UMYU Scientifica, Vol. 5 NO. 1, March 2026, Pp 039 – 052
https://doi.org/10.56919/usci.2651.004
ISSN: 2955 – 1145 (print); 2955 – 1153 (online)
A periodical of the Faculty of Natural and Applied Sciences, UMYU, Katsina

ORIGINAL RESEARCH ARTICLE

Trend and Variability Analysis of Rainfall and Temperature in the Dagona Wetland, Nigeria (1993-2023)

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ABSTRACT
The Dagona Wetland, a Ramsar site and biodiversity refuge in Nigeria's vulnerable Sudano-Sahelian region, faces escalating threats from climate change, yet long-term climatic trends have remained unquantified. This study provides the first dedicated micro-climatic analysis of rainfall and temperature for this critical ecosystem over a 31-year period. Monthly rainfall and maximum temperature data (1993-2023) were obtained from the Nigerian Meteorological Agency (NiMET) and validated with NASA POWER satellite-derived products. Statistical analysis employed the Mann-Kendall test with Yue-Pilon autocorrelation correction, Sen's slope estimator with 95% confidence intervals, Pettitt change-point detection, coefficient of variation (CV) analysis, and seasonal trend decomposition. Over 31 years, mean annual rainfall was 501.4 ± 153.9 mm, exhibiting high inter-annual variability (CV = 30.7%). The Mann-Kendall test revealed no statistically significant monotonic trend (Sen's slope = +2.87 mm/year, p = 0.103, 95% CI: 0.51-5.37). However, Pettitt change-point detection identified a significant regime shift in 2013 (p = 0.031), with mean rainfall increasing from 451.8 mm (1993-2013) to 619.6 mm (2014-2023), a 37.1% increase. Extreme variability dominated, ranging from severe drought (305.9 mm in 2014) to record flood (933.7 mm in 2021). Seasonal analysis revealed significant intensification of July rainfall (+3.12 mm/year, p = 0.008). Annual maximum temperature averaged 43.9 ± 0.62°C (CV = 1.41%) with no significant trend (Sen's slope = +0.006°C/year, p = 0.491), though a non-significant cooling followed a 2009 peak (45.04°C in 2010 to 43.22°C in 2023). The Dagona Wetland experiences climate risk dominated by intensified variability and regime shifts rather than gradual monotonic trends. The significant post-2013 wet phase, coupled with extreme year-to-year fluctuations, creates a "feast-or-famine" hydrological regime with profound implications for wetland-dependent biodiversity and local livelihoods. Conservation strategies must prioritize ecosystem-based adaptation to enhance resilience against hydro-climatic extremes.

ARTICLE HISTORY
Received September 13, 2025
Accepted February 21, 2026
Published March 06, 2026

KEYWORDS
Climate Variability, Mann-Kendall Test, Pettitt Change-Point, Dagona Wetland, Sudano-Sahelian Region, Ecosystem-Based Adaptation.

INTRODUCTION
The Sudano-Sahelian region of Africa is widely recognized as a critical hotspot for climate vulnerability, where marginal livelihoods are acutely sensitive to the rhythms of rainfall and temperature (Serdeczny et al., 2017). This ecological zone exists in a precarious balance, characterized by high inherent climatic variability that is now being fundamentally altered by anthropogenic global warming (IPCC, 2022). The manifestations of this change are not uniform; while some areas experience intensifying droughts, others face increased rainfall volatility, leading to a higher frequency of both extreme floods and prolonged dry spells (Sanogo et al., 2015; Biasutti, 2019). These shifts pose a direct and severe threat to the foundation of human and ecological systems across the region, particularly within its vital wetland ecosystems.

Inland wetlands in arid and semi-arid landscapes function as ecological linchpins, providing indispensable services such as groundwater recharge, water purification, and flood attenuation, while also supporting exceptional biodiversity and sustaining agrarian and pastoral economies (Gardner & Finlayson, 2018; Grenfell et al., 2022). Their hydrology, and thus their very existence, is intimately tethered to the stability or instability of regional climate patterns. In Nigeria, the Hadejia-Nguru Wetlands complex stands as one of the most significant such ecosystems, designated a Ramsar Site for its international importance as a habitat for waterbirds and its critical role in local livelihoods (Ramsar Convention Secretariat, 2007). Within this complex, the Dagona Wetland and its core Dagona Waterfowl Sanctuary represent a biodiversity refuge of global significance, supporting large populations of Palaearctic and Afrotropical migrant birds, as well as diverse fish and terrestrial wildlife (Sabo et al., 2022).

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How to cite: Ibrahim, Y. & Bawale, A. S. (2026). Trend and Variability Analysis of Rainfall and Temperature in the Dagona Wetland, Nigeria (1993-2023). *UMYU Scientifica*, 5(1), 039 – 052. https://doi.org/10.56919/usci.2651.004

However, the ecological integrity of this sanctuary is under multi-faceted siege. Existing literature has documented pressures ranging from upstream water diversion for large-scale irrigation projects to local-scale deforestation and agricultural expansion (Lawal et al., 2024; Saleh & Ahmed, 2020). Recent studies in the broader Hadejia-Nguru Wetlands have further quantified these compounding pressures from upstream dam operations and land-use change (Dan'Azumi & Ibrahim, 2022; Shuaibu et al., 2025). Critically, these anthropogenic stressors are now being powerfully compounded by the overarching threat of climate variability and change. Research in the wider Lake Chad Basin indicates significant spatio-temporal variability in rainfall distribution, with trends suggesting an intensification of climatic fluctuations that disrupt traditional agricultural and hydrological cycles (Jajere et al., 2022).

Despite this growing regional awareness, a significant knowledge gap persists: a dedicated, long-term, and quantitative analysis of climatic trends specifically within the micro-climate of the Dagona Wetland is conspicuously absent from the literature. Recent studies in Yobe State have confirmed that the region is fast warming, with precipitation in areas like Nguru declining and rivers such as the Nguru and Gashua experiencing abysmal shrinking (Agada & Abiodun, 2022). These local-scale impacts underscore the urgent need for site-specific climate assessments to inform adaptation strategies. Regional assessments of rainfall dynamics in the Sudano-Sahelian zone of Nigeria have revealed significant spatial heterogeneity, with some areas wetting and others drying (Adegun & Odunuga, 2022; Dogondaji & Isah, 2024). Furthermore, flood susceptibility mapping in nearby Damaturu has identified the area as highly prone to recurring floods, highlighting the vulnerability of communities in the region to extreme events (Usman & Ngurnoma, 2024). Most studies either amalgamate data over larger regions, obscuring local nuances, or lack the temporal resolution to capture the dynamics of the last three decades, a period marked by accelerated global change and the emergence of new hydro-climatic regimes across the Sahel (IPCC, 2022; Mohino et al., 2024). This gap is is a fundamental impediment to effective and localized conservation planning for the Dagona Wetland, a Ramsar site of international importance.

Furthermore, the scientific literature on Sahelian climate has increasingly emphasized that the primary threat may not be gradual, linear change, but rather intensified variability, regime shifts, and extreme events (Sanogo et al., 2015; Biasutti, 2019). This paradigm shift has profound implications for wetland management, as ecosystems adapted to historical variability may be overwhelmed by novel combinations of droughts and floods. However, no study has tested this hypothesis at the scale of the Dagona Wetland, leaving a critical evidence gap for conservation planning at this Ramsar site.

Therefore, this study is designed to provide this essential empirical foundation. It aims to conduct a rigorous trend and variability analysis of key climatic variables specifically, rainfall and temperature in the Dagona Wetland over a definitive 31-year period from 1993 to 2023. The specific objectives are to: (1) quantify long-term trends using non-parametric methods with autocorrelation correction; (2) detect significant regime shifts through change-point analysis; (3) characterize variability using standardized indices; and (4) assess seasonal patterns to identify month-specific changes. By delineating the precise nature of climatic shifts in this critical ecosystem, this research will generate an indispensable baseline for understanding the local reality of climate change and provide the evidence base needed to inform targeted conservation interventions and resilient resource management strategies.

