EVALUATING THE SPATIOTEMPORAL DYNAMICS OF AGROMETEOROLOGICAL DROUGHTS IN SEMI-ARID GWAYI AGROECOSYSTEMS (1990-2020) USING MULTIPLE INDICES.

Bright Chisadza
Dr Simon Peter Musinguzi
Dr Onalenna Gwate

Abstract

This study evaluates the spatiotemporal dynamics of agrometeorological droughts in the Gwayi catchment, focusing on the period from 1990 to 2020. Climate variability (CV) and land use change (LUC) exacerbate drought impacts, posing significant threats to smallholder farmers in semi-arid regions. The research assesses the frequency, severity, extent, and magnitude of drought events, comparing the performance of drought indices such as the Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Vegetation Condition Index (VCI), and Vegetation Health Index (VHI). Additionally, it identifies areas of heightened drought vulnerability and examines the implications for water availability and agricultural productivity. The findings aim to inform resilience strategies for smallholder farmers affected by the increasing unpredictability of climate patterns in the catchment.

Methodology

Meteorological data Collection
Meteorological data for this study was sourced from six stations: Victoria Falls, Tsholotsho, Nkayi, Lupane, Hwange, and Binga, focusing on daily rainfall and temperature records from 1990 to 2020. To ensure data integrity, inconsistencies were detected and corrected during preprocessing. Autocorrelation in the data was assessed using the Durbin-Watson test, specifically for rainfall and temperature parameters. If significant autocorrelation was identified, the ARIMA model, guided by the Partial Autocorrelation Function (PACF), was applied to correct for it. This step was crucial for removing autocorrelation and ensuring the reliability of subsequent statistical analyses.

Earth Observation data (1990-2020- November to March)

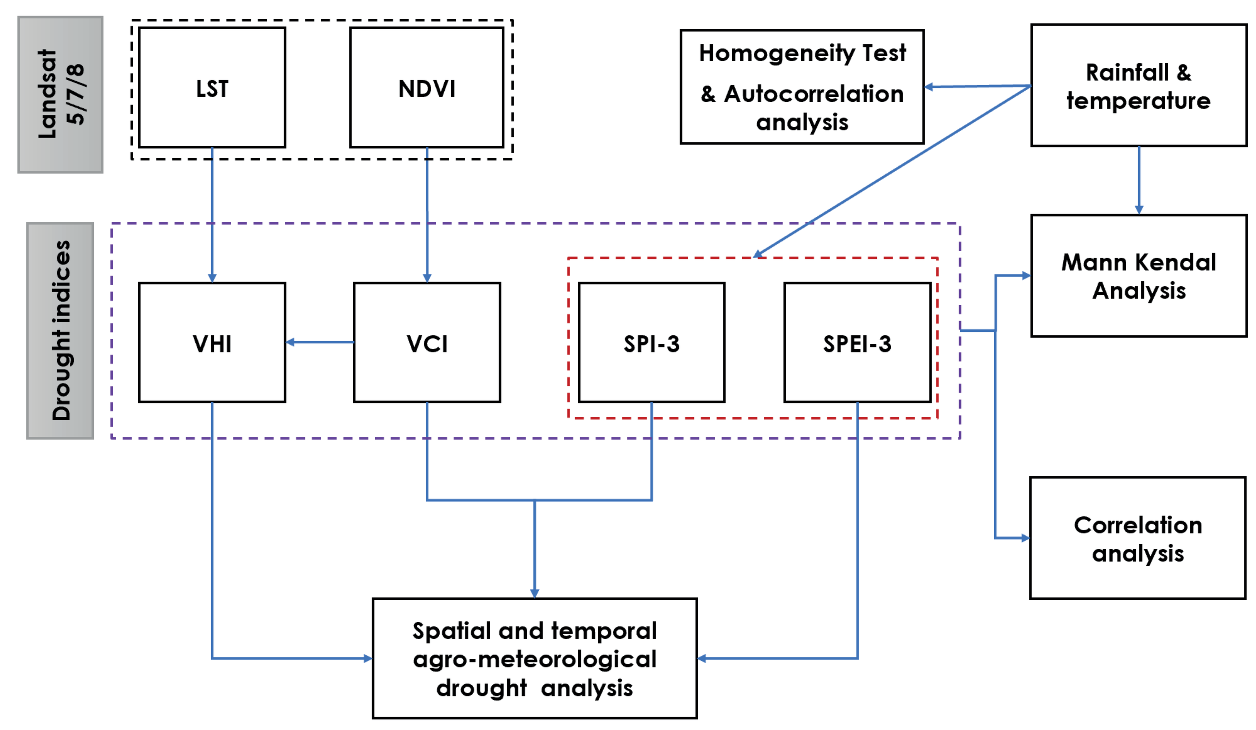
#	Variable	Source	Resolution	Derived variable	Reference
1	NDVI	Landsat 5, Landsat 7, and Landsat 8 Top-of-Atmosphere (TOA)	30 m	VCI/VHI	(Liou, Nguyen and Li, 2020)
3	SPI	TerraClimate	4 km	Spatial SPI-3	
4	SPEI	TerraClimate	4 km	Spatial SPEI-3	
5	LST	Landsat 5/7/8 TOA	30 m	TCI	(Zeng et al., 2022)

