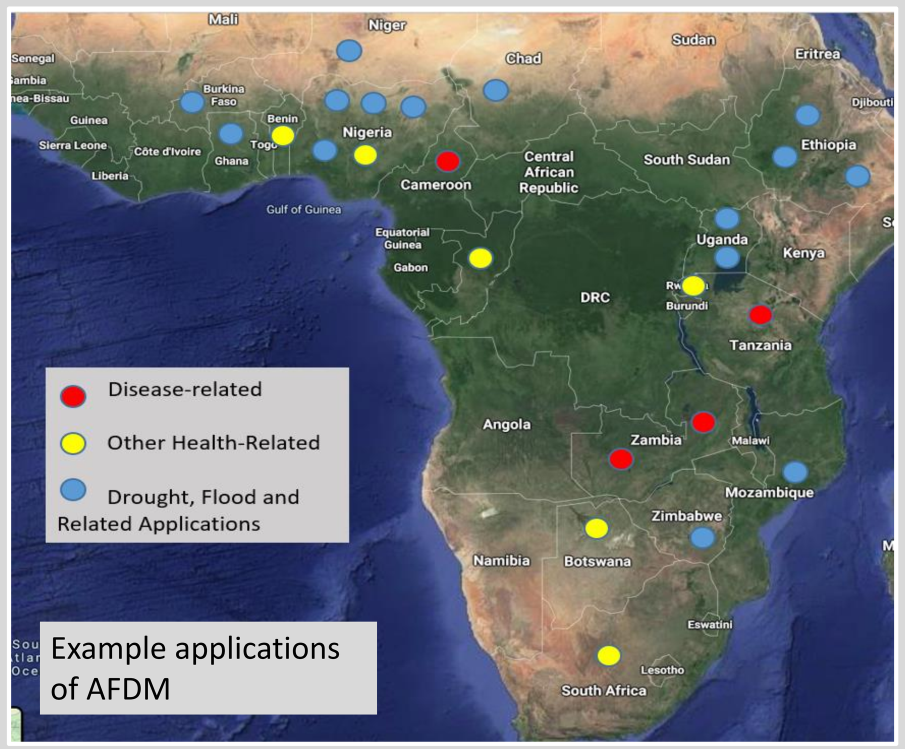
Many diseases endemic to Africa are connected directly or indirectly to the water cycle and temperature. For example, malaria is transmitted by mosquitoes, who spend most of their life cycle in water. The bacteria that causes cholera lives in fresh and salt waters. "Sleeping sickness" is carried by tsetse flies who have a seasonal life cycle. Worms and nematode parasites are affected by soil moisture.

The African Flood and Drought monitor (below) provides information of rain, temperature, soil moisture and related parameters, using satellite generated information and modeling. Such a system is especially useful where ground-based weather stations are scarce, as in many parts of Africa.

This presentation describes some examples of how the monitor has been used in studies of health and disease, including malaria, cholera and trypanosomiasis, as well as related human health issues connected to animal parasites, human migration, drought stress, and stunted growth in children.

Overall, these examples show that climate and hydrological information can help us address major health challenges in Africa, and elsewhere.





Abstract:

The **African Flood and Drought Monitor** (AFDM; above figure) was developed by Princeton University in collaboration with UNESCO-IHP, regional hydroclimate centers in Africa and ICIWaRM. It is now being hosted, and further developed, by Princeton Climate Analytics (PCA). Based on advanced land surface modeling driven by satellite data, the system provides 25-km resolution near-real-time evaluations of the terrestrial water cycle, plus forecasting by merging seasonal climate forecasts with hydrological modeling. Originally targeted toward hydrometeorological services, drought managers and researchers, the AFDM has found many applications in health and epidemiology. These include:

Malaria: In northern Zambia, populations of the two malaria-carrying mosquito species had strong, time-lagged correlations to rainfall events. Relations to temperature were more complex. The AFDM helped show the effectiveness of targeted indoor residual spraying (Hast et al., 2019a, b).

Cholera: In Cameroon, associations were found between AFDM average daily maximum temperature and risk of cholera transmission that varied across four climate subzones (Ngwa et al., 2016).

Trypanosomiasis: In the Maasai Steppe of Tanzania, negative relationships were found between abundance of two tsetse fly species and AFDM temperature. Trypanosome prevalence in the species increased with rising maximum temperatures from 26-31° C, and then declined (Nnko et al., 2017).