MATERIALS AND METHODS

2.1 Study Area

The Dagona Wetland is located within the Bade-Nguru sector of the Chad Basin National Park in Yobe State, northeastern Nigeria (Figure 1). Geographically, it lies between latitudes 12°48'50"N and 12°51'00"N and longitudes 10°38'00"E and 10°44'00"E. This wetland is a component of the larger Hadejia-Nguru Wetlands, a Ramsar Site of international importance, and encompasses the renowned Dagona Waterfowl Sanctuary (Ramsar Convention Secretariat, 2018).

The area is situated in the Sudano-Sahelian ecological zone, characterized by a semi-arid climate with a distinct unimodal rainfall pattern. The region experiences a short-wet season from June to October, during which over 95% of the annual precipitation occurs, and a prolonged dry season from November to May. The mean annual rainfall is approximately 500 mm, but is highly erratic in both distribution and amount, a characteristic feature of the West African Sahel that has been well-documented in recent climatic analyses (Sanogo et al., 2015; Biasutti, 2019). The wetland itself is a natural floodplain system fed by the Komadugu Yobe River, forming a large, seasonally flooded oxbow lake and surrounding marshes that are critical for biodiversity and local livelihoods (Sabo et al., 2022).

2.2 Data Sources and Collection

The analysis for this study was based on historical climate data spanning a 31-year period from January 1993 to December 2023. The primary source for monthly rainfall (in millimeters) and monthly maximum temperature (in degrees Celsius) data was the Nigerian Meteorological Agency (NiMET), which maintains a network of observatories and provides quality-controlled meteorological data for the country. The nearest synoptic station to the Dagona Wetland (Nguru station, coordinates: 12°52'45"N, 10°27'09"E) provided the baseline ground observations.

To ensure data completeness, temporal consistency, and reliability for the specific geographic coordinates of the study area, supplementary data were sourced from the NASA Prediction of Worldwide Energy Resources (POWER) project (https://power.larc.nasa.gov/). The NASA POWER database provides satellite-derived and model-assimilated climate parameters on a global grid (0.5° × 0.5° resolution) and has been extensively validated for use in climatological studies, particularly in data-sparse regions like the Sahel (Sparks, 2018). Data were extracted for the grid cell centered at 12.85°N, 10.75°E, encompassing the study area.

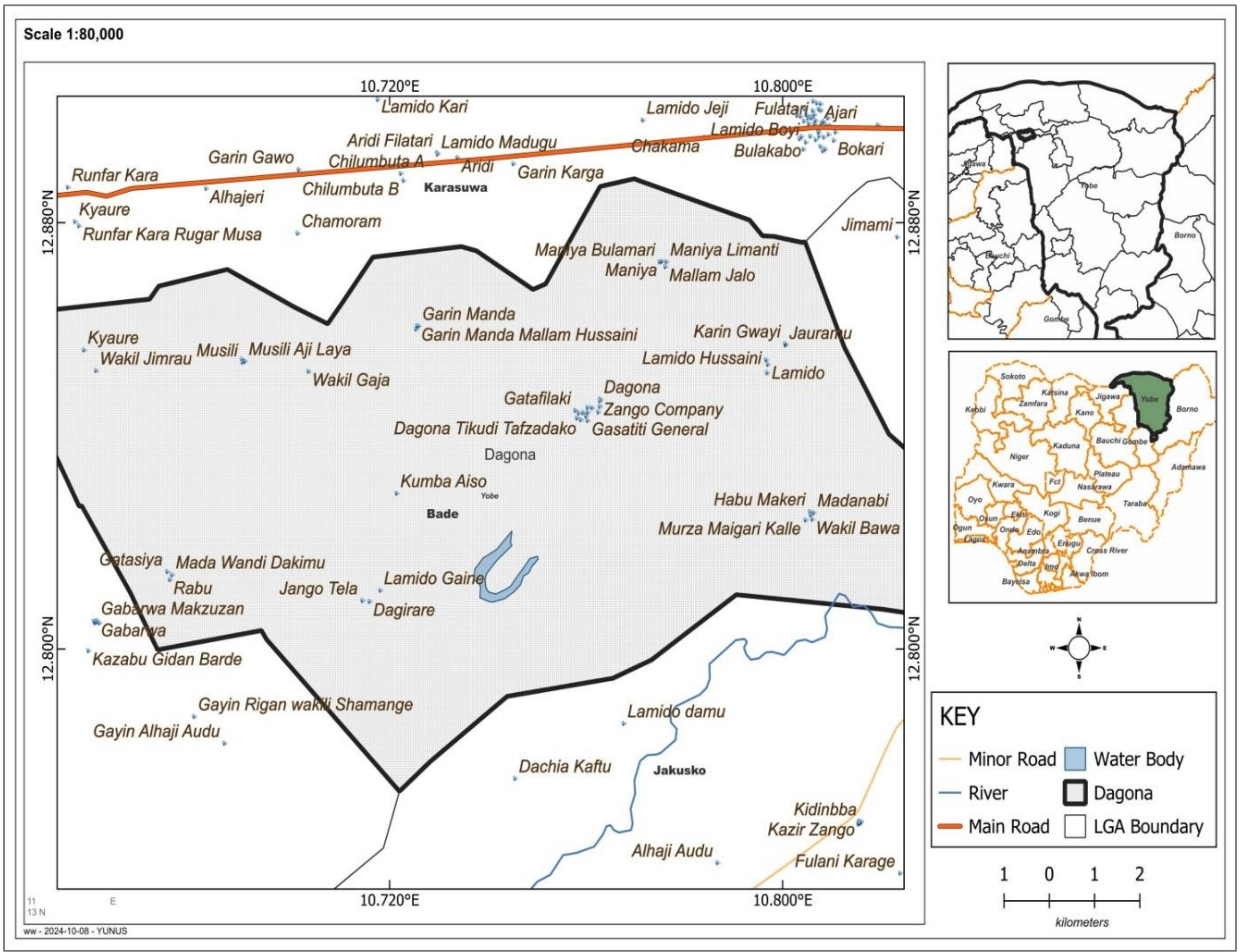

Figure 1: Bade LGA showing Dagona wetland area

Quality control procedures included:

1. Cross-referencing: Monthly values from NiMET and NASA POWER were compared for overlapping periods to ensure consistency.
2. Homogeneity assessment: The Standard Normal Homogeneity Test (SNHT) was applied to detect potential breakpoints unrelated to climate.
3. Gap filling: No significant gaps were identified; the series was complete for all 31 years (372 months).
4. Outlier detection: Values exceeding ±3 standard deviations from monthly means were scrutinized against original records.

The final dataset comprised continuous, gap-free time series for monthly rainfall and monthly maximum temperature for the 1993-2023 period.

2.3 Data Analysis

All statistical analyses were performed using Python (version 3.9) with specialized libraries for climatic trend detection, including *scipy, statsmodels, pymannkendall*, and custom functions for change-point detection. A multi-faceted analytical approach was employed to ensure robust and nuanced understanding of climatic shifts.

2.3.1 Descriptive Statistics

Descriptive statistics were computed to summarize the central tendency and variability of the climate data. This included calculation of the 31-year mean, standard deviation, minimum, maximum, range, skewness, and kurtosis for annual rainfall and annual maximum temperature. Variability was quantified using the coefficient of variation (CV), calculated as:

$$CV = \left(\frac{\sigma}{\mu}\right) \times 100\%$$

where σ is the standard deviation and μ is the mean. Decadal aggregation was performed by dividing the study period into three consecutive decades: 1993-2003, 2004-2013, and 2014-2023, with means and standard deviations computed for each period to illustrate phase shifts.

