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Hydrologic modeling for monitoring water availability in Sub-Saharan Africa

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Abstract

Drought monitoring typically focuses on supply side conditions (precipitation and associated surface, ground, and soil water availability). Now, however, satellites and models are improving such that we have more accurate estimates of states and fluxes in water and energy budgets [1]. USAID's Famine Early Warning Systems Network (FEWS NET) has adopted the NASA Land Information System for the purpose of tracking droughts and their impact, including the 2015-16 failure of the Gaborone Reservoir, Botswana (Figs. 1&2). While benefitting from better supply side estimates, drought impacts can be further improved by integrating population data as a proxy for water demand. Here we describe FEWS NET's routine water availability monitoring and ongoing research regarding changes in supply, demand, and water stress.

Fig 1. Full Reservoir
Gaborone Reservoir, Botswana July 2009
Photo credit: Google Earth

Fig 2. Empty Reservoir
Gaborone Reservoir, Botswana April 2015
Photo credit: Google Earth

Methodology

Generating Runoff Estimates

NASA Land Information System [2]	• FEWS NET Land Data Assimilation System (FLDAS) [3]
FEWS NET inputs	• CHIRPS rainfall [4] • MERRA-2 meteorology [5]
Hydrologic models	• Noah33 LSM • VIC412 LSM • HyMAP routing
Water balance Evaluation	• SSEBop ET [6] • GRACE TWS • Streamflow