Preprocessing to correct atmospheric, radiometric corrections

Drought Indices Calculation
Satellite data from Landsat 5, 7, and 8 was used to compute key drought indices for the November to March growing season. NDVI and LST were derived to calculate the Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI), which combines VCI and TCI. Meteorological drought was assessed using the 3-month Standardized Precipitation Index (SPI-3) and Standardized Precipitation Evapotranspiration Index (SPEI-3). These indices together provided insights into vegetation health and short-term drought dynamics.

Trend, Correlation, and Spatial Analysis
To detect trends in temperature, rainfall, and drought indices (VCI, VHI, SPI-3, SPEI-3), the Mann-Kendall test was applied to identify monotonic trends, while the Pettitt test was used to detect abrupt shifts in rainfall and temperature patterns. Temporal and correlation analysis involved spatial statistics and Pearson Correlation Matrices, conducted using XLSTAT (1990–2020), to explore relationships between VCI, VHI, SPI, and SPEI. For spatial analysis, ArcGIS 10.8 was used to map VCI, VHI, SPI-3, and SPEI-3 across the Gwayi catchment for selected drought years (1990-1991, 1994-1995, 2000-2001, 2004-2005, 2009-2010, 2014-2015), highlighting spatial patterns and identifying areas most affected by drought.

Research design



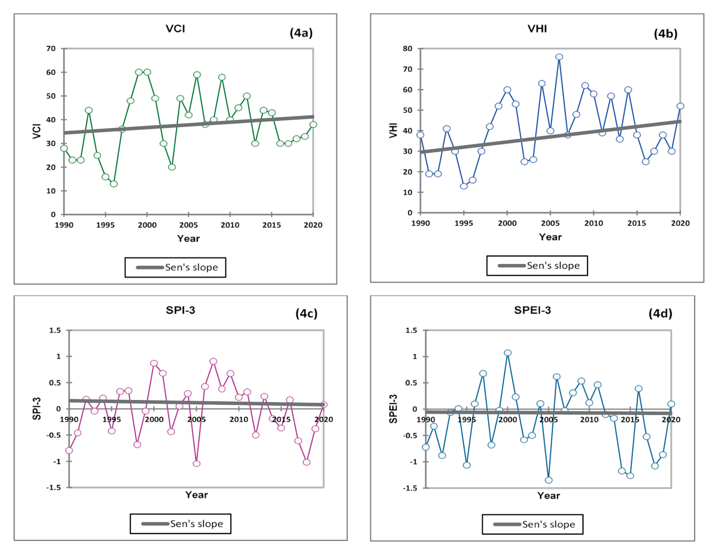
Results

Rainfall and Temperature Statistics

Rainfall	Durbin–Watson test		Mann–Kendall test		
Station	DW	rho	Kendall's tau	p value	Sen's slope
Vic Falls	0.620	0.507	0.310	**0.016**	7.250
Tsholotsho	0.565	0.519	0.037	0.786	0.650
Nkayi	0.567	0.530	0.089	0.496	2.339
Lupane	0.569	0.521	-0.028	0.838	-0.703
Hwange	0.593	0.522	0.155	0.227	3.517
Binga	0.567	0.560	0.154	0.234	3.246