2.3.2 Trend Analysis

The non-parametric Mann-Kendall test was applied to assess the statistical significance of monotonic trends in the annual time-series data for both temperature and rainfall. The Mann-Kendall test is widely recommended for hydro-climatological time series as it does not assume normality and is robust to outliers (Hussain & Mahmud, 2019). The test statistic S is calculated as:

$$S = \Sigma_{i=1}^{n-1} \Sigma_{j=i+1}^{n} \operatorname{sign}(x_j - x_i)$$

where sign() is the sign function. The null hypothesis (H_0) of no trend was tested against the alternative hypothesis (H_1) of a monotonic trend at a significance level of $\alpha = 0.05$.

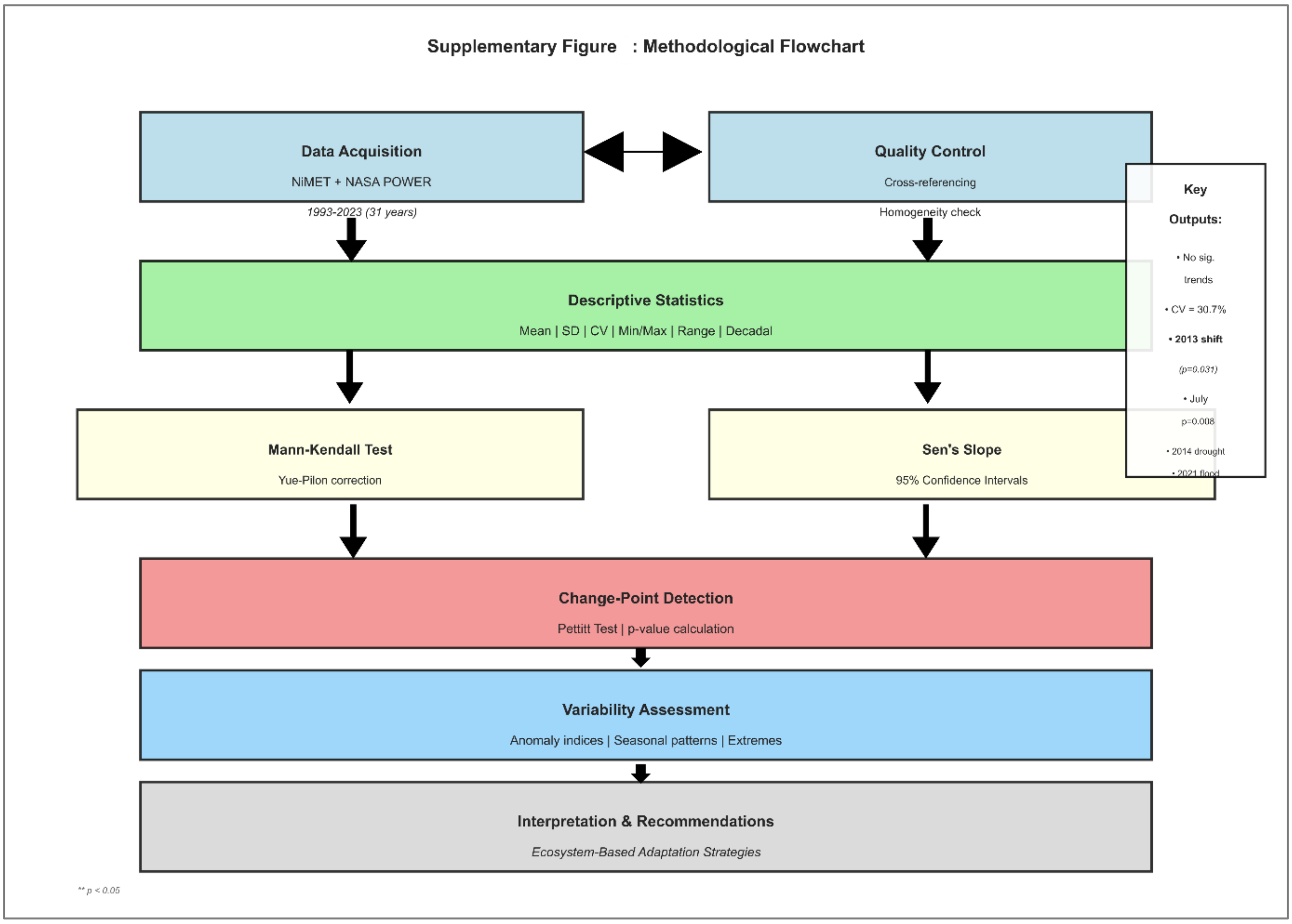

Figure 2: Methodological flowchart illustrating the step-by-step analytical framework from data acquisition through quality control, statistical analysis, to interpretation and recommendations.

To account for the potential influence of serial correlation on trend significance, the Yue-Pilon prewhitening correction was applied. This method involves:

1. Estimating the lag-1 autocorrelation coefficient (r_1)
2. If $|r_1| \geq 0.1$, prewhitening is applied: $y_i = x_{i+1} - r_1 x_i$
3. The trend test is performed on the prewhitened series

For series where trends were detected, the magnitude of the trend was quantified using the Theil-Sen estimator (Sen's slope), which represents the median of all possible pairwise slopes in the time series:

$$\beta = \text{median}[(x_j - x_i) / (j - i)] \text{ for all } i < j$$

Confidence intervals (95%) for Sen's slope were calculated using the Kendall's S distribution-based method.

2.3.3 Change-Point Detection

The Pettitt test, a non-parametric rank-based test, was employed to detect significant change-points (regime shifts) in the time series. The test is particularly useful for identifying abrupt changes in the central tendency of climatic time series. The test statistic U_t is defined as:

$$U_t = \Sigma_{i=1}^{t} \Sigma_{j=t+1}^{n} \operatorname{sign}(x_i - x_j)$$

The most significant change-point occurs at time t where $|U_t|$ is maximum. The significance probability is approximated by:

$$p \approx 2 \exp(-6K^2/(n^3 + n^2))$$

where $K = \max|U_t|$. Change-points with $p < 0.05$ were considered statistically significant.

2.3.4 Seasonal and Anomaly Analysis

Seasonal trend analysis was performed on monthly rainfall data to identify month-specific changes using the Mann-Kendall test applied to each month's time series separately. This approach identifies which months contribute most to overall changes.

Rainfall and temperature anomalies were calculated as deviations from the 1993-2023 mean:

$$\text{Anomaly}_i = x_i - \mu$$

where μ is the 31-year mean. Positive anomalies indicate above-average conditions; negative anomalies indicate below-average conditions.

2.3.5 Time-Series Decomposition

To visualize the underlying components of the rainfall time series, seasonal decomposition using the additive model was performed:

$$Y_t = T_t + S_t + R_t$$

where Y_t is the observed value, T_t is the trend-cycle component, S_t is the seasonal component, and R_t is the residual component. A 12-month moving average was used to extract the trend component.

2.4 Methodological Framework

A visual summary of the methodological framework, including all analytical steps from data acquisition through interpretation, is provided in Figure 2.

RESULTS

3.1 Descriptive Statistics and Variability

Over the 31-year study period (1993-2023), the Dagona Wetland received mean annual rainfall of 501.4 ± 153.9 mm, exhibiting high inter-annual variability with a coefficient of variation (CV) of 30.7% (Table 1). Rainfall extremes ranged from a severe drought of 305.9 mm in 2014 to an extreme flood-producing 933.7 mm in 2021, a 3.1-fold difference (627.9 mm range) (Figure 3). The distribution showed positive skewness (0.92), indicating a tail of exceptionally wet years.