Monthly Runoff Anomalies

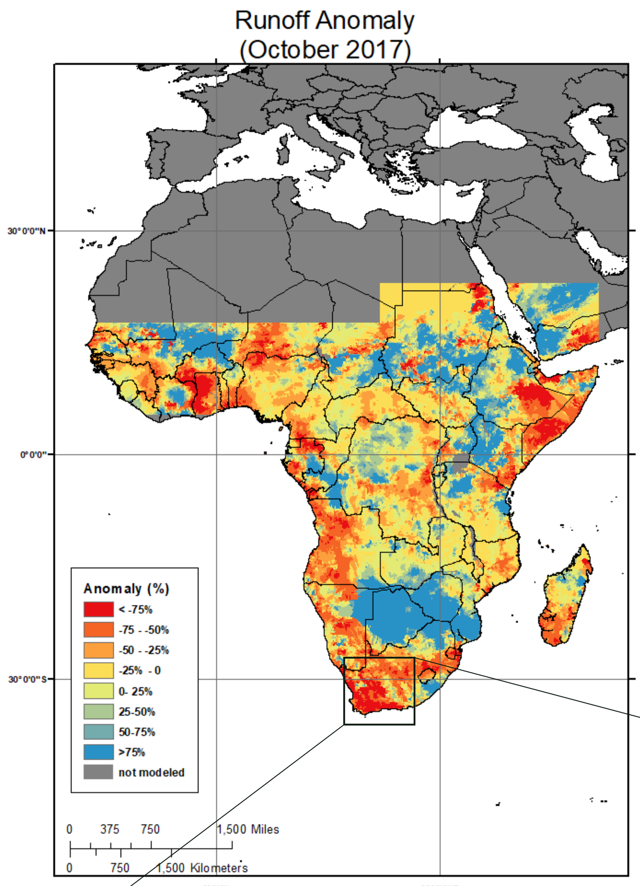
Mapping water stress

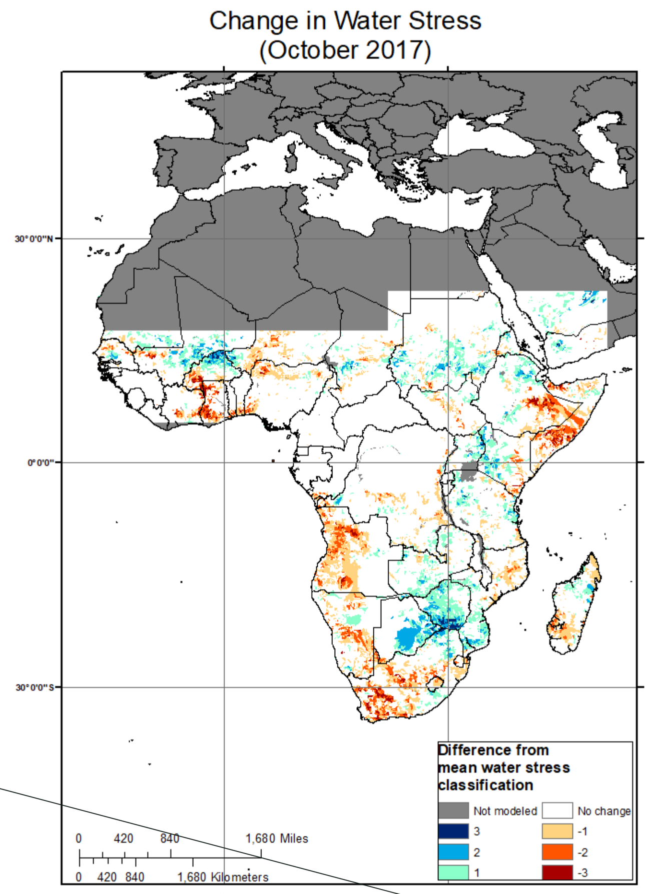
Hydro. units	• Aggregate by Pfafstetter basins [7]
Pop. data	• JRC's GHS population [8] • World Pop [9]
Runoff per capita	• Falkenmark Index [10] • Water Stress Anomalies

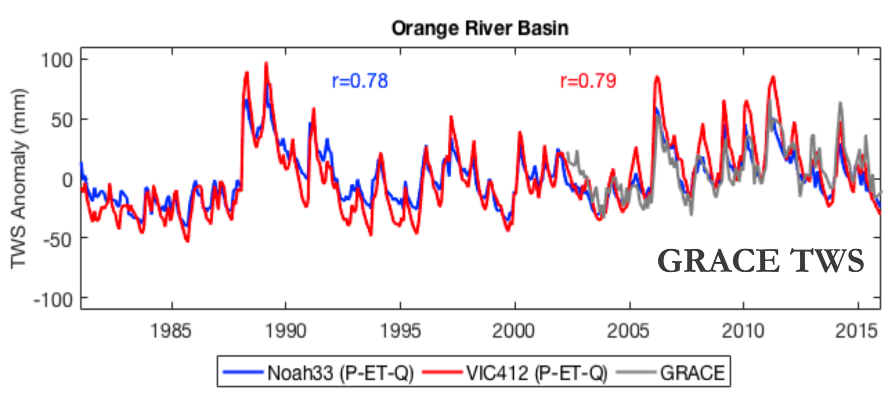
Water Stress Anomalies

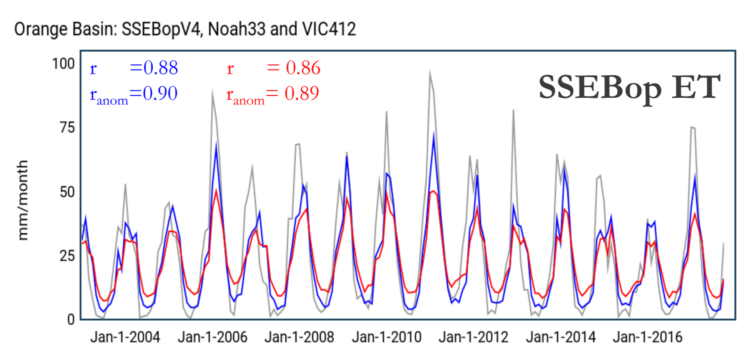
Results

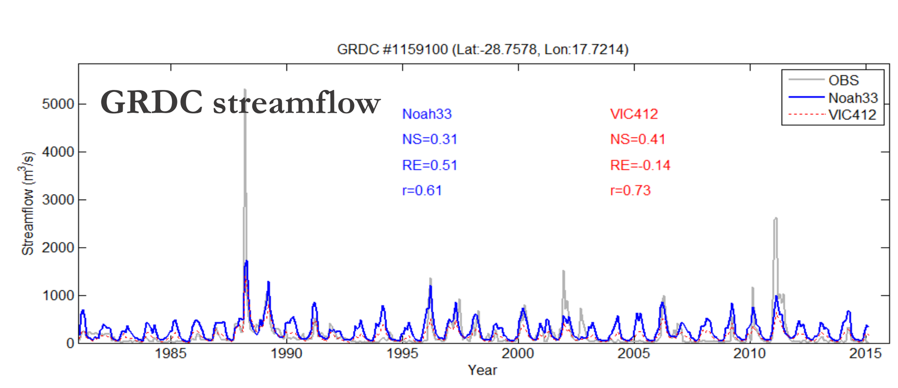
updated monthly at:
https://lis.gsfc.nasa.gov/projects/fewsnet