Related studies using AFDM data with implications for human health and well-being in Africa, include:

Stunted growth: In four African countries, a rainfall deficit of 1 standard deviation from the mean was associated with an increase of stunting in children age 0-60 months of 2.2 to 3.2% (Hill et al., 2019).

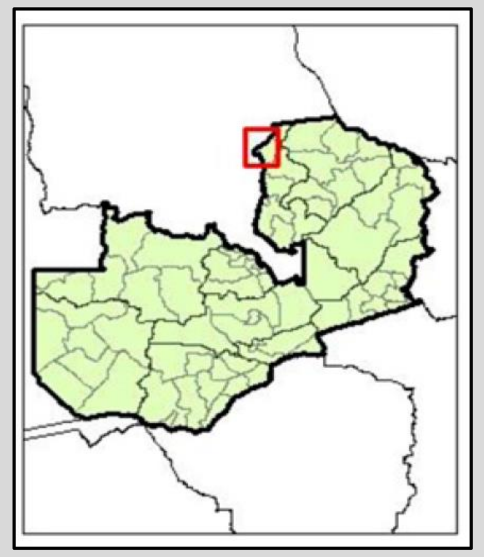
Human migration: Rainfall shortages and excess temperature, and less so soil moisture, are strong drivers of out-migration from South Africa, especially for black and low-income migrants (Mastrorillo et al., 2015).

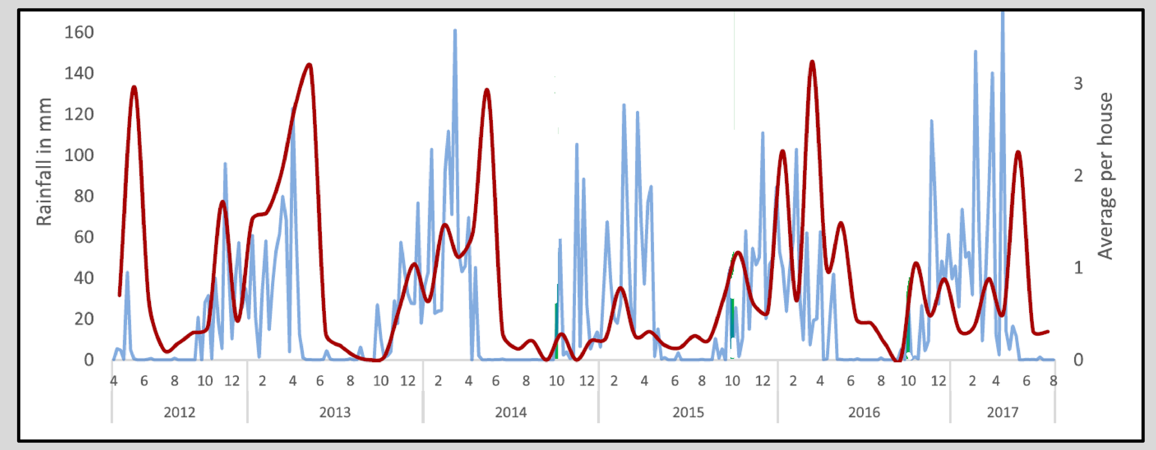
Herbivore parasites: In Botswana, temperature had a small negative effect on abundance of nematode parasites of herbivores (Walker et al., 2016), and modeled helminth larval development affecting goats was primarily driven by daily rainfall (Walker et al., 2018).

Overall, these and other examples provide evidence that the provision of climate and hydrological information in consistent and accessible ways can help enable health-related research and applications.

A) Malaria in Zambia (Hast et al., 2019a and 2019b)

Hast (2019a,b) studied predictors of vector abundance for malaria transmission in Nchelenge district, Luapula Province, northern Zambia, a high-transmission setting with limited impact of malaria control. Between April 2012 and July 2017, mosquitoes were collected indoors using CDC light traps. Various demographic, environmental, and climatological correlates of vector abundance were identified using log-binomial regression models. The primary malaria vectors in this setting were Anopheles funestus (s.s.) and Anopheles gambiae (s.s.). Among other correlations, An. gambiae abundance was positively associated with AFDM-derived rainfall estimates at lags of 3–10 weeks (Figure) and Anopheles funestus was negatively associated with rainfall at lags of 2–6 weeks.





