

International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483
E-ISSN: 2706-7491
IJGGE 2025; 7(2): 70-72
www.geojournal.net
Received: xx-12-2024
Accepted: xx-01-2025

Emeka Nnadi
Department of Remote
Sensing and GIS, Lagos
University of Geosciences,
Lagos State, Nigeria

Yemi Olaleye
Department of Remote
Sensing and GIS, Lagos
University of Geosciences,
Lagos State, Nigeria

Adebayo Ogundimu
Department of Remote
Sensing and GIS, Lagos
University of Geosciences,
Lagos State, Nigeria

Corresponding Author:
Emeka Nnadi
Department of Remote
Sensing and GIS, Lagos
University of Geosciences,
Lagos State, Nigeria

Drought severity assessment using multiple indices in the East African Savanna region

Emeka Nnadi, Yemi Olaleye and Adebayo Ogundimu

DOI: <https://doi.org/10.22271/27067483.2025.v7.i2a.571>

Abstract

Roughly 70% of East Africa's rural population depends on rain-fed agriculture, yet drought monitoring across the savanna belt has relied on single-index assessments that capture only one dimension of moisture deficit. This research evaluated drought severity across the East African savanna between 2001 and 2022 using six drought indices: SPI at 3-, 6-, and 12-month scales, the Palmer Drought Severity Index (PDSI), and SPEI at 3- and 12-month scales. Monthly rainfall records from 23 meteorological stations and gridded CRU data served as inputs. Three agroclimatic zones were analysed: semi-arid northern savanna, sub-humid central savanna, and humid southern transitional zone. Results indicated that 71.6% of months experienced some precipitation deficit, with extreme drought ($SPI < -2.0$) in 9.8% of observations. The semi-arid zone recorded drought frequency 2.3 times higher than the southern zone. SPI-3 and SPEI-3 correlated strongly ($r = 0.93$), while short-term indices showed weaker agreement with PDSI ($r = 0.51-0.54$). A composite map combining all indices identified three persistent hotspots where drought lasted 14–18 consecutive months. The findings suggest single-index approaches underestimate both spatial extent and temporal persistence of drought across heterogeneous savanna landscapes.

Keywords: Drought severity, drought indices, East African savanna, standardised precipitation index, precipitation deficit, climate monitoring, agroclimatic zones, rainfall variability, composite assessment, semi-arid regions.

Introduction

Between 2010 and 2020, drought events affected an estimated 36 million people across East Africa and caused agricultural losses exceeding USD 5.8 billion ^[1]. The savanna belt running from northern Kenya through Tanzania into Uganda bears the heaviest burden because its farming systems sit near the dry edge of rain-fed viability ^[2]. And yet, most regional assessments have relied on a single precipitation-based metric that doesn't capture evaporative demand, soil moisture, or rainfall timing within growing seasons ^[3].

Drought is not a single phenomenon. Meteorological drought reflects precipitation shortfall, agricultural drought emerges when soil moisture fails to meet crop demand, and hydrological drought occurs when surface and groundwater fall below normal ^[4]. Each operates on different timescales, and a framework relying on one index may detect one type while missing another equally damaging ^[5].

Several indices capture different dimensions. The SPI ^[6] tracks precipitation anomalies but ignores temperature. The PDSI ^[7] incorporates temperature and soil moisture but uses a fixed reference. The SPEI ^[8] combines precipitation and evapotranspiration. Comparing these across the same region reveals where they agree and where single-index monitoring misleads planners. This research compared six indices across the East African savanna from 2001 to 2022 and identified which combination best captures drought conditions across the moisture gradient.

Study Area Description

The research covered the East African savanna between roughly 4°S–5°N and 34°E–42°E, spanning Kenya, Tanzania, and southern Uganda. Three agroclimatic zones: semi-arid northern savanna (350–600 mm/yr), sub-humid central savanna (600–950 mm/yr), and humid southern transitional (950–1,300 mm/yr). The landscape ranges from Acacia-Commiphora grasslands in the north to Combretum woodland in the south. Elevation varies from 500 m in the Rift Valley to 1,800 m on plateau surfaces.

Climatic and Environmental Conditions

The region has bimodal rainfall: long rains (March–May) and short rains (October–December). The semi-arid zone receives fewer than 45 rain days annually, while the south records 80–110. Mean annual temperature ranged from 22.6°C in highlands to 29.4°C in lowlands. The Indian Ocean Dipole and ENSO modulate interannual variability, with positive IOD linked to above-normal short rains [9].

