A Novel Multivariate Drought Index for Enhanced Drought Monitoring in the Greater Horn of Africa

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The Greater Horn of Africa has been subjected to severe droughts, posing significant threats to livelihood and food security. However, current drought monitoring methodologies in the region predominantly rely on univariate drought indices, which do not fully capture the complex hydrological processes for drought conditions. This study presents a novel multivariate drought index, the Great Horn of Africa Drought Index (GHDI), which integrates precipitation, evapotranspiration, soil moisture, and GRACE-derived terrestrial water storage through a copula-based probabilistic framework to effectively capture agricultural and hydrological droughts. The GHDI was developed using a zonal approach to accommodate regional climatic variations, with the Gaussian copula successfully modeling the joint probability of drought occurrence. The index was validated against the Standardized Precipitation Index (SPI) and FEWS NET IPC food insecurity classification. The GHDI demonstrated a stronger correlation with flood insecurity crisis ($r=-0.53$) compared to SPI and was able to identify prolonged drought period even after SPI indicated recovery. An examination of the temporal evolution of 2010/2011 and 2020-2023 droughts revealed that the GHDI accurately detected drought onset and peak periods and sustained hydrological deficits.

The GHDI exhibited a strong correlation with SPI at longer timescales ($r = 0.78$ at 12 months), when both indices reflect long-term drought effects. Sensitivity analysis indicated that incorporating terrestrial water storage and soil moisture enhances the detection of long-term drought persistence. Run theory analysis results demonstrated that the GHDI effectively identified prolonged, high-intensity drought, with severity exceeding -20 in Somalia, Kenya, and Ethiopia.

These findings suggest that by integrating diverse hydro-metrological variables using a copula, GDHI provides a more comprehensive and holistic approach to drought monitoring in the Greater Horn of Africa.

Keywords: Drought; copula; drought index; GRACE satellite; TWS; satellite gravimetry; multivariate analysis; joint probability