GRACE Terrestrial Water Storage average of three spherical harmonic gravity solutions (JPL, CSR, and GFZ) https://grace.jpl.nasa.gov/data/get-data/monthly-mass-grids-land/

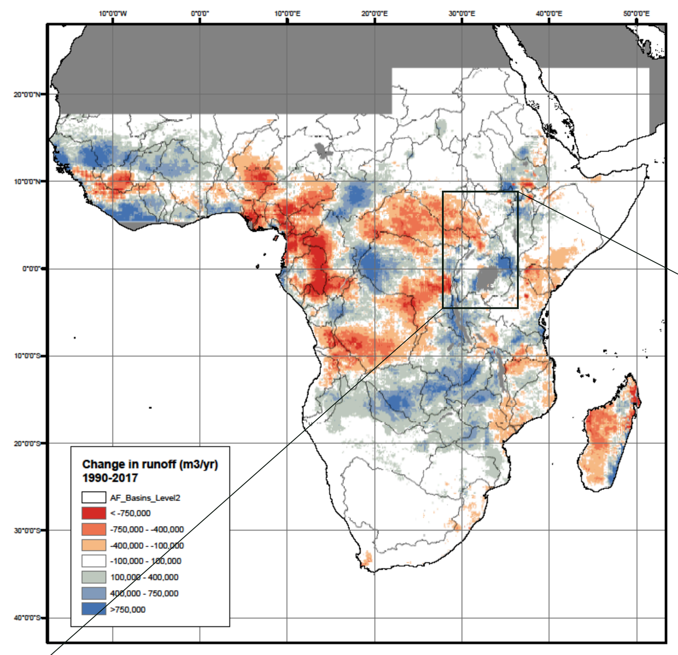
Global Runoff Data Center (GRDC) streamflow http://www.bafg.de/GRDC/EN/Home/homepage_node.html

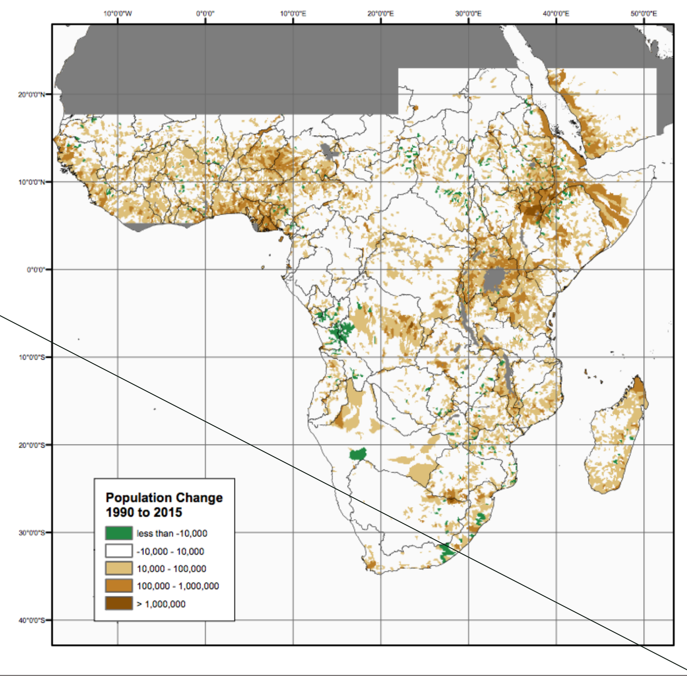
SSEBop v4 Evapotranspiration [6] https://earlywarning.usgs.gov/fews/product/464

