Hydrological drought over the Nile River Basin: Insight into drought characteristics and prevalence during 1901-2018

Gizaw Mengistu Tsidu
email:mengistug@biust.ac.bw, Department of Earth and Environmental Sciences

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Synopsis

There are indications that global warming enhances evaporation and intensifies droughts. The drought of 1984 in Ethiopia and Sudan killed over 300,000 people. More recently, in 2010-2011, a severe drought in Kenya, Ethiopia and Somalia caused a devastating famine. In view of these challenges, it is important to understand characteristics of recurrent drought and its potential impacts on the water resource in the Nile basin. The present study uses Standardized Precipitation Evapotranspiration Index (SPEI) to examine characteristics of droughts in the basin. SPEI is determined from accumulated water balance on the time scale of 12 months for the 1901-2018 period to characterize hydrological drought. The lower catchment, covering most of Sudan Republic and Egypt, have record large number of droughts with longer duration, higher severity and intensity, and more of short return periods than that of droughts occuring over the upper catchments, covering parts of Ethiopia, South Sudan, Uganda, Kenya and Tanzania. Further characterization of drought in terms of drought variables with consideration of their interdependence is vital for water resource planning and management. The risk of having extended and severe drought of the 1980s-type within the 10-year design lifetime of hydrological system (e.g. dam) over upper catchments ranges from 0 to 20% in contrast to 30% over lower catchment. These differences and areal extent of drought should be taken into consideration in the formulation of proper drought mitigation and water resource planning during the operation of hydrological system. However, as drought is a stochastic process and localized, any transboundary water use agreement should not solely depend on such information as mentioned often with respect to recent ongoing negotiation on the filling of Ethiopian GERD dam. Basin-wide comprehensive water balance, equitable use and allocation in the basin should be worked out to avoid potential conflicts.

Background

Recurrent and localized drought, increasing food insecurity and diseases with hydrologic origin cause millions of deaths every year. In the case of transboundary river basin, there is a potential for conflict. African countries share one or more rivers. The Nile River Basin is one of the world's most famous river basin with its two sources in the Equatorial Plateau and the Ethiopian Highlands. The Ethiopian highlands contributes more than 80% of the Nile's total water supply, while the remainder comes from the Lake Plateau of East Africa. The Basin has been vital source of water to both upper and lower catchments of the Basin. However, Egypt in the lower catchment has exploited this resource almost exclusively in the past. For example, the Aswan High Dam which was completed in 1970 yields enormous benefits to the economy of Egypt. The dam controls the floodwaters and generates enormous amounts of electric power (about 10 billion kilowatt-hours annually). The reservoir supports a fishing industry. Recently, due to population increase in the basin and climate change, there are some initiatives by the upstream states such as Ethiopia to use this vital water resource (e.g., for energy generation). Although, Egypt fears the dam construction may harm its economy, there is general consensus by the scientific community that development of dams in Ethiopia could be more advantageous to downstream countries because less from evaporation and seepage are generally less in the Ethiopian Highlands than in the desert regions.

Data and Methodology

Rainfall and evapotranspiration data are obtained from Climatic Research Unit (CRU), University of East Anglia. SPEI-12 is assumed to represent hydrological drought **[1]**. Marginal distributions are fitted with the observed drought duration, severity and intensity. The joint bi-/tri-variate probability distrbutions are constructed based on Copula theory **[2]**. Marginal and copula probability distributions are selected using AIC from distributions that passed K-S test.

