

Application of Exponentially Weighted Moving Average Charts for Monitoring Rainfall Variability Across Nigeria's Geopolitical Zones

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Abstract– This study investigates rainfall variability across Nigeria's six geopolitical zones using Exponentially Weighted Moving Average (EWMA) control charts and long-term rainfall data spanning 1981–2022. EWMA control charts were employed to detect shifts, trends, and anomalies in rainfall patterns because of their sensitivity to small changes in time-series data reveal clear spatial disparities: the northern regions experienced prolonged low-rainfall anomalies, whereas the southern regions showed increasing variability and frequent high-rainfall anomalies. These patterns reflect the impacts of emerging climate change and the associated hydrological risks. The findings demonstrate that EWMA control charts provide a reliable statistical framework for rainfall monitoring and support evidence-based policy decisions in agriculture, water resource management, and disaster risk reduction.

Keywords: Rainfall Variability, EWMA Control Chart, Climate Change, Nigeria, Statistical Monitoring

I. INTRODUCTION

Rainfall plays a critical role in shaping Nigeria's environmental systems, economic activities, and livelihoods, particularly in agriculture and water resource management. Nigeria spans diverse climatic zones, ranging from the semi-arid Sahel in the north to the humid rainforest in the south, resulting in substantial spatial variability in rainfall distribution (Adefolalu, 1986). In recent decades, rainfall patterns have become increasingly unpredictable due to climate change, intensifying extreme events such as floods and droughts (Oladipo, 1995).

Traditional statistical approaches fail to detect subtle changes in rainfall patterns over time. Advanced statistical techniques, such as control charts, have gained relevance in environmental monitoring. Among these, the Exponentially Weighted Moving Average (EWMA) control chart is particularly effective for identifying small and gradual shifts in time-series data (Montgomery, 2009). This study

applies EWMA control charts to monitor rainfall variability across Nigeria's geopolitical zones, providing empirical evidence to support climate adaptation and risk management strategies.

EWMA control charts are widely used for monitoring time-series data because of their ability to detect small and gradual shifts while accommodating autocorrelation. They have been applied to rainfall, temperature, and drought monitoring in climatology. Bovens et al. (2010) demonstrated their effectiveness in identifying long-term precipitation trends in Europe, whereas Kumar and Iyer (2015) applied EWMA charts to rainfall variability in India to support agricultural decision-making.

Several studies have highlighted the relevance of EWMA charts for detecting extreme rainfall events and seasonal shifts (Becker et al., 2012; Singh et al., 2013). In the African context, EWMA-based analyses have been used to identify rainfall anomalies linked to climate variability. However, non-normality, seasonality, and smoothing parameter selection remain critical considerations (Alwan et al., 1995; Mokhtar et al., 2014). This study extends the existing literature by applying EWMA control charts to long-term rainfall data across Nigeria's six geopolitical zones, offering a comprehensive spatial perspective.

II. METHODOLOGY

2.1 Data Description

The study utilizes yearly average rainfall data derived from monthly observations across Nigeria's six geopolitical zones (North-West, North-East, North-Central, South-West, South-East, and South-South) from 1981 to 2022. Data were obtained from the Nigerian Meteorological Agency.

2.2 EWMA Control Chart

Let X_1, X_2, \dots , be a sequence of observations that are normally distributed with mean μ and variance σ^2 . Assuming the process $X_t \sim N(\mu, \sigma^2)$ is in control for some period, say $t \leq t_0$, on the other hand, when $t > t_0$, the process $X_t \sim N(\mu_1, \sigma^2)$ is out of control because of the unknown mean shift of the process, such that μ_1 is the out-of-control mean of the process. Let $Y_t \sim (X_t - \mu)/\sigma$, then $Y_t \sim N(0,1)$, for $t \leq t_0$, and $Y_t \sim (\delta, 1)$, for $t \geq t_0$, such that $\delta = |\mu_1 - \mu|/\sigma$ are the standardized mean shift. Generally, t_0 and δ are unknown occurrence times and relative shift sizes, respectively. An EWMA control chart-based statistic is given as follows:

$$EWMA_t = \lambda \bar{Y}_t + (1 - \lambda)EWMA_{t-1} \quad (1)$$

where λ is the smoothing parameter ($0 < \lambda < 1$), \bar{Y}_t is the standardized observed value at time t and $EWMA_{t-1}$ is the previous EWMA value. The quantity $EWMA_0$ represents the starting value, often the target value μ_0 .