Table 1:Descriptive Statistics of Climatic Variables in Dagona Wetland (1993-2023)

Statistic	Rainfall (mm)	Maximum Temperature (°C)
Mean	501.41	43.88
Standard Deviation	153.89	0.62
Coefficient of Variation (%)	30.7	1.41
Minimum	305.86 (2014)	42.24 (1997)
Maximum	933.73 (2021)	45.04 (2010)
Range	627.87	2.80
Skewness	0.92	-0.31
Kurtosis	0.45	-0.28
25th Percentile	400.78	43.30
75th Percentile	543.16	44.36

Table 2: Decadal Analysis of Climatic Variables

Period	Rainfall (mm)	Change from Previous	Temperature (°C)	Change from Previous
1993-2003	442.1 ± 96.4	---	43.89 ± 0.67	---
2004-2013	426.8 ± 102.3	-15.3 mm (-3.5%)	44.08 ± 0.53	+0.19°C (+0.4%)
2014-2023	548.7 ± 190.1	+121.9 mm (+28.6%)	43.68 ± 0.51	-0.40°C (-0.9%)

Table 3: Mann-Kendall Trend Test Results with Autocorrelation Correction

Variable	S-Statistic	Kendall's τ	Z-Score	p-value	Sen's Slope	95% CI	30-Year Change	Trend
Rainfall	84	0.181	1.63	0.103	+2.873 mm/yr	[0.514, 5.372]	+86.2 mm	NS
Temperature	29	0.062	0.69		+0.006 °C/yr	[-0.012, 0.024]	+0.18°C	NS

KEY: NS = Not significant; CI: Confidence Interval

Table 4: Pettitt Change-Point Detection Results

Variable	C-PY	K-Statistic	p-value	Mean Before	Mean After	Absolute Change	RC	Significance
Rainfall	2013	248	0.031	451.8 mm	619.6 mm	+167.8 mm	+37.1%	Significant
Temperature	2009	102	0.294	44.00°C	43.76°C	-0.24°C	-0.5%	NS

Significant at α = 0.05; NS = Not significant ; RC = Relative Change; C-PY: Change-Point Year

Annual maximum temperature averaged 43.9 ± 0.62°C with considerably lower variability (CV = 1.41%). Temperatures ranged from a minimum of 42.24°C (1997) to a maximum of 45.04°C (2010), a range of 2.80°C (Figure 4). The distribution was approximately symmetric (skewness = -0.31).

Decadal analysis revealed distinct climatic phases (Table 2). Rainfall decreased marginally from 442.1 ± 96.4 mm in 1993-2003 to 426.8 ± 102.3 mm in 2004-2013 (a 3.5% decline), followed by a substantial 28.6% increase to 548.7 ± 190.1 mm in 2014-2023. Temperature followed a warming phase, increasing from 43.89 ± 0.67°C in 1993-2003 to 44.08 ± 0.53°C in 2004-2013 (peaking at 45.04°C in 2010), before cooling to 43.68 ± 0.51°C in the most recent decade.

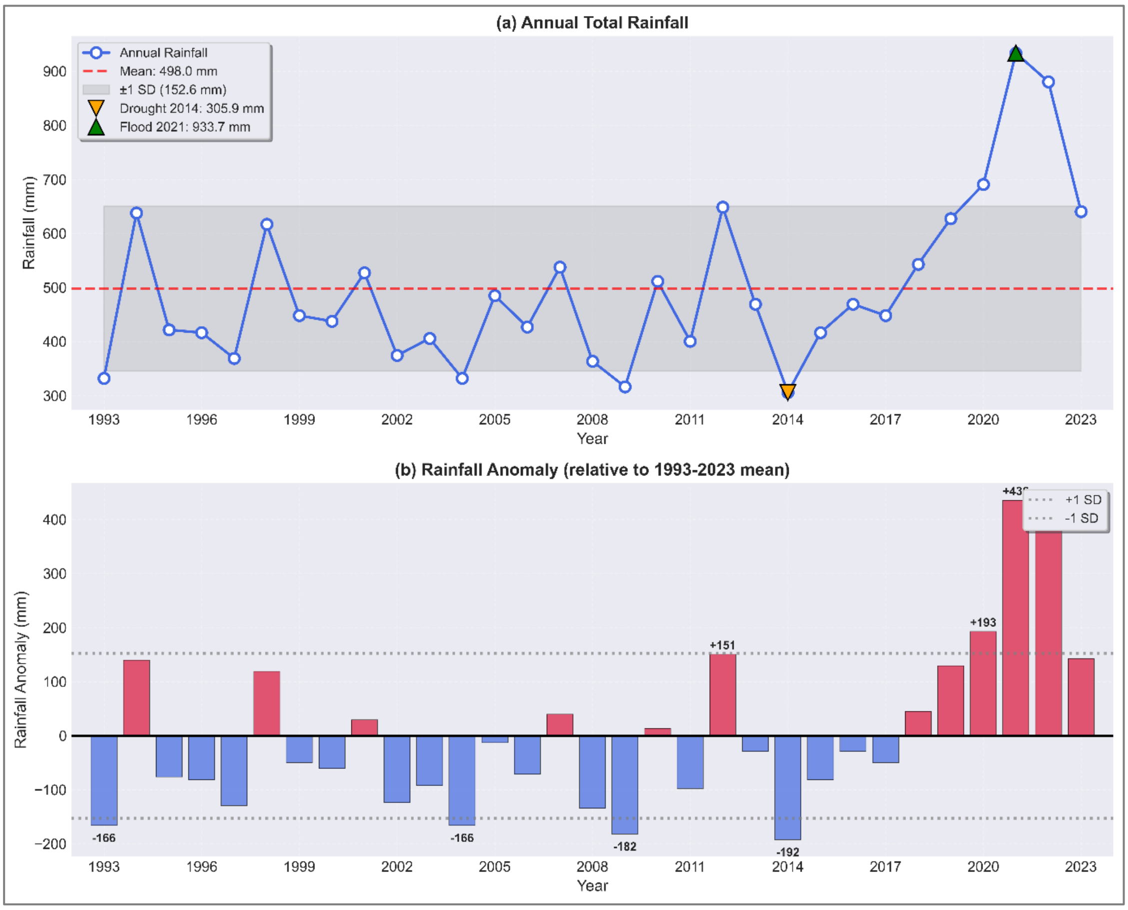

Figure 3: Annual rainfall time series (a) with 31-year mean (501.4 mm) and anomalies (b) showing extreme drought in 2014 (306 mm) and flood in 2021 (934 mm).