Homogeneous drought regimes

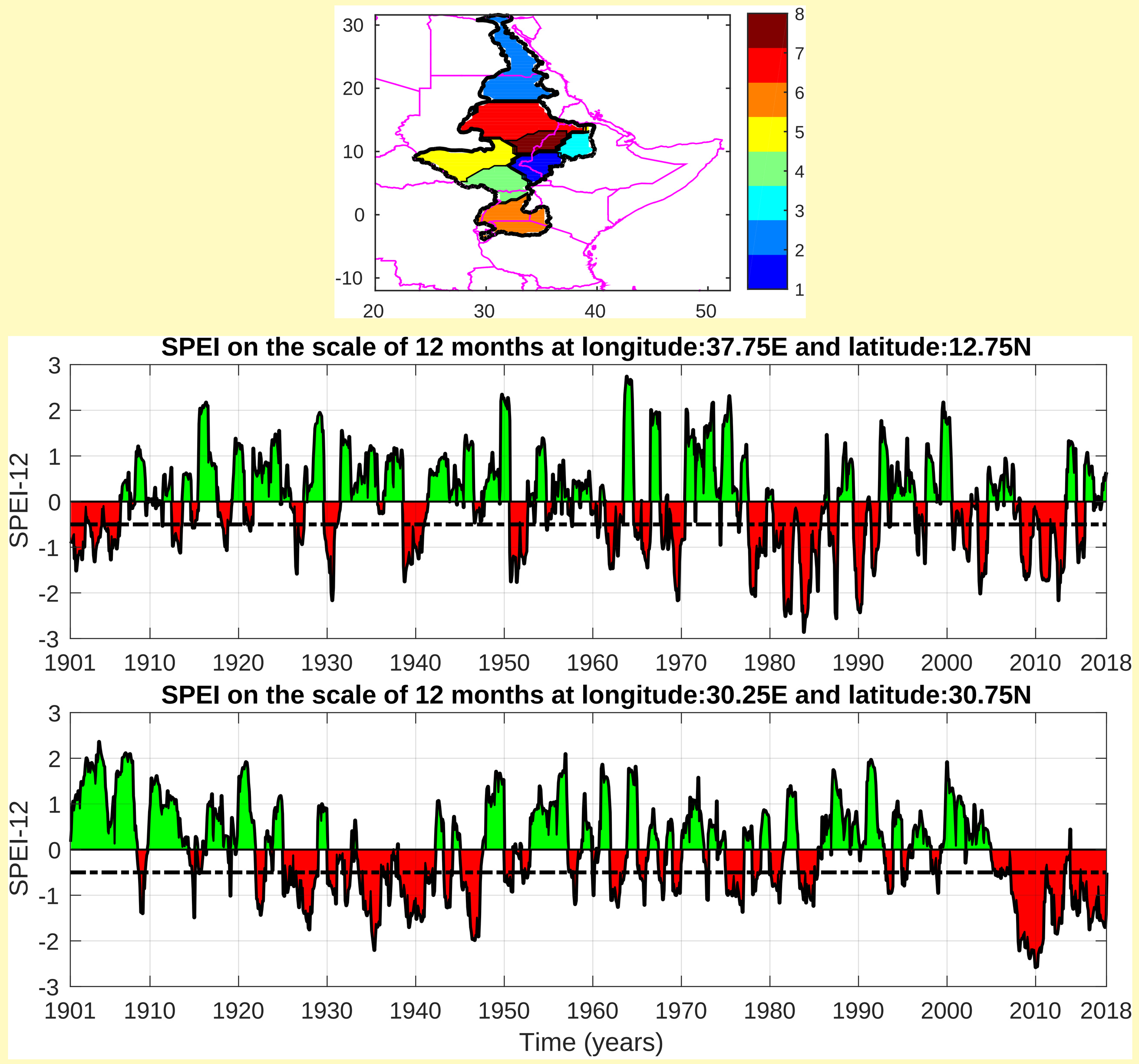

Fig.1. Homogeneous drought regimes (top), SPEI time series for drought regime 3 (middle) and 2 (bottom).

- Eight homogeneous drought regimes are identified over Nile Basin, which represent the different catchments of the Basin; and
- SPEI time series for ranomly selected grid in regime 3 and 2. Drought over regime 3 appears to be driven by ENSO whereas that of regime 2 has multi-decadal time scale (e.g. AMO, PDO). For example, much of Egypt has been dry during the recent two decades (bottom panel).