This scheme signals when statistic $EWMA_t$ exceeds specified control limit. In general, the upper and lower control limits of the EWMA Chart for time varying are given by

$$\begin{cases} CL = \mu_0 + L\sigma \sqrt{\frac{\lambda}{2-\lambda}(1 - (1-\lambda)^{2t})} \\ CL = \mu_0 \\ UCL = \mu_0 - L\sigma \sqrt{\frac{\lambda}{2-\lambda}(1 - (1-\lambda)^{2t})} \end{cases} \quad (2)$$

L is suitable in the control width limit, and σ is the standard deviation of the process. Montgomery (1996) provides a detailed discussion on EWMA control schemes.

2.2.1 Implementation of the EWMA for monitoring Data Collection: Rainfall data would need to be collected over a significant period (e.g., monthly data spanning several years) from different meteorological stations across Nigeria's geopolitical zones.

Smoothing Parameter (λ): The choice of λ depends on the data variability. A typical value might range between 0.1 and 0.3, though it could be adjusted based on the rainfall data characteristics in each zone.

2.2.2 EWMA Chart Construction:

Step 1: Select a smoothing constant λ based on the expected variability in rainfall patterns.

Step 2: The EWMA values for each month are calculated using the formula.

Step 3: The EWMA values are plotted over time to identify any trends or shifts in rainfall patterns.

Control Limits: Control limits can be set to monitor whether the rainfall falls within the expected levels. If the EWMA value exceeds the control limits, it could indicate a significant change in the rainfall pattern, which might warrant further investigation or intervention.

2.2.3 Analytical Procedure

Descriptive statistics were computed and the spatial precipitation was presented to examine the rainfall distribution across the six geopolitical regions. The EWMA charts were then constructed for each geopolitical zone to identify trends, anomalies, and shifts in rainfall patterns.

III. RESULTS AND DISCUSSION

3.1 Descriptive Statistics of the Study

Table 2: Rainfall data from various geopolitical zones

	NW	NE	NC	SW	SE	SS
Max	129.68	105.85	144.09	179.61	245.16	259.57
Min	48.66	27.17	60.65	74.56	139.18	141.78
Mean	86.71	72.69	100.86	125.57	196.50	192.61
SD	16.59	13.05	18.96	24.15	24.73	27.57
Skewness	0.66	-0.74	0.23	0.06	-0.22	0.26
Kurtosis	0.87	3.11	-0.05	-0.35	0.05	-0.42

Source: Analysis

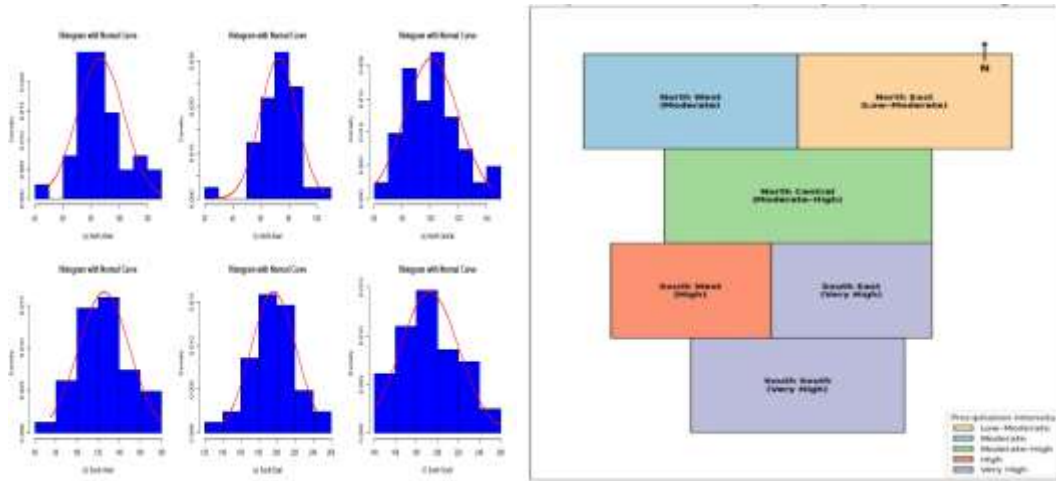


Figure 1: Precipitation distribution by geopolitical zone in Nigeria,

Table 1 shows the clear spatial variation in rainfall across Nigeria’s geopolitical zones, reflecting a pronounced north-to-south climatic gradient. The southern zones, particularly the South–South and South–East, recorded the highest mean and maximum rainfall values, whereas the South–West exhibited relatively high but moderate levels. The North–Central zone represents a transitional region with moderate rainfall, whereas the North–West and North–East zones experience the lowest mean and minimum rainfall amounts. The rainfall variability is generally higher in the southern zones, indicating greater fluctuations in precipitation intensity, whereas the northern zones show lower variability but persistently low rainfall. The skewness and kurtosis values suggest near-normal rainfall distributions with occasional extremes. Figure 1 visually reinforces these results by highlighting higher precipitation concentrations in southern Nigeria and decreasing rainfall in the northern zones.

