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Validation of CHIRPS- and ERA5-Derived SPI and SPEI for Drought Monitoring and Characterization Using Ground-Based Meteorological Station Data in Arid Landscape

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Abstract
Drought poses a significant environmental challenge in the arid and semi-arid regions of South Africa, primarily due to low and erratic rainfall coupled with rising temperatures. Effective monitoring of drought conditions requires continuous spatial and temporal data; however, this is often compromised by uneven distribution and malfunctioning ground stations, leading to inconsistent datasets. Remote sensing offers a promising alternative, providing extensive spatial coverage and near-real-time data, although its use in South African dry regions remains underexplored.
The current study evaluates the performance of remotely sensed drought indices derived from Google Earth Engine (GEE) by validating them against ground-station data. Additionally, the study examined the spatio-temporal variations of drought using the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) at 3-, 6-, and 12-month timescales. The results indicate that the SPI derived from CHIRPS data shows moderate to strong agreement with ground observations, particularly at longer timescales, achieving R^2 values of up to 0.88 and demonstrating reduced Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) values. However, some spatial inconsistencies remain at certain stations. In contrast, the SPEI demonstrates consistently strong agreement across all stations and timescales, with R^2 values ranging from 0.95 to 0.99 at shorter and medium timescales, indicating high reliability.
Spatial analysis reveals that drought severity increases with longer accumulation periods. The SPI indicates widespread dry conditions across central, northern, and eastern regions, while the southwestern areas remain relatively wetter. The SPEI highlights a persistent west-east gradient, showing wetter conditions in the west and more severe drought in the central and eastern regions. Temporal analysis identifies a prolonged drought from 2015 to 2020, followed by wetter conditions beginning in 2021 onwards. Overall, GEE-derived indices, particularly the SPEI, are effective tools for monitoring drought in data-scarce environments.

Keywords: Drought, Standard Precipitation Index, Standard Precipitation Evapotranspiration Index, Google Earth Engine.

Introduction
Drought is a recurrent climatic hazard that threatens water resources, ecosystems, and socio-economic activities, particularly in arid and semi-arid regions (Muralikrishnan et al., 2021). The Northern Cape Province of South Africa is highly susceptible to drought due to its low and variable rainfall, high evapotranspiration rates, and increasing temperatures associated with

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climate change (Bahta and Myeki, 2022). These conditions have intensified the frequency and severity of drought events, highlighting the need for reliable drought monitoring systems to support sustainable water resource management and agricultural planning.

Conventional drought monitoring relies on in-situ meteorological observations, such as rainfall and temperature records, which provide accurate point-based measurements but are often limited in spatial coverage, particularly in remote regions. Consequently, remotely sensed drought indices have become valuable alternatives for monitoring drought over large areas (Alahacoon and Edirisinghe, 2022). The SPI is widely used to assess meteorological drought based on precipitation alone, whereas the SPEI incorporates both precipitation and potential evapotranspiration, making it more responsive to the effects of rising temperatures and climate change.

The availability of cloud-based platforms such as Google Earth Engine has enabled the efficient generation of SPI and SPEI from long-term climate datasets, including CHIRPS precipitation and ERA5 temperature products. Although these datasets provide extensive spatial and temporal coverage, their reliability must be evaluated against ground-based observations before they can be confidently applied for operational drought monitoring. Therefore, this study aims to validate Google Earth Engine-derived SPI and SPEI using in situ meteorological data from the Northern Cape, compare their performance across multiple temporal scales, and assess their suitability for drought monitoring in arid and semi-arid environments. The findings are expected to strengthen drought assessment frameworks and support evidence-based water resource management and climate adaptation strategies.

Methodology

The study integrated remotely sensed and ground-based meteorological data to assess and validate drought conditions in the Northern Cape, South Africa, from 2013 to 2023. Monthly precipitation data from CHIRPS and potential evapotranspiration (PET) data from ERA5-Land were processed in Google Earth Engine (GEE) to compute the SPI and SPEI at 3-, 6-, and 12-month timescales. Ground-based rainfall and temperature observations were sourced from South African Department of Water and Sanitation weather stations located in Brandvlei, Calvinia, De Aar, Kathu, Kimberley, and Pofadder. These observations were quality-controlled, aggregated to monthly values, and used to derive corresponding SPI and SPEI for validation. Satellite-derived drought indices were extracted at weather station locations and compared with ground-based indices using the correlation coefficient (r), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE). Finally, spatial drought maps, temporal trend analyses, and drought severity classifications were produced to evaluate the spatial and temporal dynamics of drought across the province.