Drought characteristics: Climatology

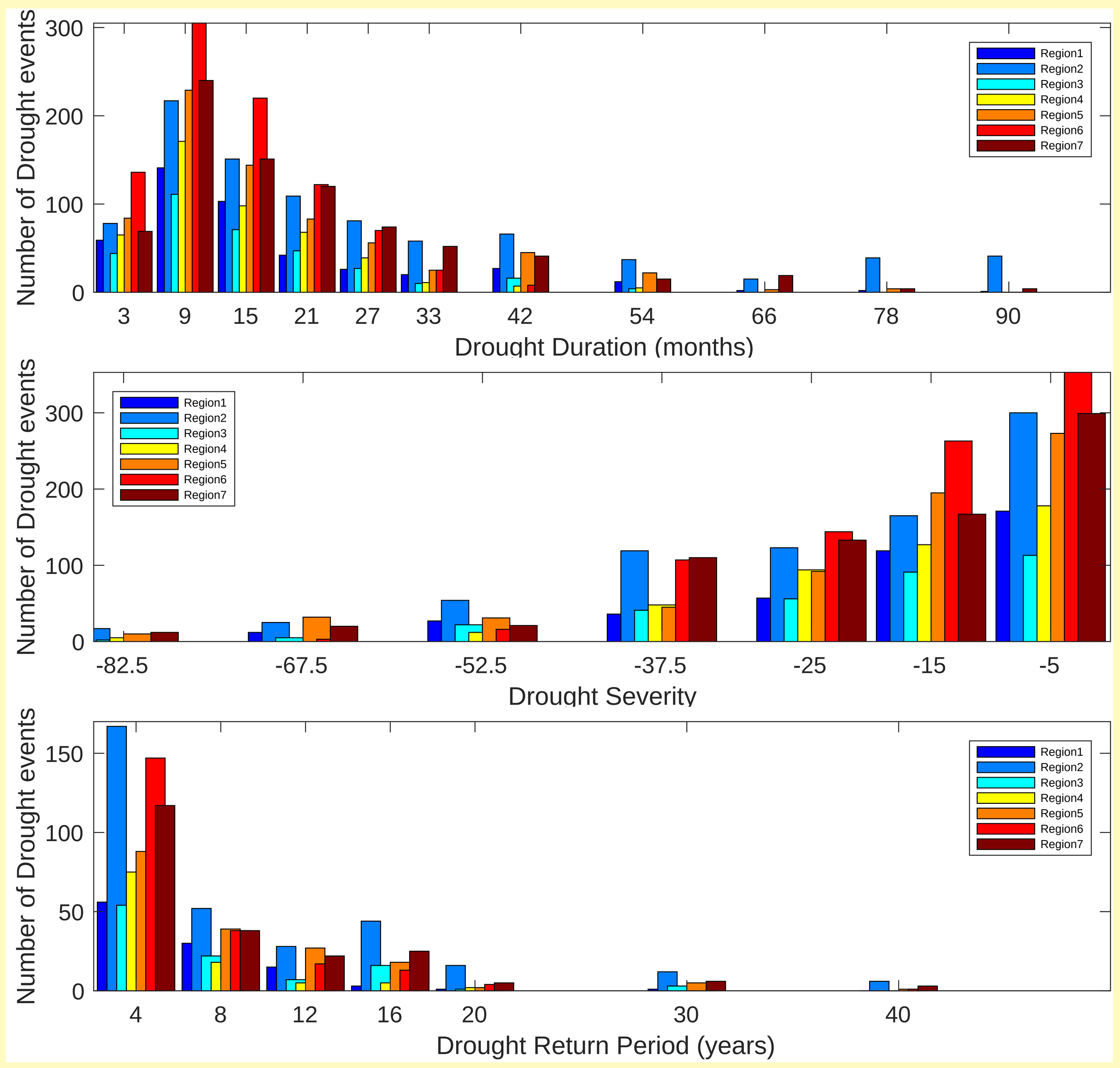

Fig.2. Climatology of drought duration (top), severity (middle) and return periods (bottom) for all drought regimes (clusters).