3.2 Implementation of the EWMA Chart

In this section, the EWMA statistic $EWMA_t$ is computed using Equation (1), and the upper lower control limit of the EWMA chart is determined using Equation (2), since the focus is on detecting an upward and downward shift. A tabular EWMA data scheme was developed to monitor and detect any change in the rainfall statistics across the geopolitical zones in Nigeria using screening data obtained from the NMA between January 1981 and December 2022.

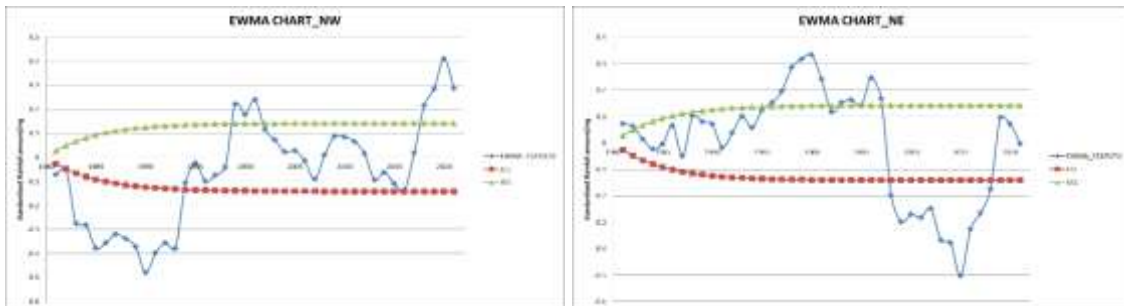
The out-of-control Average Run Length (ARL_0) is assumed to be 370, and the chart coefficient L and smoothing constant λ are set to 2.73 and 0.1, respectively. The observed data and the corresponding values of the EWMA statistic $EWMA_t$ and control limits are presented in Table 3 and plotted on the EWMA control chart as given in figure 2(a)-(f). The EWMA chart designed to detect upward and downward shifts will indicate an out-of-control signal whenever $LCL < EWMA_t > UCL$.

Table 3: Components of the EWMA Control Chart for various geopolitical zones in Nigeria $\lambda = 0.1, L = 2.73$ and $ARL_0 = 370$

EWMA_STATISTIC						CONTROL LIMITS	
NW	NE	NC	SW	SE	SS	LCL	UCL
-0.073	0.072	-0.107	-0.012	0.025	0.066	-0.027	0.027
-0.050	0.062	-0.218	-0.174	0.039	0.018	-0.049	0.049
-0.274	0.014	-0.110	-0.368	-0.167	-0.133	-0.067	0.067
-0.282	-0.024	-0.207	-0.377	-0.220	-0.104	-0.081	0.081
-0.378	-0.005	-0.193	-0.435	-0.185	-0.126	-0.093	0.093
-0.357	0.065	-0.236	-0.552	-0.125	-0.167	-0.102	0.102
-0.320	-0.051	-0.370	-0.439	-0.207	-0.025	-0.110	0.110
-0.339	0.101	-0.368	-0.246	-0.118	0.010	-0.116	0.116