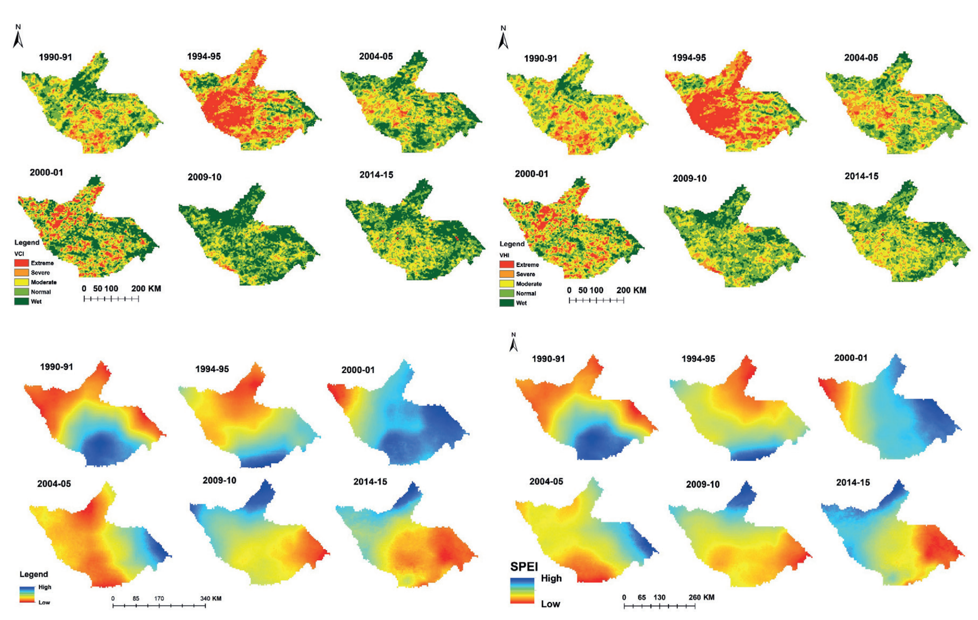
Autocorrelation & ARIMA Models
Positive autocorrelation detected at all six stations; ARIMA models successfully addressed this issue
Trend Analysis
Significant increasing trend in rainfall at Victoria Falls (Sen's slope = 7.25 mm/year); no significant trends at other stations (p > 0.05).
No significant trends in temperature
Correlation Analysis
Strong positive correlations between all stations; Lupane and Tsholotsho had very strong correlations.

Temporal Dynamics of Agrometeorological Drought



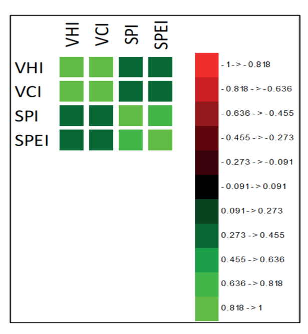
Key Findings
Spatial Patterns: North-south gradient in vegetation health and drought severity; northeastern areas generally healthier.
Drought Extent: Severe 1994-1995 drought affected 28% of the catchment (VCI);2009-10 saw significant improvement.
Index Comparisons: Different spatial patterns for vegetation (VCI, VHI) vs. meteorological indices (SPI, SPEI).

VARIABLES VCI; VHI; SPI; SPEI



Variables	VHI	VCI	SPI	SPEI
VHI	**1**	**0.877**	0.304	**0.392**
VCI	**0.877**	**1**	0.281	**0.405**
SPI	0.304	0.281	**1**	**0.783**
SPEI	**0.392**	**0.405**	**0.783**	**1**

Values in bold are different from 0 with a significance level alpha=0.05



Drought Classification
Mixed conditions; VCI and SPI show highest occurrences of mild drought.
Severe droughts consistently observed in 1995 and 2005.
Index Discrepancies
VCI/VHI and SPI/SPEI show varied sensitivities; VCI indicated extreme drought in 1994-95, while SPI and SPEI showed
significant drought in 2004-2005.
Trend Analysis
No significant trends for average indices; significant negative trend in SPEI and SPI at Tsholotsho.

Correlation & overall drought analysis

Index	Drought Level	Number of Years
VHI	Mild Drought	12
	Moderate Drought	4
	Severe Drought	2
	Extreme Drought	2
VCI	Mild Drought	14
	Moderate Drought	4
	Severe Drought	2
	Extreme Drought	0
SPI-3	Mild Drought	8
	Moderate Drought	7
	Severe Drought	4
	Extreme Drought	3
SPEI-3	Mild Drought	10
	Moderate Drought	4
	Severe Drought	5
	Extreme Drought	3

Discussion

Spatiotemporal dynamics of agrometeorological droughts
Interannual Variability: Analysis of agrometeorological droughts from 1990-2020 in the Gwayi catchment reveals significant interannual variability without long-term trends (Franchi et al., 2024).
Threats to Agriculture: Moderate and severe droughts pose substantial risks to agricultural productivity and food security, especially in high-risk areas (Ntali et al., 2023; Tanarhte et al., 2024).
Vulnerability in Specific Regions: Spatial distribution analysis identifies the southwest regions of the Gwayi catchment as most vulnerable to drought, with significant negative trends in Tsholotsho (Omotoso et al., 2023; Uwizewe et al., 2024).
Need for Area-Specific Assessments: Localized trends in Tsholotsho and southwest regions underscore the importance of area-specific assessments, considering variations influenced by seasonality and land use (Omotoso et al., 2023; Uwizewe et al., 2024).
Complementary Drought Indices: Utilizing different drought indices provides complementary insights, emphasizing the necessity of a multifaceted analysis to capture the complexity of drought patterns (Franchi et al., 2024).