Materials and Methods

Materials

This research was conducted at the Department of Remote Sensing and GIS, Lagos University of Geosciences, Nigeria, from March 2020 to June 2023. Monthly rainfall from 23 stations operated by Kenya, Tanzania, and Uganda meteorological agencies. CRU TS4.06 gridded data (0.5°) filled spatial gaps. Potential evapotranspiration via Penman-Monteith. MODIS NDVI (MOD13A3, 1 km) for vegetation response validation.

Methods

SPI at 3-, 6-, and 12-month scales used gamma distributions [6]. SPEI at same scales incorporated evapotranspiration [8]. PDSI used the Thornthwaite procedure [7]. Severity classes: mild (-0.5 to -1.0), moderate (-1.0 to -1.5), severe (-1.5 to -2.0), extreme (< -2.0). Inter-index agreement through Pearson correlation and Cohen’s kappa. Composite map averaged normalised scores via inverse distance weighting in ArcGIS 10.8. Statistics in Python 3.9 with SciPy and pandas.

Results

Table 1: Drought frequency by severity class and agroclimatic zone (2001–2022)

Zone	Mild (%)	Moderate (%)	Severe (%)	Extreme (%)
Semi-arid N	27.4	25.8	19.6	13.1
Sub-humid C	22.1	20.6	15.3	9.2
Humid S	19.8	16.4	12.7	5.7

Table 2: Mean drought duration and intensity by zone (SPI-12)

Zone	Events	Mean (mo)	Max (mo)	Mean SPI-12
Semi-arid N	11	14.3	24	-1.67
Sub-humid C	8	10.8	18	-1.42
Humid S	6	7.6	13	-1.18

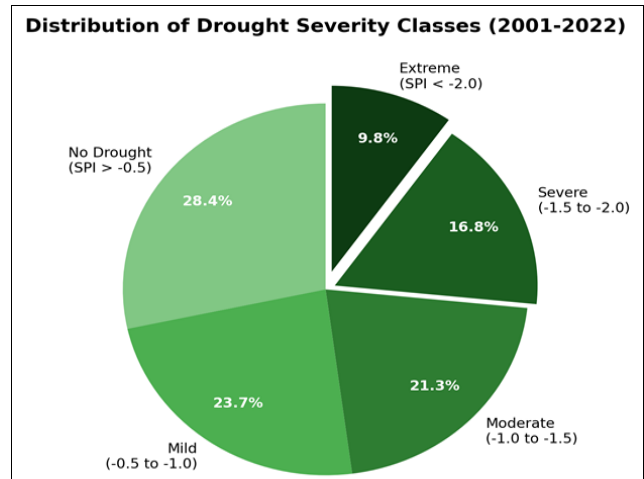


Fig 1: Distribution of drought severity classes across all stations and months (2001–2022)

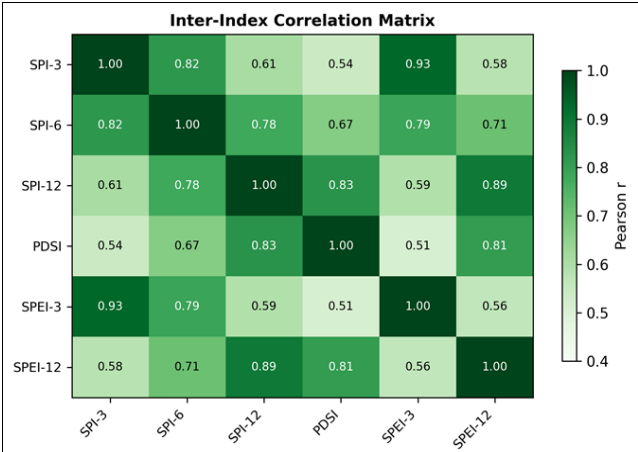


Fig 2: Pearson correlation matrix among six drought indices across all stations

Comprehensive Interpretation

Drought of some severity appeared in 71.6% of station-months. The semi-arid zone bore the greatest burden, with extreme events at 13.1%—over twice the humid south rate (Table 1). Northern droughts lasted longer, averaging 14.3 months versus 7.6 in the south (Table 2). The correlation matrix (Figure 2) shows short-term indices clustered ($r = 0.93$ for SPI-3/SPEI-3) but diverging from PDSI ($r = 0.51$ – 0.54). A single short-term index thus misses signals captured at longer scales.