-0.373	0.080	-0.345	-0.269	-0.044	-0.134	-0.121	0.121
-0.480	0.070	-0.274	-0.230	0.092	-0.096	-0.125	0.125
-0.399	-0.018	-0.317	-0.144	0.161	-0.123	-0.128	0.128
-0.356	0.037	-0.057	-0.225	0.162	-0.211	-0.131	0.131
-0.380	0.099	-0.156	-0.158	0.085	-0.110	-0.133	0.133
-0.107	0.057	-0.170	-0.263	0.171	-0.074	-0.135	0.135
-0.025	0.123	-0.103	-0.182	0.238	-0.017	-0.136	0.136
-0.100	0.152	-0.050	-0.123	0.337	0.007	-0.137	0.137
-0.075	0.195	0.107	0.052	0.473	0.005	-0.138	0.138
-0.042	0.285	0.276	-0.100	0.194	0.082	-0.139	0.139
0.221	0.316	0.232	-0.195	0.228	0.140	-0.140	0.140
0.177	0.333	0.150	-0.258	0.196	0.025	-0.140	0.140
0.239	0.239	0.169	-0.287	0.155	-0.028	-0.140	0.140
0.115	0.117	-0.060	-0.144	0.136	-0.063	-0.141	0.141
0.072	0.151	-0.159	-0.067	0.180	-0.009	-0.141	0.141
0.022	0.162	-0.292	-0.004	-0.034	-0.140	-0.141	0.141
0.027	0.141	-0.204	-0.010	-0.068	-0.213	-0.141	0.141
-0.016	0.245	-0.152	0.022	-0.064	-0.012	-0.142	0.142
-0.092	0.167	-0.243	0.100	-0.110	0.151	-0.142	0.142
0.009	-0.198	-0.113	0.135	0.007	0.049	-0.142	0.142
0.086	-0.299	-0.130	0.073	0.203	0.146	-0.142	0.142
0.083	-0.270	-0.113	0.006	0.089	-0.053	-0.142	0.142
0.065	-0.283	0.011	0.120	0.078	-0.140	-0.142	0.142
0.014	-0.249	0.043	0.074	0.038	-0.136	-0.142	0.142
-0.094	-0.368	0.060	0.126	-0.079	-0.172	-0.142	0.142
-0.064	-0.379	-0.052	0.337	-0.165	-0.042	-0.142	0.142
-0.110	-0.504	-0.007	0.194	-0.185	-0.153	-0.142	0.142
-0.138	-0.326	0.033	0.143	-0.162	-0.134	-0.142	0.142
0.017	-0.266	0.034	0.170	-0.279	0.012	-0.142	0.142
0.214	-0.177	0.245	0.149	-0.207	-0.008	-0.142	0.142
0.285	0.095	0.270	0.319	0.002	0.235	-0.142	0.142
0.410	0.070	0.317	0.245	-0.072	0.066	-0.142	0.142
0.287	-0.003	0.299	0.299	-0.080	0.161	-0.142	0.142

From Analysis



(a): North-West

(b): North-East

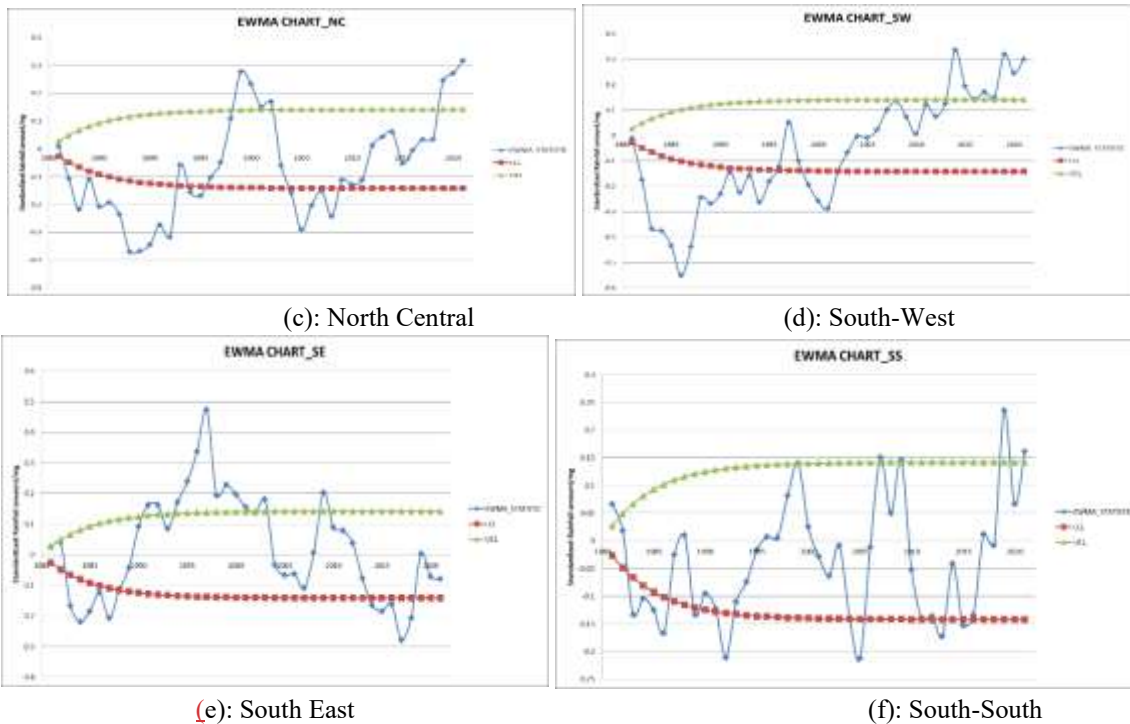


Figure 2: EWMA Charts for monitoring rainfall statistics from different geopolitical zones