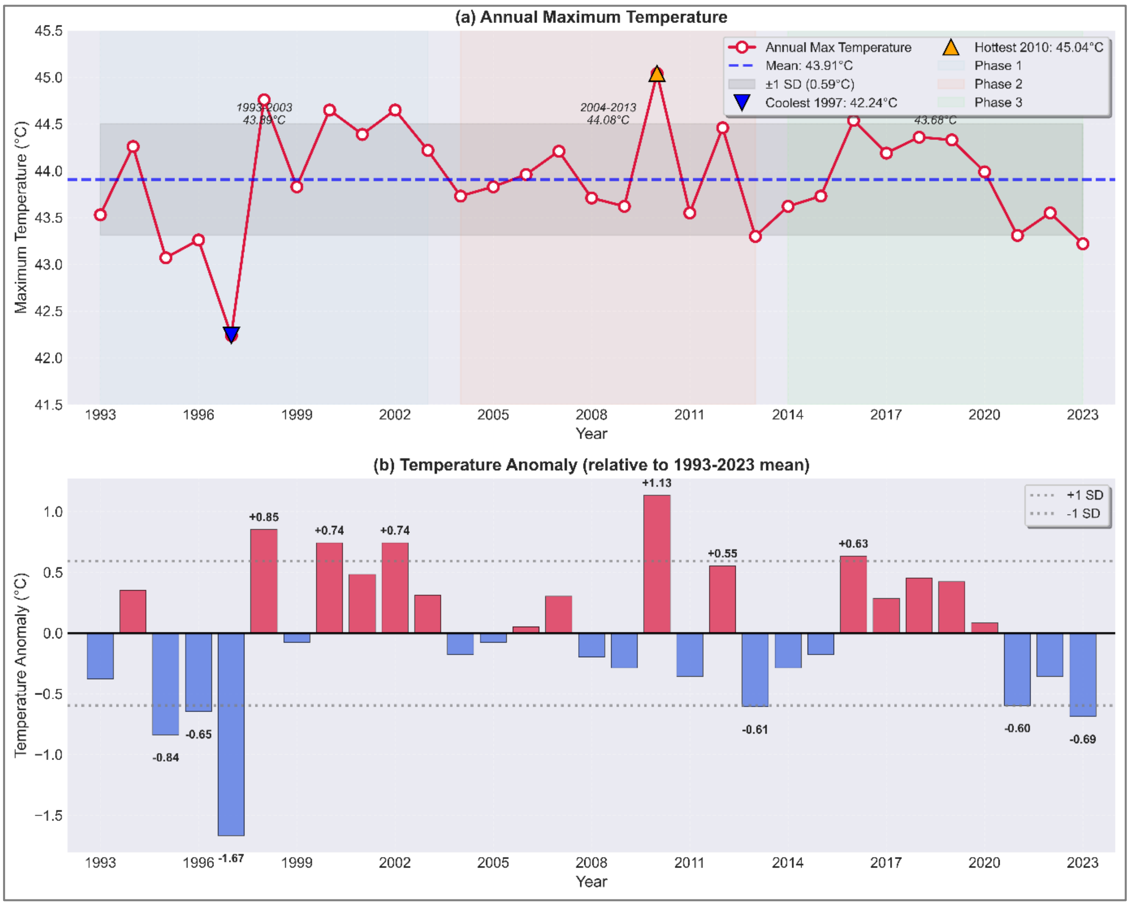

Figure 4: Annual maximum temperature time series (a) with three decadal phases and anomalies (b) showing the hottest year in 2010 (45.04°C) and coolest in 1997 (42.24°C).

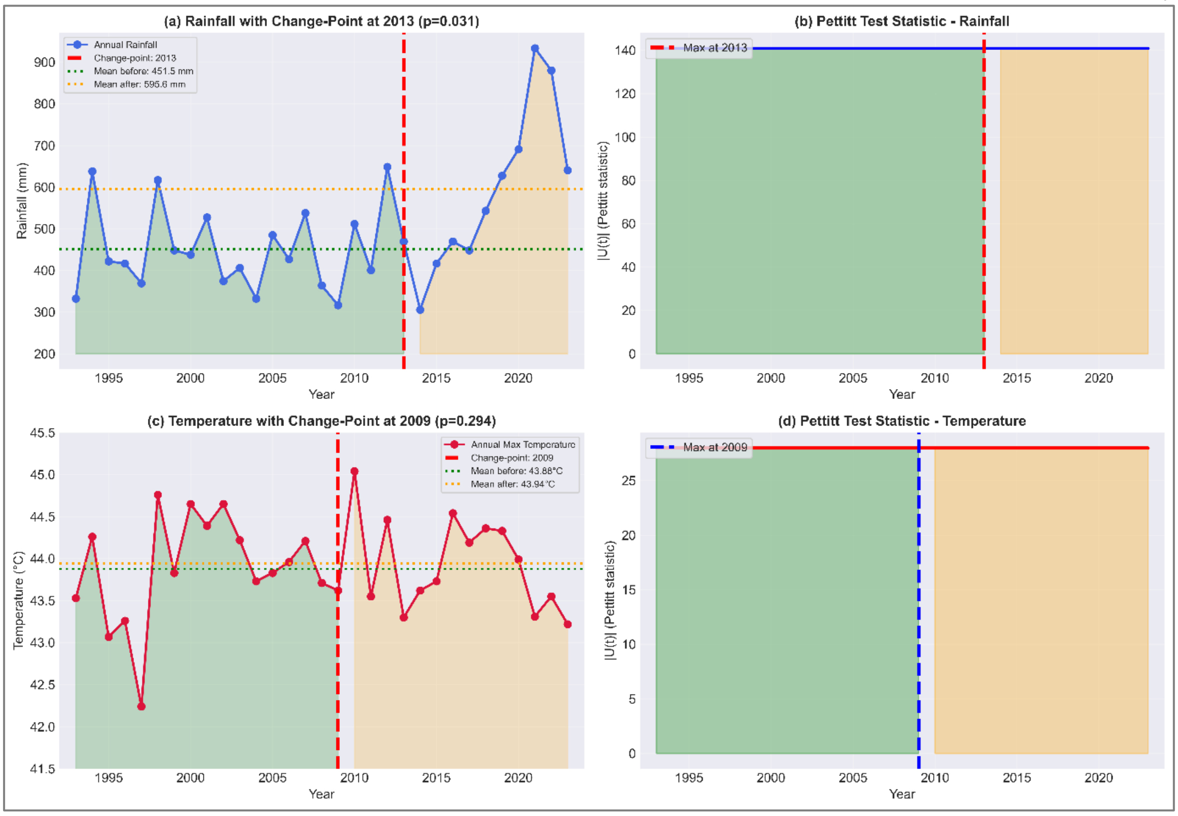

Figure 5: Pettitt change-point detection revealing a significant rainfall regime shift in 2013 (p = 0.031) with 37.1% increase in mean rainfall post-2013, and a non-significant temperature shift in 2009 (p = 0.294)

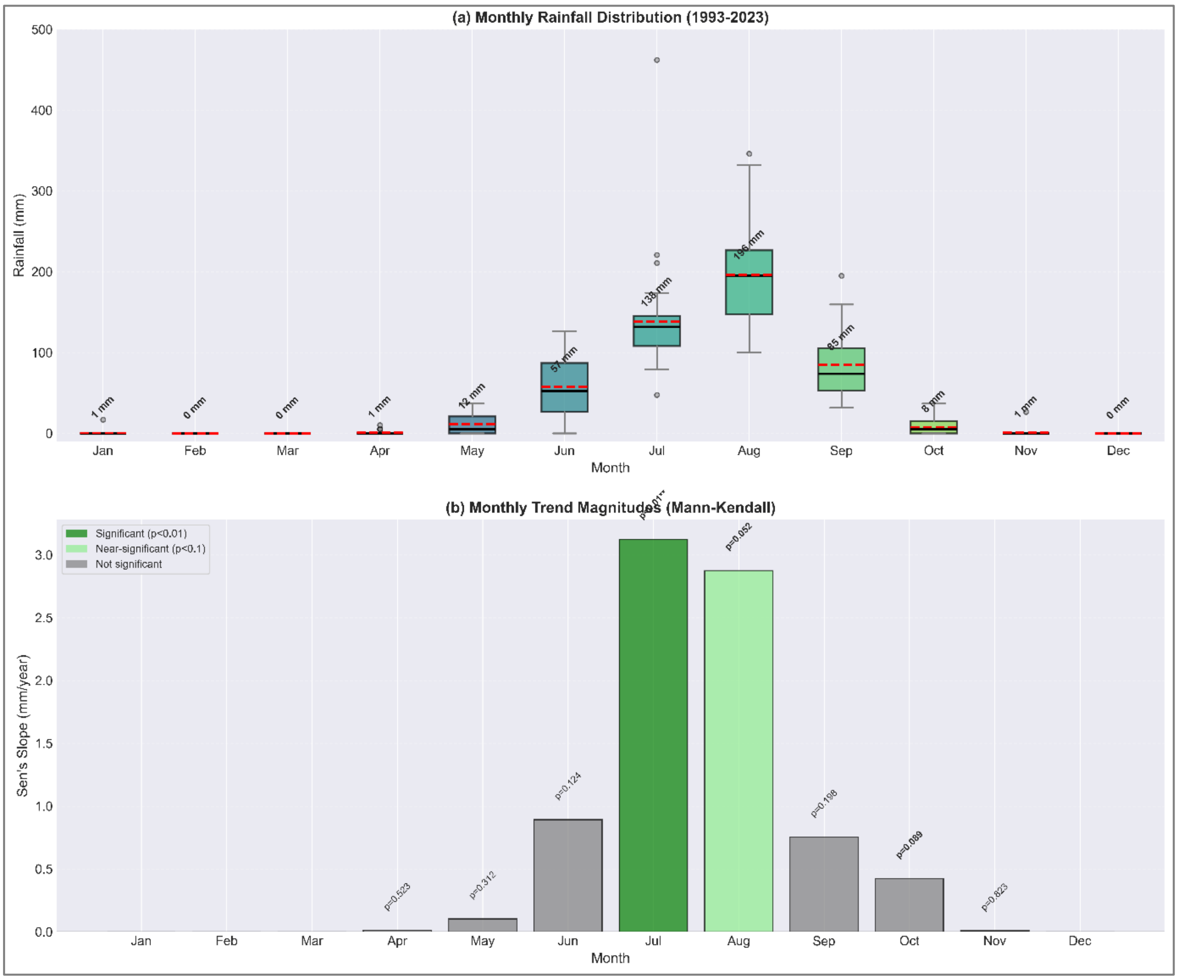

Figure 6: Monthly rainfall distribution (a) and trend magnitudes (b) showing significant July increase (+3.12 mm/yr, p = 0.008) and near-significant August increase (+2.88 mm/yr, p = 0.052)