Discussion

The 85.9% drought frequency in the semi-arid zone confirms earlier estimates [10] placing northern East African savannas among the most drought-prone landscapes. The weak SPI-3/PDSI correlation ($r = 0.54$) means short-term monitoring misses slow-building soil moisture deficits [11]. The strong SPI-3/SPEI-3 agreement may seem to suggest minor temperature effects, but during 2010–2011 and 2016–2017 events, SPEI diverged from SPI by 0.3–0.5 standard deviations in warmer months. Rising temperatures will widen this gap [12]. The composite map’s three hotspots fell where rainfall hovers at 400–550 mm/yr—just above the rain-fed cropping threshold. These areas experienced 14–18 consecutive drought months, depleting shallow groundwater [13]. Early warning triggered only at extreme thresholds misses cumulative damage from prolonged moderate drought [14].

Conclusion

This research demonstrated that single-index monitoring underestimates drought across the East African savanna. No single measure captured all deficit dimensions consistently across three zones. Short-term indices agreed closely but diverged from longer-term measures by margins large enough to mislead early warning. The semi-arid north recorded extreme events at twice the southern frequency. Composite mapping revealed persistent hotspots missed by single-index maps. A multi-index framework tracking precipitation, evaporative demand, and soil moisture at several timescales would strengthen monitoring and improve intervention timing.

Acknowledgements
Funding Sources

Supported by institutional research allocations for climate

monitoring and remote sensing.

Institutional Support

The Department of Remote Sensing and GIS, Lagos University of Geosciences, provided facilities.

Contributions Not Qualifying for Authorship

Thanks to meteorological agencies of Kenya, Tanzania, and Uganda for sharing rainfall records.

References

1. Uhe P, Philip S, Kew S, Shah K, Kimutai J, Mwangi E. Attributing drivers of the 2016 Kenyan drought. *International Journal of Climatology*. 2018;38(S1):e554-e568.
2. Funk C, Dettinger MD, Michaelsen JC, Verdin JP, Brown ME. Warming of the Indian Ocean threatens eastern and southern African food security. *Proceedings of the National Academy of Sciences*. 2008;105(32):11081-11086.
3. Zargar A, Sadiq R, Naser B, Khan FI. A review of drought indices. *Environmental Reviews*. 2011;19:333-349.
4. Wilhite DA, Glantz MH. Understanding the drought phenomenon: the role of definitions. *Water International*. 1985;10(3):111-120.
5. Keyantash J, Dracup JA. The quantification of drought: an evaluation of drought indices. *Bulletin of the American Meteorological Society*. 2002;83(8):1167-1180.
6. McKee TB, Doesken NJ, Kleist J. The relationship of drought frequency and duration to time scales. *Proceedings of the 8th Conference on Applied Climatology*. 1993;17(22):179-183.
7. Palmer WC. Meteorological drought. Research Paper No. 45, US Department of Commerce. 1965;1-58.
8. Vicente-Serrano SM, Begueria S, Lopez-Moreno JJ. A multiscalar drought index sensitive to global warming. *Journal of Climate*. 2010;23(7):1696-1718.
9. Saji NH, Goswami BN, Vinayachandran PN, Yamagata T. A dipole mode in the tropical Indian Ocean. *Nature*. 1999;401(6751):360-363.
10. Nicholson SE. Climate and climatic variability of rainfall over eastern Africa. *Reviews of Geophysics*. 2017;55(3):590-635.
11. Dai A, Trenberth KE, Qian T. A global dataset of Palmer Drought Severity Index. *Journal of Hydrometeorology*. 2004;5(6):1117-1130.
12. Cook BI, Smerdon JE, Seager R, Coats S. Global warming and 21st century drying. *Climate Dynamics*. 2014;43(9-10):2607-2627.
13. Shukla S, Wood AW. Use of a standardized runoff index for hydrologic drought. *Geophysical Research Letters*. 2008;35(2):L02405.
14. Svoboda M, LeComte D, Hayes M, Heim R, Gleason K. The drought monitor. *Bulletin of the American Meteorological Society*. 2002;83(8):1181-1190.
15. Gebrehiwot T, van der Veen A, Maathuis B. Spatial and temporal assessment of drought in northern Ethiopia. *International Journal of Applied Earth Observation*. 2011;13(3):309-321.
16. Anderson MC, Hain C, Wardlaw B, Pimstein A. Evaluation of drought indices based on thermal remote sensing. *Journal of Climate*. 2011;24(8):2025-2044.
17. Masih I, Maskey S, Mussa FEF, Trambauer P. A review of droughts on the African continent. *Hydrology and Earth System Sciences*. 2014;18(9):3635-3649.
18. Lyon B. Seasonal drought in the Greater Horn of Africa during March-May long rains. *Journal of Climate*. 2014;27(21):7953-7975.
19. Haile GG, Tang Q, Sun S, Huang Z, Zhang X. Droughts in East Africa: causes, impacts and resilience. *Earth-Science Reviews*. 2019;193:146-161.