- Regimes representing lower catchment are charcterized by drought of longer duration, higher severity and relatively shorter return periods than those droughts occuring over the middle and upper catchments.

Bi-/tri-variate drought return periods

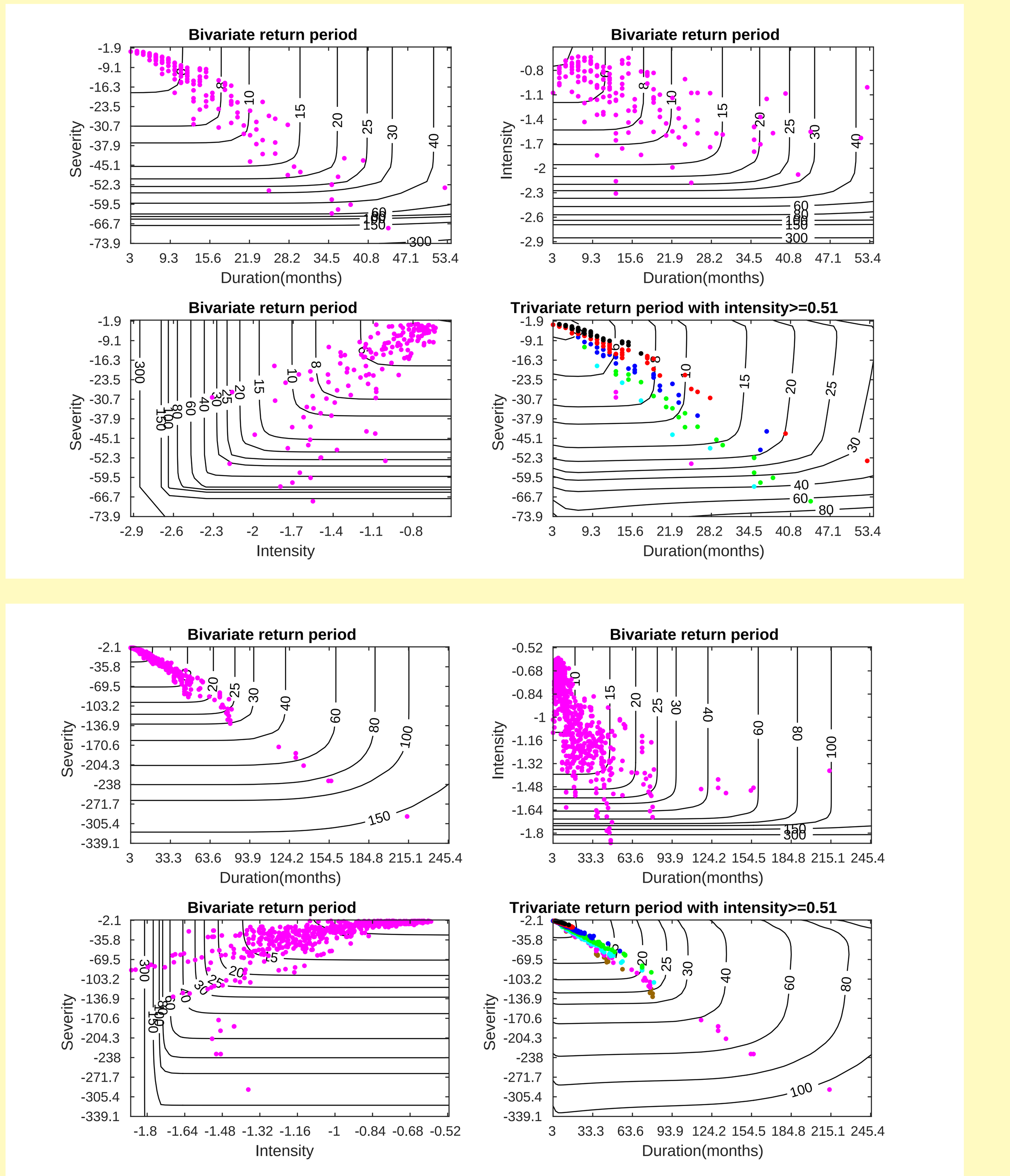

Fig.3. Probability map of bi-/tri-variate return periods for regime 3 (Ethiopia) (top: four panels) and regime 2 (most of Egypt) (bottom: four panels). The data points represents indiviadual drought events.

- Most of the historical drought events over both drought regimes are of short duration, low severity and short return periods under both bivariate and trivariate drought characterization;
- However, there is a large number of drought events with longer duration, higher severity and shorter return period (in years) over Egypt than over Ethiopian highlands.