Figures 2(a)–2(b) present the EWMA control charts, which reveal clear regional differences and long-term shifts in rainfall anomalies across Nigeria. In the North-West, prolonged low rainfall dominated the early years (1981–1993), followed by brief high-rainfall spikes around 1999–2001, a long period of relative stability, and a recent sharp increase above the upper control limit, indicating intensifying wet conditions likely linked to climate change. The Northeast experienced stable rainfall in the early 1980s, sustained high rainfall anomalies between 1996 and 2006, a prolonged drought phase from 2007 to 2017, and more stable conditions in recent years. In the North-Central region, extended drought periods occurred in the 1980s and mid-2000s, which were interrupted by short episodes of excessive rainfall around 1999–2002. In recent years, a strong upward trend has been observed beyond the control limit. The Southwest showed early drought conditions, a long phase of moderate variability, and a marked rise in rainfall anomalies from 2013 to 2021, indicating increasingly extreme wet events. In the southeast, alternating drought and excessive rainfall phases were observed, with notable dry periods in the mid-1980s and mid-2010s and strong wet anomalies in the 1990s and late 2000s. The South-South region exhibited intermittent drought episodes alongside pronounced high-rainfall anomalies in selected years, while most periods reflected moderate variability. The EWMA charts

highlight growing rainfall instability and recent upward trends in several regions, underscoring the influence of climate change and the need for improved agricultural planning, water resource management, and disaster preparedness nationwide. These findings are consistent with recent evidence of climate-induced hydrological changes in Nigeria (Okoro, 2023). The observed north-south contrast underscores the need for regional climate adaptation and risk management strategies.

IV. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

This study demonstrates the effectiveness of Exponentially Weighted Moving Average (EWMA) control charts for monitoring rainfall variability across Nigeria's geopolitical zones. The results reveal increasing climatic disparities, with prolonged dry conditions in the northern regions and rising rainfall variability in the southern zones. These patterns are consistent with the growing influence of climate change and associated environmental risks.

4.2 Recommendations:

- Strengthening meteorological monitoring systems to enable real-time rainfall assessment.

- Integrating EWMA-based rainfall monitoring into agricultural planning, flood control, and water resource management
- Build technical capacity on statistical monitoring tools among policymakers and climate stakeholders.
- Extend future research to incorporate additional climatic variables, such as temperature and humidity, for comprehensive climate risk assessment.

REFERENCES

- [1] Bovens, P., et al. (2010). "Detection of long-term climate trends in rainfall patterns." *European Journal of Climate*.
- [2] P. M. S. N. Kumar and D. N. R. Iyer (2015). "EWMA for monitoring rainfall variability in India." *Indian Journal of Meteorology*.
- [3] Becker, P., et al. (2012). "EWMA for detecting trends in rainfall data in Central Africa." *Journal of Climate Research*.
- [4] Singh, R., et al. (2013). "Application of EWMA in seasonal rainfall patterns of India." *Agricultural Meteorology Journal*, vol., p..
- [5] Jaramillo, L., et al. (2011). "EWMA in drought monitoring in South America." *International Journal of Water Resources*.
- [6] Okoro, U.K. (2023). Decadal rainfall trends and variability across Nigeria. *International Journal of Environment and Climate Change*. <https://doi.org/10.9734/ijecc/2023/v13i113434>.
- [7] Ogundari et al. (2023). Rainfall variability and trends in Nigeria: implications for agricultural production *Microeconomics Studies*
- [8] Research Square (2023). Rainfall, Drought, and Flood Events in Nigeria: Variability and Climate Change Implications
- [9] Adefolalu, D. O. (1986). Rainfall trends in Nigeria. *Theoretical and Applied Climatology*, 37(3-4), 205–219. <https://doi.org/10.1016/j.tclim.1986.16.009>.
- [10] Oladipo, E. O. (1995). Some statistical characteristics of drought area variations in the savanna region of Nigeria. *Theoretical and Applied Climatology*, 50(2), 147–155. <https://doi.org/10.1016/j.tacc.1995.1995>.
- [11] Montgomery, D. C. (2009). *Introduction to statistical quality control* (6th ed.). Wiley.