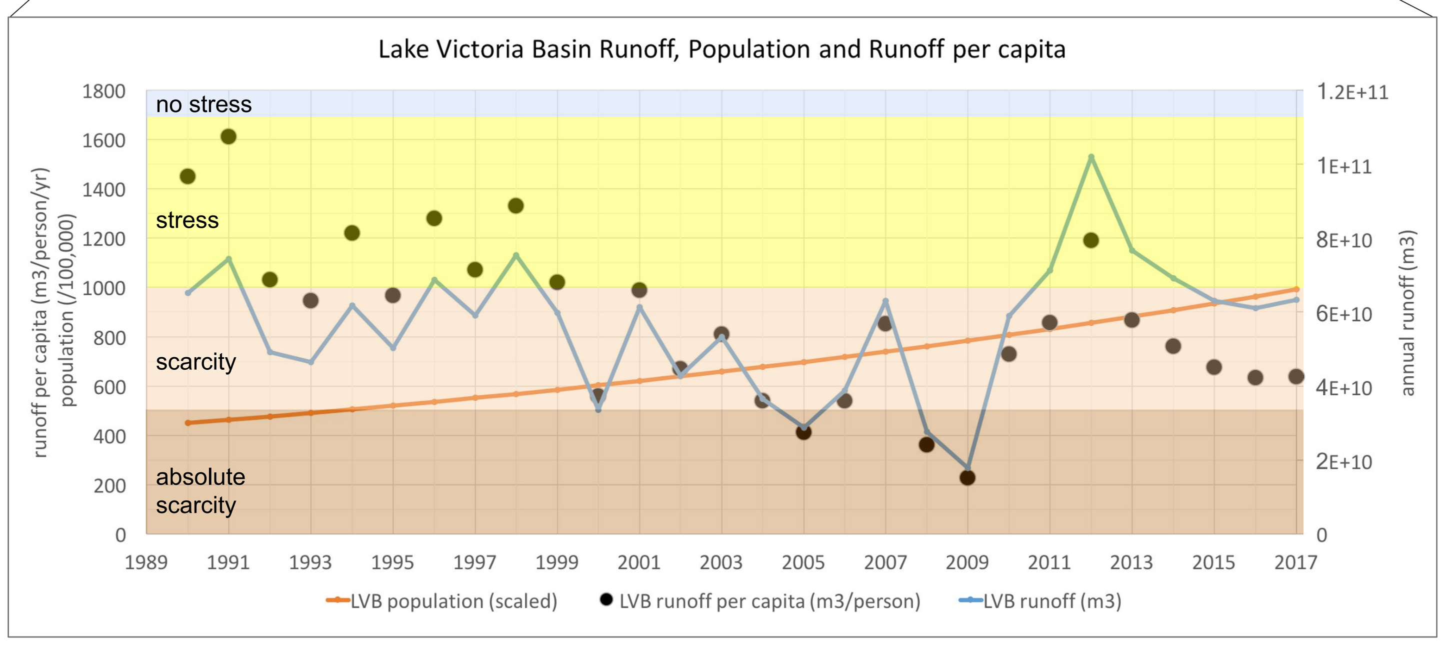
Objectives

- **Model** water and energy budgets with FLDAS using CHIRPS rainfall and MERRA-2 meteorological inputs, from 1982-present.
- **Map** water availability and stress, with respect to human population, to highlight where water insecurity may exacerbate food insecurity.
- **Explore** how water supply (precipitation, runoff) and demand (population, agriculture) are changing water availability over time.

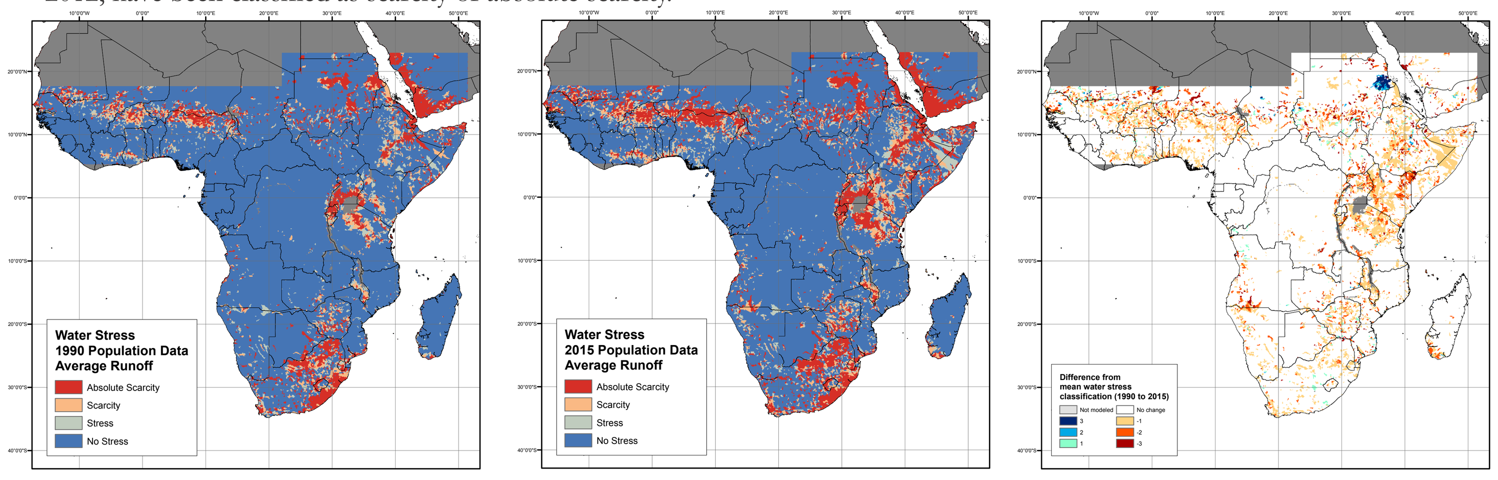
How are supply & demand changing?