B) Cholera in Cameroon (Ngwa et al., 2016)

Recurrent cholera outbreaks have been reported in Cameroon since 1971, but understanding of the epidemiology of the disease has been limited due in part to the diversity of Cameroon's climate subzones (Figure) and a lack of comprehensive data at the health district level. Ngwa et al. (2016) used a spatiotemporal autoregressive Poisson regression model to identify associations between the risk of transmission and factors including AFDM-derived average daily maximum temperatures, and precipitation levels, over the preceding two weeks. The direction and/or magnitude of these associations differed between climate subzones, but associations were found between AFDM average daily maximum temperature (plus precipitation, presence of a major water body, and presence of a highway) and risk of cholera transmission that varied across four climate subzones (Figure).

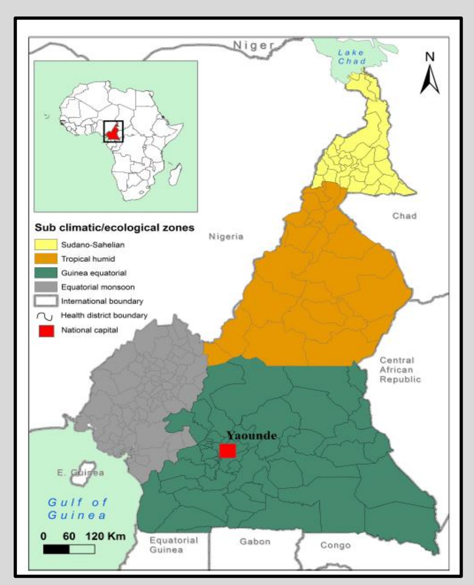


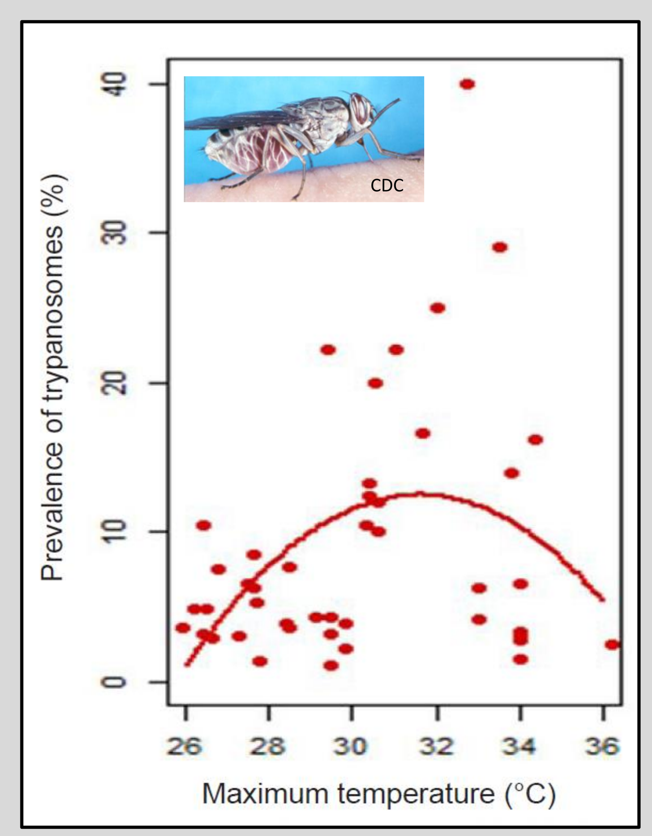
Table 1. Incidence Rate Ratio (IRR) estimates from two multivariable spatiotemporal autoregressive Poisson model fits to reported cholera case counts for the health districts of Cameroon during 2010–2011.