Drought risk probability

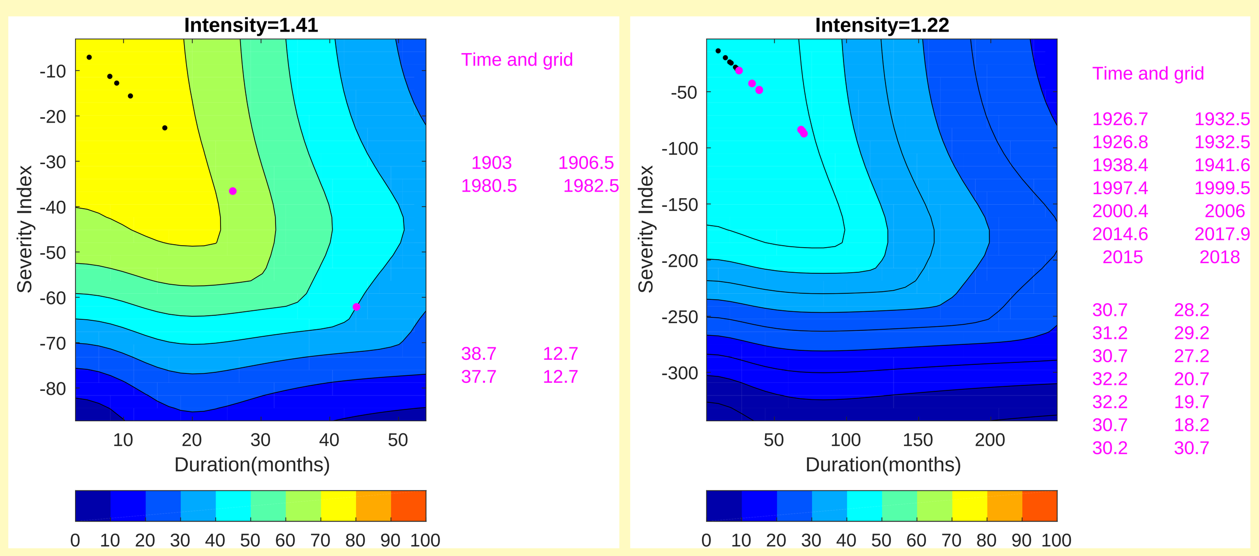

Fig.4. Drought risk map for hydrological system with a design lifetime of 10 years based on trivariate joint distrbution of drought duration, severity and intensity for regime 3 (left) and 2 (right). The dots represent historical drought events at locations and periods in the legend.

- The risk of occurrence (in %) of drought events with longer duration and high severity is high over lower catchment (e.g. most of Egypt);
- In contrast, drought of the same characteristics has low chance of occurrence over upper catchment (e.g. parts of Ethiopia).

Acknowledgement

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References

1. Vicent-Serrano, S. M., Journal of Climate, 23, 1696-1718, (2009). 2. Shiau, J. T., Water Resources Management 20, 795-815, (2006).