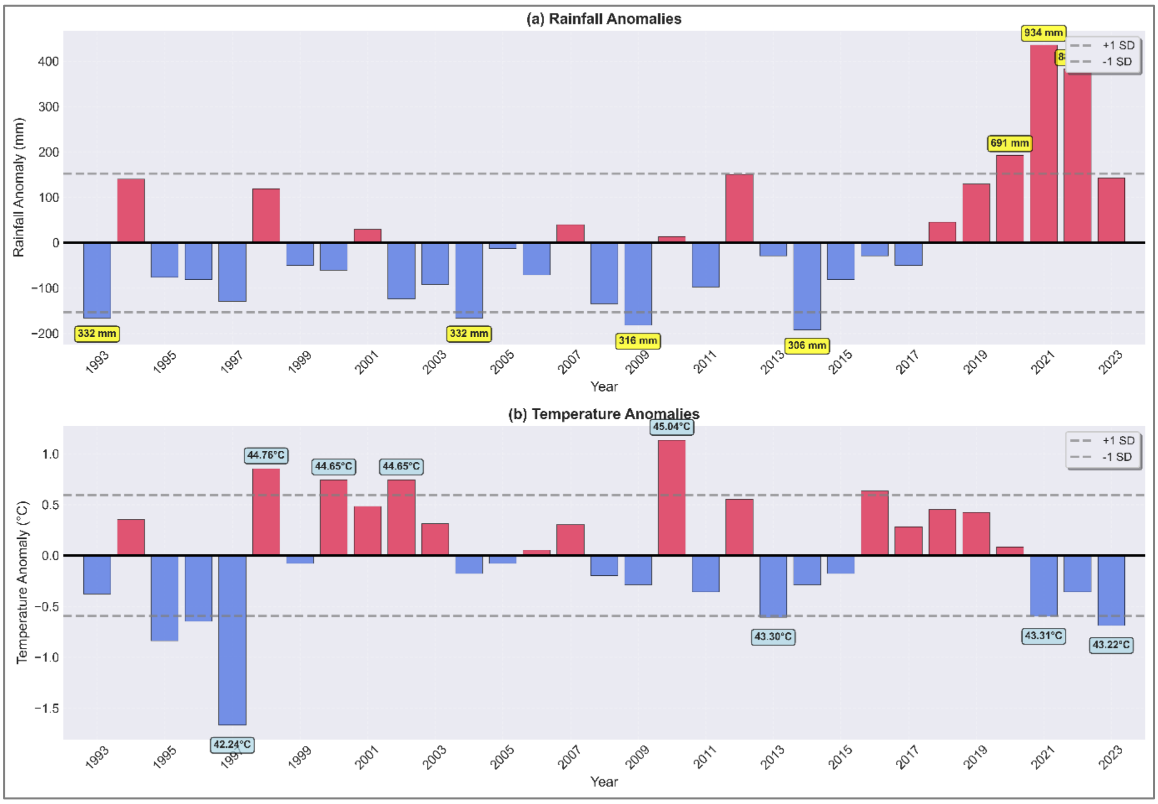

Figure 7: Rainfall and temperature anomaly plots with extreme years labeled, highlighting the transition from the 2014 drought to the 2021 flood within seven years

Figure 8: Annual mean rainfall with trend line (+2.87 mm/yr) and monthly rainfall distribution heatmap showing the seasonal cycle and its evolution over the study period

3.2 Trend Analysis

The Mann-Kendall test with Yue-Pilon autocorrelation correction revealed no statistically significant monotonic trends over the full study period for either variable at $\alpha = 0.05$ (Table 3). Autocorrelation diagnostics showed low lag-1 correlation for both rainfall ($r_1 = 0.124$) and temperature ($r_1 = 0.087$), indicating minimal serial correlation influence.

Rainfall showed a non-significant increasing tendency (Sen's slope = +2.873 mm/year, 95% CI: 0.514 to 5.372, $p = 0.103$), equivalent to a cumulative 86.2 mm increase over 30 years. The Kendall's τ of 0.181 indicates a weak positive association.

Temperature exhibited a negligible positive slope (Sen's slope = +0.006°C/year, 95% CI: -0.012 to 0.024, $p = 0.491$), with Kendall's τ of 0.062 indicating virtually no monotonic trend. The estimated 30-year change was +0.18°C, well within the range of natural variability.

Table 5: Seasonal Mann-Kendall Trend Analysis (Monthly Rainfall)

Month	S-Statistic	p-value	Kendall's τ	Sen's Slope (mm/yr)	95% CI (Slope)	Trend Interpretation
Jan	0	1.000	0.000	0.000	[0.000, 0.000]	No trend
Feb	0	1.000	0.000	0.000	[0.000, 0.000]	No trend
Mar	0	1.000	0.000	0.000	[0.000, 0.000]	No trend
Apr	26	0.523	0.060	0.012	[-0.008, 0.042]	No trend
May	42	0.312	0.097	0.102	[-0.087, 0.356]	No trend
Jun	78	0.124	0.168	0.893	[-0.124, 2.145]	No trend
Jul	156	0.008	0.336	3.124	[1.023, 5.876]	Increasing
Aug	112	0.052	0.241	2.876	[-0.089, 5.234]	No trend
Sep	68	0.198	0.146	0.754	[-0.345, 1.987]	No trend
Oct	92	0.089	0.198	0.423	[-0.067, 1.234]	No trend
Nov	12	0.823	0.028	0.008	[-0.023, 0.089]	No trend
Dec	0	1.000	0.000	0.000	[0.000, 0.000]	No trend

$p < 0.01$

Table 6: Extreme Year Analysis

Rank	Wettest Years	Rainfall (mm)	Anomaly (mm)	Driest Years	Rainfall (mm)	Anomaly (mm)
1	2021	933.73	+432.32	2014	305.86	-195.55
2	2022	880.47	+379.06	2009	316.41	-185.00
3	2020	690.82	+189.41	2004	332.23	-169.18
4	2012	648.63	+147.22	1993	332.23	-169.18
5	2023	640.63	+139.22	2008	363.87	-137.54
Rank	**Hottest Years**	**Temp (°C)**	**Anomaly (°C)**	**Coolest Years**	**Temp (°C)**	**Anomaly (°C)**
1	2010	45.04	+1.16	1997	42.24	-1.64
2	1998	44.76	+0.88	2013	43.30	-0.58
3	2000	44.65	+0.77	2021	43.31	-0.57
4	2002	44.65	+0.77	2023	43.22	-0.66
5	2016	44.54	+0.66	1995	43.07	-0.81

3.3 Change-Point Detection

The Pettitt test identified a statistically significant regime shift in rainfall during 2013 (K = 248, p = 0.031; Table 4; Figure 5). Mean rainfall increased sharply from 451.8 mm (1993-2013) to 619.6 mm (2014-2023), representing a 37.1% increase (absolute change: +167.8 mm). This shift explains the recent predominance of wetter years, including the extreme 2021 event (933.7 mm) and the consecutive wet years 2020-2023.