Parameters	Climate Subzone Specific Model: Sudano-Sahelian (SS) IRR[a] (95% CI)	Tropical Humid (TM) IRR[a] (95% CI)	Guinea Equatorial (GE) IRR[a] (95% CI)	Equatorial Monsoon (EM) IRR[a] (95% CI)	National Model (NM) IRR[a] (95% CI)
Hazard of reported cholera associated with exposure to the preceding week's (t-1) cases for the same health district, (NM, $\lambda x10^{-6}$; All others, $\lambda_Z x10^{-6}$)	2.64 (2.04–3.40)	3.43 (2.13–5.54)	1.64 (1.41–1.90)	5.05 (4.55–5.60)	3.03 (2.86–3.21)
Mean of the maximum daily temperature (°C)[b]					
Medium (M) versus Low (L)	1.09 (1.04–1.15)	0.85 (0.78–0.92)	1.56 (1.42–1.71)	0.87 (0.82–0.93)	0.93 (0.90–0.96)
High (H) versus Low (L)	1.87 (1.71–2.05)	0.89 (0.80–0.99)	1.72 (1.51–1.96)	0.46 (0.43–0.49)	1.42 (1.38–1.46)
Mean daily precipitation (mm)[b]					
Medium (M) versus Low (L)	1.33 (1.02–1.73)	0.81 (0.67–0.98)	1.19 (1.03–1.38)	1.11 (1.05–1.17)	1.23 (1.18–1.28)
High (H) versus Low (L)	1.99 (1.54–2.56)	0.62 (0.51–0.75)	1.30 (1.12–1.51)	0.96 (0.91–1.01)	1.30 (1.24–1.36)
Presence of a major body of water (inland or ocean)	1.32 (1.22–1.43)	4.02 (2.56–6.33)	1.48 (1.20–1.84)	1.11 (1.06–1.16)	1.11 (1.07–1.13)
Presence of a Highway	0.97 (0.93–1.02)	2.48 (1.59–3.87)	1.14 (1.05–1.25)	0.97 (0.90–1.05)	0.88 (0.86–0.91)

C) Trypanosomiasis in Tanzania (Nnko et al., 2017)

Nnko et al. (2017) assessed the temporal variation of the relative abundance of tsetse fly species and trypanosome prevalence in relation to climate in the Maasai Steppe of Tanzania in 2014-2015 (Figure). Gridded data on daily, maximum and minimum temperature, and total precipitation were acquired from the AFDM repository and used to characterize the weather of the study area (Emboreet village).

A strong positive relationship was found between trypanosome prevalence and maximum temperature (Figure). Environmental temperature is believed to regulated the switching of the trypanosomes from the bloodstream form to the form present in the salivary glands ready to infect a host.



D) Stunting in Sub-Saharan Africa (World Bank/Hill et al., 2019)

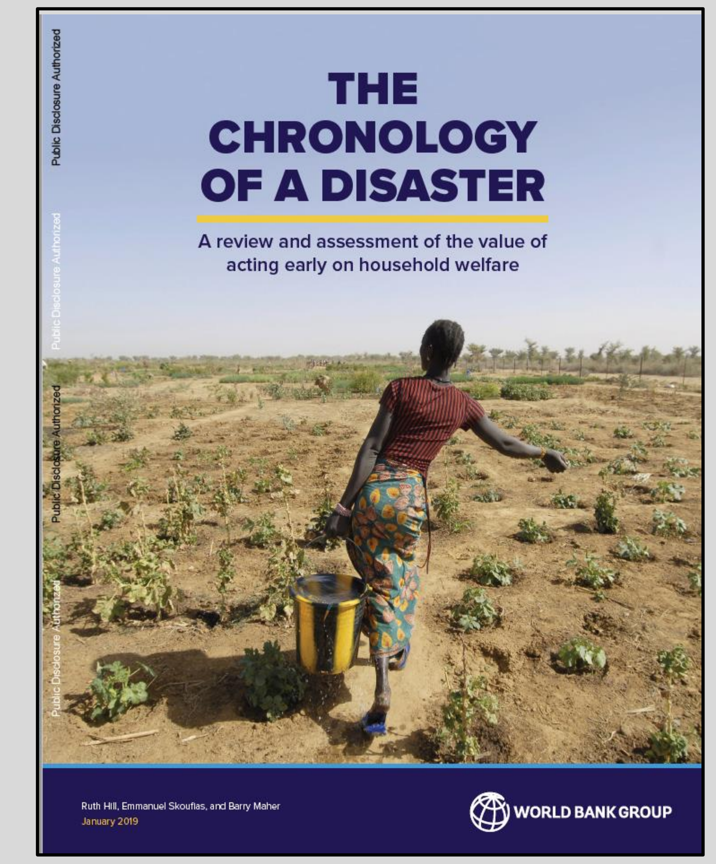
To support the disaster risk financing dialog globally, The World Bank Group did a review and assessment of the value of acting early on household welfare. To examine the impacts of drought, the authors downloaded AFDM-calculated Standardized Precipitation Index (SPI) gridded data from the last completed growing season prior to the date of interview with households and their members in various African countries.