Changes in runoff and population (1990-2017) and Lake Victoria Basin (LVB) annual water availability Blue line shows total annual basin runoff, with a positive/neutral trend (see change in runoff map above). Orange line shows total basin population, values interpolated from JRC's GHS 1990, 2000, and 2015 estimates. Black dots are annual water per capita. Color blocks denote Falkenmark [10] thresholds (no stress >1700, stress 1700-1000, scarcity 1000-500, absolute scarcity <500, in units m3/person/yr). Despite the positive/neutral trend in runoff, all years since 2001, with the exception of 2012, have been classified as scarcity or absolute scarcity.



Change in mean water stress due to population
Using mean annual runoff (1982-2016) we compare water stress maps for 1990 and 2015 population estimates. The map on the right is the difference, highlighting where population change has likely impacted the water availability per capita. Positive trends in runoff in West Africa (e.g. Burkina Faso) may have off-set increases in population while negative trends in runoff in Ethiopia, northern Tanzania, and South Africa may have exacerbated water stress. Future work will investigate the timing and magnitude of hydrologic trends, and associated impacts on water availability, on a seasonal time scale.

Conclusions

- In major basins (Pfafstetter level 2), FLDAS hydrologic estimates generally correspond well with remotely sensed and in situ hydrologic observations.
- Population growth points toward increasing chronic water stress, meanwhile, change in the distribution of water availability is important for early warning and analysis of acute food and water insecurity.
- Routine monitoring of water availability highlights where water insecurity may exacerbate food insecurity and require humanitarian intervention.

References

[1] Rodell, Matthew, et al. "The observed state of the water cycle in the early twenty-first century." *Journal of Climate* 28.21 (2015): 8289-8318.

[2] Kumar, S. *et al.* Land information system: An interoperable framework for high resolution land surface modeling. *Environmental Modelling and Software* **21**, 1402–1415 (2006).

[3] McNally, A., et al. (2017). A land data assimilation system for sub-Saharan Africa food and water security applications. Scientific Data, 4, 170012.

[4] Funk, C. *et al.* The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data* **2**, 150066 (2015).

[5] Bosilovich, M. *et al.* MERRA-2: Initial Evaluation of the Climate. *NASA Technical Report Series on Global Modeling and Data Assimilation, NASA/TM-2015* **39**, 136 (2015).

[6] Senay, Gabriel B., et al. "Operational evapotranspiration mapping using remote sensing and weather datasets: A new parameterization for the SSEB approach." *JAWRA Journal of the American Water Resources Association* 49.3 (2013): 577-591.

[7] Verdin, K.L., 2017, Hydrologic Derivatives for Modeling and Analysis—A new global high-resolution database: U.S. Geological Survey Data Series 1053, 16 p., https://doi.org/10.3133/ds1053.

[8] JRC's GHS_POP_GPW4_GLOBE_R2015A Population data

[9] Linard, Catherine, et al. "Population distribution, settlement patterns and accessibility across Africa in 2010." *PloS one* 7.2 (2012): e31743.

[10] Falkenmark, Malin. "The massive water scarcity now threatening Africa: why isn't it being addressed?." Ambio (1989): 112-118.

Water Availability Monitoring