Results and Discussion

Remote Sensing vs ground station data validation

The validation results indicated that the CHIRPS-derived SPI and SPEI effectively captured drought conditions in the Northern Cape, although their performance varied by timescale and station. The SPI demonstrated moderate to strong agreement with in-situ observations, with improvements observed from SPI-3 to SPI-12. Brandvlei exhibited the strongest agreement, while Calvinia performed poorly at shorter timescales but showed improvement at SPI-12. In contrast, SPEI outperformed SPI across all stations and timescales, displaying high correlations (R^2 = 0.95–0.99) and minimal errors, particularly at SPEI-3 and SPEI-6. Overall, while the SPI provides reliable drought estimates over longer periods, the SPEI proves to be more robust and accurate for monitoring drought variability in the region.

Spatial distribution of drought events

The spatial distribution of drought conditions, as indicated by the SPI for 3, 6, and 12 months, shows significant variability across the study area (Figure 1). At the SPI-3 timescale, the western and southwestern regions are mostly moderately dry to very dry, while the central and eastern

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areas are near-normal to moderately wet. By SPI-6, drier conditions spread, impacting the central, northern, and eastern regions, although the southwestern areas remain moderately wet. At the SPI-12 timescale, long-term drought is evident in the central, northern, and eastern regions, which are very dry to extremely dry, while the southwestern region stays wetter. Overall, there is a trend of increasing drought severity with longer timescales.

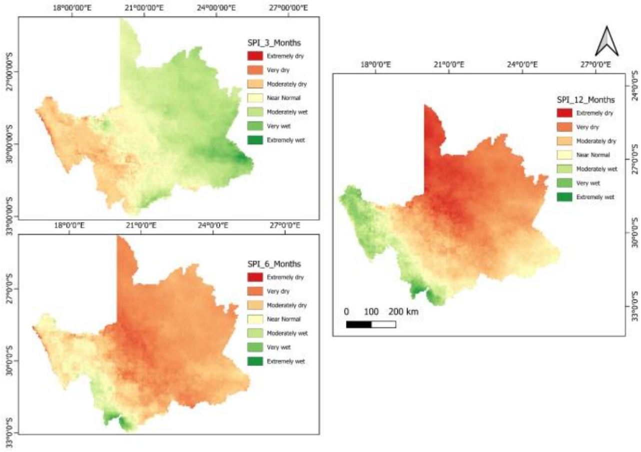

Figure 1: Spatial distribution of the SPI at 3, 6, and 12-month timescales across the Northern Cape province.

The SPEI-3 (3-month) timescale reveals a stark spatial contrast: the western and southwestern regions experience moderately wet to extremely wet conditions (Figure 2). In contrast, the central to northeastern areas experience near-normal to extremely dry conditions, with conditions particularly intense in the northeast (Figure 2). At the SPEI-6 (6-month) timescale, the western and southern areas remain very wet, indicating sustained moisture, while drought conditions expand in the central and northeastern regions. For the SPEI-12 timescale, a more balanced distribution emerges, with the northeastern and central regions showing moderately dry to very dry conditions, and the western and southwestern areas retaining moderately wet to extremely wet conditions, albeit slightly less pronounced than at shorter timescales. Overall, this reflects a consistent west–east gradient, with wetter conditions in the west and drier conditions in the east across all timescales, highlighting the influence of evapotranspiration and persistent drought in the eastern regions.

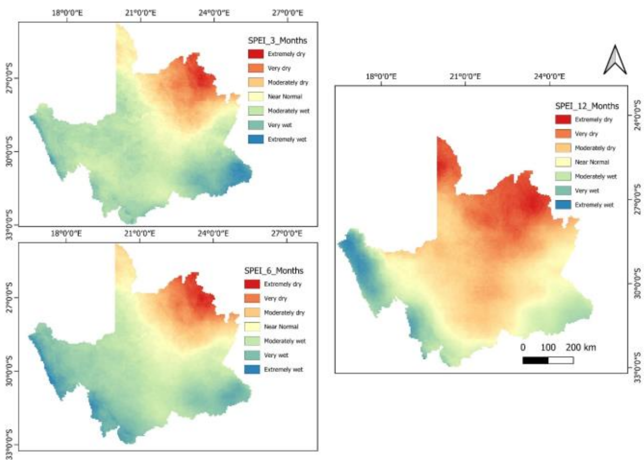

Figure 2: Spatial distribution of the SPEI at 3, 6, and 12-month timescales across the Northern Cape province.