A rainfall deficit of 1 standard deviation from the mean was associated with an increase of stunting in children age 0–60 months of 3.2% in Benin, 3.31% in Democratic Republic of Congo, 2.42% in Nigeria, and 2.21 pp increase in Rwanda. Stunting leads to cascading effects; "poor households often resort to negative coping strategies when faced with disaster impacts, and…these strategies have long-term, irreversible, and sometimes intergenerational effects."

RELATIONSHIP BETWEEN RAINFALL SHORTFALLS DURING THE GROWING SEASON AND THE PREVALENCE OF STUNTING AMONG CHILDREN LESS THAN 60 MONTHS OF AGE IN SELECTED COUNTRIES IN SSA

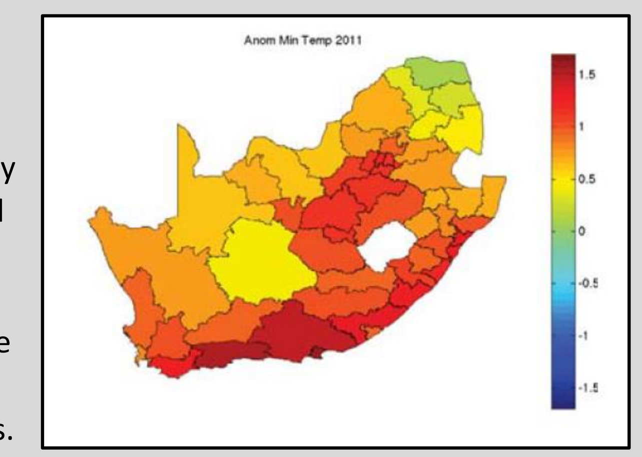
VARIABLES	Benin 2011–12	Congo, Dem. Rep. 2007, 2013–14	Mozambique 2014	Nigeria	Rwanda
Rainfall shortfall in sd units during the last growing season	0.0320* (0.0167)	0.0331* (0.0178)	0.0155 (0.0107)	0.0242** (0.00945)	0.0221* (0.0124)
Year of interview dummies	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes
Observations	4,142	1,845	5,021	13,073	1,970
R-squared	0.040	0.056	0.042	0.090	0.077

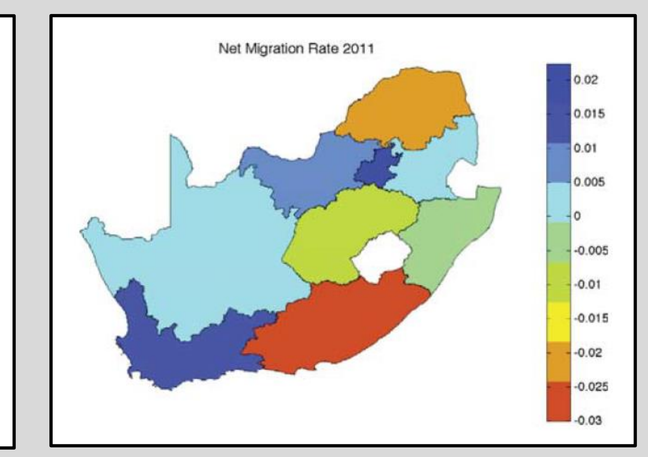
Source: World Bank staff estimates.



E) Health-related topics—Climate driven immigration, Domesticated animal disease, and Measuring Effects of Drought on Food Security

Mastrorillo et al. (2016) combined data from South African censuses and AFDM temperature, precipitation and soil moisture to investigate the impact of climate variability on internal migration flows in post-apartheid South Africa. They found that an increase in positive temperature extremes and positive and negative excess rainfall at the origin have push effect and enhance out-migration, especially for black and low-income migrants.





Walker (2018) identified the optimal timing of antiparasitic treatment in livestock for a semi-arid system in Botswana. They used the AFDM daily rainfall, evaporation and mean temperature data to model worm population dynamics. They determined that in this region, rainfall is the primary driver of seasonality of transmission, although wildlife migration leads to spatial differences in the effectiveness of treatment in domestic animals.

USAID (2016) used month-by-month AFDM data on measures of rainfall (Standardized Precipitation Index, SPI) and vegetation coverage (Normalized Difference Vegetation Index, NDVI) in Niger and Burkina Faso to show correlations of drought conditions with reduced food security, increased hunger, and reduced dietary diversity. These also correlated with area-wide downstream economic impacts, particularly increases in staple food prices and reductions in livestock prices.

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