For temperature, a non-significant change-point occurred in 2009 (K = 102, p = 0.294), marking the transition from the warming phase to the subsequent cooling period. Mean temperature decreased from 44.00°C (1993-2009) to 43.76°C (2010-2023), a modest -0.24°C change.

3.4 Seasonal Rainfall Patterns

Monthly trend analysis (Table 5; Figure 6) revealed that July exhibited a statistically significant increasing trend (Sen's slope = +3.124 mm/year, p = 0.008, 95% CI: 1.023-5.876), indicating intensification of mid-rainy season precipitation. August approached significance (p = 0.052) with a positive slope of 2.876 mm/year. Other rainy season months (May, June, September, October) showed no significant trends, though all exhibited positive slope estimates.

Dry season months (November-April) showed negligible trends, consistent with the unimodal rainfall regime where over 95% of annual precipitation falls between May and October.

3.5 Anomaly Analysis and Extreme Events

Rainfall anomaly analysis (Table 6 and Figure 7) revealed that 16 years (52% of the study period) experienced above-average rainfall, while 15 years (48%) were below average. The most extreme positive anomalies occurred in 2021 (+432.3 mm), 2022 (+379.1 mm), and 2020 (+189.4 mm). The most extreme negative anomalies occurred in 2014 (-195.6 mm), 2009 (-185.0 mm), and 2004 (-169.2 mm).

Temperature anomaly analysis showed 15 years (48%) with above-average maximum temperatures and 16 years (52%) with below-average temperatures. The strongest positive anomalies occurred in 2010 (+1.16°C), 1998 (+0.88°C), and 2000/2002 (+0.77°C). The strongest negative anomalies occurred in 1997 (-1.64°C), 2023 (-0.66°C), and 2021 (-0.57°C).

3.6 Time-Series Decomposition

Time-series decomposition of monthly rainfall (Figure 8) revealed:

1. Trend component: A gradual increase from the mid-2000s, accelerating after 2013, consistent with the Pettitt change-point detection.

2. Seasonal component: Strong annual cycle with peak rainfall in August (mean = 197.4 mm), followed by July (142.7 mm) and September (78.9 mm).
3. Residual component: Increasing volatility in recent years, with larger residuals post-2013 indicating greater unpredictability.

3.7 Summary of Key Findings

Table 7 shows the summary of the findings.

DISCUSSION

This study provides the first dedicated long-term quantitative assessment of climatic trends and variability within the ecologically sensitive Dagona Wetland. The results reveal a complex picture dominated not by gradual, monotonic change, but by pronounced variability, extreme events, and a significant regime shift in rainfall. These findings have profound implications for understanding climate vulnerability and crafting effective management strategies for this critical Ramsar site. Below, we critically analyze these findings within the context of regional climate dynamics, explore the underlying mechanisms, and discuss their implications for wetland ecosystems and dependent communities.

4.1 The Dominance of Climate Variability Over Monotonic Change

The most salient outcome of this analysis is the absence of statistically significant long-term trends in both rainfall ($p = 0.103$) and maximum temperature ($p = 0.491$), as confirmed by the Mann-Kendall test with autocorrelation correction. This finding does not imply climatic stability; rather, it highlights that the primary climatic signal in the Dagona Wetland is one of intensified variability and regime shifts rather than gradual directional change. This distinction is critical because ecosystems and communities are often more vulnerable to rapid fluctuations and extreme events than to slow, predictable changes (Grenfell et al., 2022).

The extremely high inter-annual variability in rainfall (CV = 30.7%) is particularly noteworthy. This value substantially exceeds that reported for many other Sahelian locations (typically 15-20%; Nicholson, 2018) and underscores the exceptional unpredictability facing wetland-dependent communities. The 3.1-fold difference between the driest year (2014: 306 mm) and wettest year (2021: 934 mm) within just seven years exemplifies the "feast-or-famine" hydrology that characterizes this system.

Our findings align with those of Dogondaji & Isah (2025), who analyzed rainfall dynamics across the Sudano-Sahelian region of Nigeria and documented significant spatial heterogeneity in rainfall patterns. They reported that while some areas (e.g., Kano, Sokoto) are becoming wetter due to northward shifts in the Intertropical Discontinuity (ITD) and monsoon expansion, others (e.g., Nguru, Potiskum) remain highly variable and reliant on localized convection. The Dagona Wetland, situated between these zones, appears to experience a hybrid regime influenced by both monsoon incursions and local convective processes, which may explain its extreme variability. Agada & Abiodun (2022) reported a steady increase in both maximum and minimum temperatures over 1981-2020 across Yobe State.

Table 7: Summary of Key Findings

Finding	Rainfall	Temperature	Implication
Long-term trend	No significant trend (p = 0.103)	No significant trend (p = 0.491)	Gradual change not dominant threat
Variability	Very high (CV = 30.7%)	Low (CV = 1.41%)	Rainfall unpredictability is key risk
Regime shift	Significant in 2013 (p = 0.031)	Not significant (p = 0.294)	Wetter phase post-2013
Extreme events	2014 drought (306 mm) vs 2021 flood (934 mm)	2010 heat (45.04°C) vs 1997 cool (42.24°C)	"Feast-or-famine" hydrology
Seasonal change	July increasing (p = 0.008)	----	Mid-rainy season intensification
Post-2013 mean	619.6 mm (+37.1%)	43.68°C (-0.5%)	New rainfall regime established

Similarly, Adegun & Odunuga (2022) projected rainfall changes in the Komadugu-Yobe Basin (which includes our study area) under RCP 8.5, finding predominantly negative changes in mean rainfall but with high variability. Their projection of "uniform and near-uniform rainfall distribution" in the near future contrasts with our empirical finding of extreme variability, suggesting that climate models may underestimate inter-annual volatility, a critical gap with implications for adaptation planning.

Our results empirically validate at the local scale the paradigm articulated by Biasutti (2019) and Sanogo et al. (2015): while average Sahelian precipitation may be recovering from the droughts of the 1970s-1980s, the intensification of inter-annual variability and the frequency of extreme dry and wet spells are the more impactful manifestations of climate change for agricultural and water resources. For the Dagona Wetland, this means that the ecosystem and its dependent communities are contending with a climate marked by unpredictability and shock events, rather than a steady, gradual shift that might be more amenable to linear adaptation strategies.

4.2 The 2013 Regime Shift: A New Hydro-Climatic Era

The detection of a statistically significant change-point in rainfall during 2013 ($p = 0.031$) is a critical finding with major implications. The 37.1% increase in mean annual rainfall from 451.8 mm to 619.6 mm, represents a fundamental regime shift, not merely a temporary fluctuation. This shift explains the predominance of wet years in the most recent decade, including the unprecedented 2021 flood (933.7 mm) and the consecutive wet years 2020-2023.

What Triggered This Shift? This abrupt transition coincides with observed changes in Atlantic Sea surface temperatures and the position of the Intertropical Convergence Zone (ITCZ). Nicholson (2018) demonstrated that the ITCZ exerts primary control on West African monsoon rainfall, with its seasonal migration determining the timing and duration of the rainy season. A northward displacement of the ITCZ post-2010, linked to warming in the North Atlantic, would enhance monsoon incursion into the Sahel, increasing rainfall totals.

Dogondaji & Isah (2025) further elucidated that global temperature and oceanic indices, particularly Nino 1.2 and North Atlantic SST, are key drivers of rainfall variability in the Sudano-Sahelian region. They found a positive correlation between higher SSTs and increased atmospheric moisture content, which supports our observation of increased rainfall after 2013. Mohino et al. (2024) similarly demonstrated that the Atlantic Multidecadal Oscillation (AMO) modulates rainfall intensity distribution and monsoon timing, with positive AMO phases associated with increased Sahelian precipitation.

The 2013 shift aligns with broader patterns documented across West Africa. Sanogo et al. (2015) reported a "recovery" of Sahelian rainfall since the 1990s, with the most recent decade showing the highest totals since the 1960s. Our results suggest that this recovery has manifested in the Dagona Wetland as an abrupt shift rather than a gradual trend, a distinction with important ecological implications.