Drought temporal variation and severity

The variability of drought conditions, assessed with the SPI and SPEI at 3-, 6-, and 12-month timescales, reveals alternating wet and dry periods (Figure 3). From 2015 to 2020, SPI-3 indicates short-term moderate droughts, while SPEI-3 shows more frequent and intense droughts. Post-2021, both indices exhibit increased wet conditions, with SPI-3 reflecting stronger positive

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peaks. At the 6-month timescale, SPI-6 indicates prolonged moderate drought, transitioning to wetter conditions post-2021, whereas SPEI-6 suggests more intensity. For the 12-month timescale, SPI-12 shows a sustained moderate drought from 2015 to 2020, followed by significant wet conditions through 2023, and SPEI-12 indicates greater drought severity, particularly in 2019-2020. Overall, both indices highlight a prolonged drought from 2015 to 2020, transitioning to wetter conditions after 2021, with SPEI reflecting higher drought severity and persistence, emphasizing the need for both indices in understanding drought dynamics.

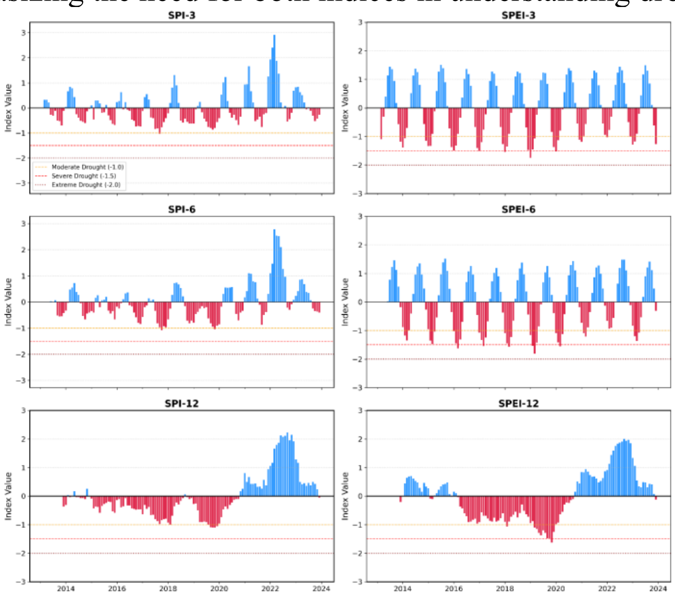

Figure 3: Temporal variations of SPI and SPEI at 3-, 6- and 12-month timescales, highlighting drought persistence and severity.

Conclusions and Outlook

This study showed that drought indices from CHIRPS and ERA-5 datasets effectively captured drought variability and aligned well with ground observations. While both SPI and SPEI were useful, SPEI consistently outperformed SPI, particularly in semi-arid areas, due to its incorporation of evapotranspiration. The analysis revealed increased drought severity and persistence from 2015 to 2020, with SPEI highlighting stronger drought signals influenced by rising temperatures. Central and eastern regions were more vulnerable to prolonged drought than the west. The findings support the use of remote sensing for drought monitoring and suggest prioritizing evapotranspiration-sensitive indices such as SPEI. Future research should incorporate more drought indicators and climate data to enhance assessment and forecasting.

References

Alahacoon, N. and Edirisinghe, M., 2022. A comprehensive assessment of remote sensing and traditional based drought monitoring indices at global and regional scale. *Geomatics, Natural Hazards and Risk*, *13*(1), pp.762-799.

Bahta, Y.T. and Myeki, V.A., 2022. The impact of agricultural drought on smallholder livestock farmers: Empirical evidence insights from Northern Cape, South Africa. *Agriculture*, *12*(4), p.442.

Muralikrishnan, L., Padaria, R.N., Choudhary, A.K., Dass, A., Shokralla, S., El-Abedin, T.K.Z., Abdelmohsen, S.A., Mahmoud, E.A. and Elansary, H.O., 2021. Climate change-induced drought impacts, adaptation and mitigation measures in semi-arid pastoral and agricultural watersheds. *Sustainability*, *14*(1), p.6.

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