Adaptation strategies
Farmers in the Gwayi catchment exhibit proactive adaptation through high adoption rates of soil and water conservation practices, the use of drought-resistant crops like sorghum and millet, and early sowing. These strategies enhance resilience, aligning with trends observed in other African contexts. However, adoption varies significantly across districts, with Binga showing higher rates due to its increased vulnerability to drought and food insecurity. Factors influencing strategy adoption include livestock ownership, participation in community programs, and prior drought experiences. Younger farmers, in particular, are more likely to adopt innovative strategies such as drought-resistant crops. Barriers to broader implementation include resource and financial constraints, underscoring the need for targeted training, technical support, and community collaboration.

Conclusion

Integrated Land Management Imperative
urgent need for integrated land management practices to address land degradation and achieve Land Degradation Neutrality (LDN) in Matabeleland North Province. Targeted restoration strategies, particularly in degradation hotspots, are critical to sustaining agroecosystems amidst ongoing land-use changes.
Adaptive Drought Management
importance of employing a multi-index approach in drought monitoring to fully capture the complex nature of agrometeorological droughts. Implementing robust, region-specific drought management strategies in vulnerable areas of the Gwayi catchment is essential to mitigate long-term impacts on agriculture.
Empowering Smallholder Farmers
Smallholder farmers face increased vulnerability due to climate and land-use changes. A multifaceted approach, including better access to resources, is crucial for resilience and food security.
Localized and Equitable Adaptation Strategies
varying effectiveness of adaptation strategies across different regions, highlighting the need for localized approaches. Enhancing resource distribution and support structures tailored to regional needs will empower smallholder farmers to better adapt to environmental challenges.

Recommendations

Theory
Invest in long-term research to assess and refine adaptation strategies based on effectiveness and emerging challenges.
Practice
Promote Effective & Tailored Adaptation Strategies
Enhance extension services and combine traditional knowledge with modern practices.
Policy
Strengthen Localized LDN Support & Drought Monitoring

Adeboa, J. and Anang, B.T. (2024) 'Perceptions and adaptation strategies of smallholder farmers to climate change in Builsa South district of Ghana', Cogent Social Sciences, 10(1). Available at: https://doi.org/10.1080/23311886.2024.2358151.
Amadou, M.L., Villamor, G.B. and Kyei-Baffour, N. (2018) 'Simulating agricultural land-use adaptation decisions to climate change: An empirical agent-based modelling in northern Ghana', Agricultural Systems, 166, pp. 196–209. Available at: https://doi.org/10.1016/j.agsy.2017.10.015.
Ayupp Dino, F., Gadiman, N.S., bin Md Isa, A.H., Entalai, M. and Wan Ahmed, W.M.H. (2023) 'Factors Influencing Small-Holder Food Crops Farmers' Adoption Intention Behaviour on Modern Agricultural Technology among the Non-Adopter in Sarawak's Rural Areas', International Journal of Academic Research in Business and Social Sciences, 13(12), pp. 2360–2381. Available at: https://doi.org/10.6007/i-jarbss/v13-i12/19455.
Belay, A., Recha, J.W., Woldeamanuel, T. and Morton, J.F. (2017) 'Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia', Agriculture & Food Security, 6(1), p. 24. Available at: https://doi.org/10.1186/s40066-017-0100-1.
Darge, A., Haji, J., Beyene, F. and Ketema, M. (2023) 'Smallholder Farmers' Climate Change Adaptation Strategies in the Ethiopian Rift Valley: The Case of Home Garden Agroforestry Systems in the Gedeo Zone', Sustainability, 15(11), p. 8997. Available at: https://doi.org/10.3390/su15118997.
Descheemaeker, K., Oosting, S.J., Homann-Kee Tui, S., Masikati, P., Falconnier, G.N. and Giller, K.E. (2016) 'Climate change adaptation and mitigation in smallholder crop–livestock systems in sub-Saharan Africa: a call for integrated impact assessments', Regional Environmental Change, 16(8), pp. 2331–2343. Available at: https://doi.org/10.1007/s10113-016-0957-8.
Dhliwayo, I., Mutanga, C.N., Mashapa, C., Muboko, N. and Gandiwa, E. (2022) 'Climate Variability Impacts and Coping Strategies in Malipati Communal Area, Chiredzi District, Southeast Zimbabwe', International Journal of Ecology. Edited by C. Li, 2022, pp. 1–8. Available at: https://doi.org/10.1155/2022/8493977.