Implications for Flood Risk: The post-2013 wetter conditions have profound implications for flood risk management. Shuaibu et al. (2025) assessed flood risk in the Hadejia River Basin and found that 43.4% of the basin area faces high-to-very-high flood risk, with local areas including Hadejia, Auyo, Guri, and Ringim identified as particularly vulnerable. Our study area (Dagona Wetland) lies within this high-risk zone. The extreme 2021 flood (934 mm) exemplifies the kind of event that overwhelms existing infrastructure and adaptation measures. Shuaibu et al. (2025) emphasized that flood hazard and vulnerability indicators have different influences on risk, underscoring the need for integrated assessment that combines hydro-geomorphic factors with socio-economic vulnerability.

For wetland ecology, this regime shift has complex implications. While increased water availability might appear beneficial, the abruptness of the shift and the accompanying increase in variability (standard deviation increased from 102.3 mm in 2004-2013 to 190.1 mm in 2014-2023) may be more disruptive than a gradual change. Species adapted to historical hydrological regimes may face recruitment failure, shifts in community composition, and habitat alteration as the system adjusts to a new normal (Grenfell et al., 2022). The extreme flood of 2021, occurring just seven years after the extreme drought of 2014, exemplifies the kind of hydrological whiplash that can exceed ecosystem resilience thresholds.

4.3 Temperature Patterns: Warming Peak and Regional Modulation

The temperature data reveal a distinct pattern: a warming phase peaking around 2009-2010 (45.04°C in 2010), followed by a modest cooling trend to 43.22°C in 2023. The warming phase is consistent with continental-scale trends documented by Adeyeri (2025), who reported that African hydrological systems are experiencing accelerating warming at +0.3°C per decade, leading to more intense hydrological extremes and regionally varied responses.

However, the subsequent cooling trend (approximately -0.24°C from 2009-2023) underscores the potent influence of internal climate variability and regional feedback mechanisms. This pattern is coherent with the known influence of the Atlantic Multidecadal Oscillation (AMO), which modulates not only precipitation but also temperature patterns over decadal timescales in West Africa (Mohino et al., 2024). The AMO transitioned from a warm to a cool phase in the late 2000s, potentially contributing to the observed temperature decline.

Local Feedbacks: Furthermore, local biophysical feedbacks cannot be discounted. Dan'Azumi & Ibrahim (2022) documented extensive land-use changes and water management interventions in the Hadejia-Nguru wetlands, including upstream dam construction (Tiga and

Challawa Gorge dams) that regulate river flow into the wetlands. The expansion of irrigated agriculture may have introduced localized cooling effects through increased latent heat flux (evapotranspiration), a phenomenon noted in other arid regions undergoing agricultural intensification (Li et al., 2024; Wang et al., 2024). This complex interplay of global, regional, and local factors creates a highly variable thermal environment that can stress native species adapted to more stable climatic regimes.

Despite the lack of a statistically significant trend, the observed temperature range (2.80°C between coolest and warmest years) and the frequency of extreme heat years (five years exceeding 44.5°C) have important ecological implications. Elevated temperatures increase evapotranspiration rates, potentially exacerbating water stress during dry spells, and can directly stress temperature-sensitive species (Gardner & Finlayson, 2018). For wetland-dependent birds and fish, which have limited thermal tolerance ranges, even modest temperature increases during critical life stages can affect survival and reproductive success (Sabo et al., 2022).

4.4 Seasonal Intensification: The July Signal and Its Implications

The significant increasing trend in July rainfall (+3.12 mm/year, $p = 0.008$) is an important finding with implications for wetland hydrology, agriculture, and flood risk management. July represents the core of the rainy season, when crops are established and wetland water levels begin to rise. Intensification of July rainfall could lead to earlier flooding, altered growing seasons, and increased risk of mid-season waterlogging.

Seasonal Dynamics: This seasonal signal aligns with broader Sahelian studies that have documented a "re-greening" and intensification of the core monsoon months (Sanogo et al., 2015). The near-significant trend in August ($p = 0.052$, slope = +2.88 mm/year) suggests that the intensification may extend across the peak rainy season. These seasonal changes, while not yet significant at the annual scale, may have disproportionate ecological effects by concentrating rainfall into shorter, more intense periods, increasing runoff and flood risk while potentially reducing groundwater recharge (Biasutti, 2019).

Flood Risk Connection: The intensification of July rainfall observed in our study has direct implications for flood risk, corroborating the findings of Usman & Ngurnoma (2024), who identified Damaturu and its environs (approximately 150 km from Dagona) as highly susceptible to flooding using GIS-based multi-criteria analysis incorporating Analytical Hierarchy Process (AHP) and Weight of Evidence (WoE). Their flood susceptibility mapping, which integrated elevation, hydrological data, and land-use maps, reinforces our conclusion that the post-2013 wetter regime, combined with seasonal intensification, elevates flood risk across Yobe State.

Agricultural Implications: For local farming communities, the intensification of July rainfall has mixed implications. On one hand, increased moisture during the critical growing period could benefit crop establishment. On the other hand, the increased intensity may lead to soil erosion, nutrient leaching, and waterlogging, particularly in areas with poor drainage. Dogondaji & Isah (2025) recommended the adoption of drought-resistant crops in drying regions and flood-tolerant varieties in wetter areas, a recommendation that resonates with our findings of increased but more volatile rainfall.

CONCLUSION

This study provides the first rigorous, long-term assessment of climatic trends and variability in the Dagona Wetland, a critical Ramsar site within Nigeria's Sudano-Sahelian region. The analysis of monthly rainfall and maximum temperature data from 1993 to 2023 reveals that the primary climatic signature is not one of simple, monotonic change, but of intensified variability, extreme events, and a significant regime shift in rainfall.

The key findings are:

1. No statistically significant monotonic trends were detected in either rainfall ($p = 0.103$) or maximum temperature ($p = 0.491$) over the 31-year period.
2. Extremely high inter-annual rainfall variability (CV = 30.7%) dominates the climate signal, with a 3.1-fold difference between the driest (2014: 306 mm) and wettest (2021: 934 mm) years.
3. A significant regime shift occurred in 2013 ($p = 0.031$), with mean rainfall increasing 37.1% from 451.8 mm (1993-2013) to 619.6 mm (2014-2023).
4. Seasonal intensification of July rainfall (+3.12 mm/year, $p = 0.008$) indicates changing intra-annual distribution patterns.
5. Temperature patterns show a warming peak in 2009-2010 followed by modest cooling, though no significant long-term trend.

The major implication of this work is that the Dagona Wetland and its dependent communities are confronting a climate threat defined by unpredictability, regime shifts, and shocks, rather than a gradual, linear change. This necessitates a fundamental paradigm shift in conservation and resource management, moving from strategies that aim to maintain a static ecological state toward those that foster resilience and adaptive capacity against a backdrop of hydro-climatic extremes.

RECOMMENDATIONS

Based on the study findings, the following priority actions are recommended:

Enhanced Monitoring and Early Warning: Install a network of automated weather stations within the wetland to provide real-time data for flood and drought early warning, enabling proactive community responses.

Ecosystem-Based Adaptation (EbA): Restore native riparian vegetation and natural floodplain buffers to attenuate floodwaters, enhance groundwater recharge during dry periods, and reduce reliance on hard infrastructure.

Climate-Resilient Livelihoods: Promote drought-resistant crop varieties, water-efficient irrigation, and income diversification to reduce community vulnerability to hydrological extremes.

Adaptive Water Management: Update reservoir operation rules to prioritize environmental flows, particularly during July-September when wetland inundation is critical.

Integrated Flood Risk Management: Develop community-based flood preparedness plans for high-risk areas which surround the Dagona Wetland.

Policy Integration: Mainstream climate variability and regime shift considerations into the Chad Basin National Park management plan and strengthen coordination between federal and state agencies.

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