Journal of Environmental Protection, 2026, 17(3), 158-177
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Analyzing Rainfall, Temperature, and Socioeconomic Factors behind Migration Trends

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How to cite this paper: Ishaku, D., Umaru, E.T., Adebayo, A.A., Löwner, R., Erdanaev, E. and Okhimamhe, A.A. (2026) Analyzing Rainfall, Temperature, and Socioeconomic Factors behind Migration Trends. *Journal of Environmental Protection*, **17**, 158-177.
https://doi.org/10.4236/jep.2026.173008

Received: November 24, 2025
Accepted: March 2, 2026
Published: March 5, 2026

Abstract

Climate change increasingly impacts environmental and socio-economic systems in vulnerable regions such as West Africa. This study investigates the relationship between long-term climate variability and migration patterns in north-eastern Nigeria, using rainfall and temperature data from 1981-2021 alongside migration statistics and household surveys. Non-parametric trend and correlation analyses reveal significant warming trends and high spatial variability in rainfall, while correlations between climate variables and net migration are weak and statistically non-significant. Qualitative evidence indicates that livelihood constraints and insecurity, rather than climate alone, are the primary drivers of migration. These findings suggest that climate change functions as an indirect stress multiplier, highlighting the need for policies that integrate climate adaptation with socio-economic development.

Keywords

Migration, Climate Change, Rainfall, Temperature, and Spearman's Rank Correlation

1. Introduction

Human migration is increasingly driven by environmental changes, particularly in vulnerable regions. Environmental changes are playing an increasingly important role in shaping human migration, particularly in regions highly sensitive to climate variability. Variability in rainfall, rising temperatures, and land degradation are undermining livelihoods, especially in rain-fed farming communities [1] [2]. As a result, people are moving in search of better living conditions, adding environmental stressors to the traditional economic, social, and political drivers of migration [3] [4]. Globally, climate-related displacement has been observed in regions including South Asia, Latin America, and the Middle East, highlighting the widespread implications of environmental stress on human mobility [5].

The Sahel region of Africa exemplifies this crisis, where desertification, prolonged droughts, and declining agricultural productivity drive population movements and reshape rural landscapes [6]. Evidence from countries such as Zambia and Ethiopia shows that migration often serves as a coping mechanism in response to deteriorating environmental conditions and failing agricultural systems [7] [8]. In Nigeria, the north-eastern states represent an acute manifestation of these dynamics. Historically reliant on fertile lands and robust agriculture, the region now faces a convergence of environmental stressors and socio-political pressures. Climate extremes are compounded by insecurity from insurgency and armed conflict, collectively disrupting agriculture and displacing millions [9] [10].

These migration patterns reshape demographic structures, strain urban infrastructures, and drive unsustainable land use changes [11]. As of 2023, north-eastern Nigeria hosts over 2.3 million internally displaced persons (IDPs), predominantly women and children [12]. Despite these challenges, research on the interplay between environmental change, insecurity, and migration in Nigeria remains limited, particularly in the northeast.

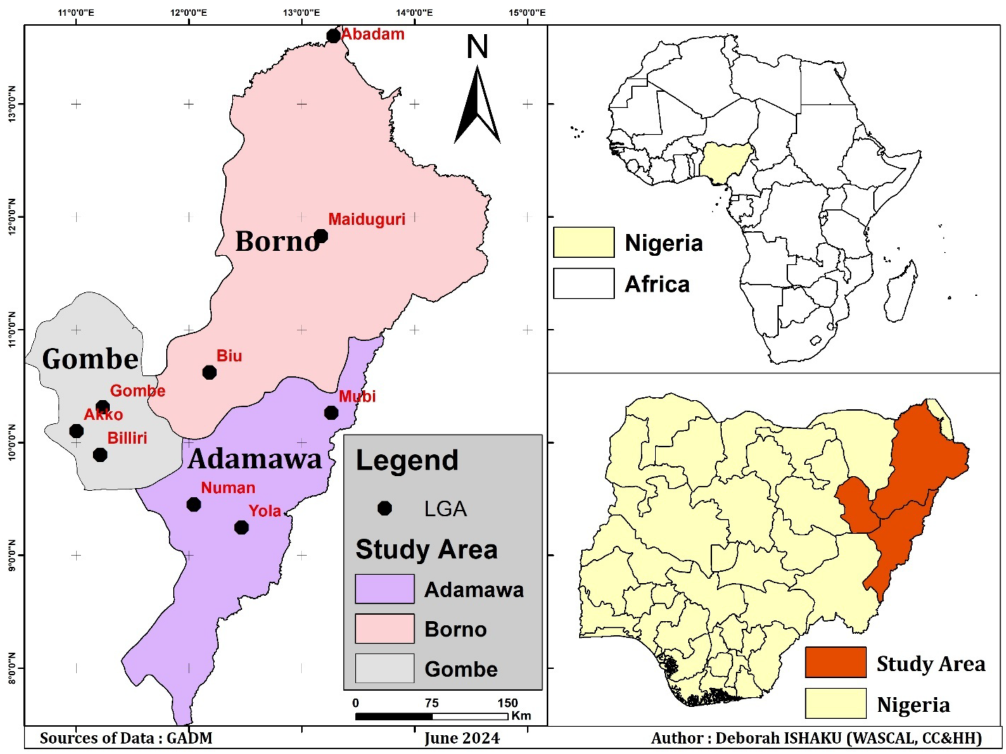
Recognition of climate change as a migration driver is growing, yet adaptive policies and effective interventions lag. The Intergovernmental Panel on Climate Change [13] warns that climate-related migration may become a defining human security challenge of the 21st century, particularly in fragile states. As land resources dwindle and migration intensifies, pressures on food security, social cohesion, and ecosystem services are likely to increase [14]-[16].

This study addresses a critical knowledge gap by analyzing rainfall, temperature, and socio-economic factors behind migration trends in north-eastern Nigeria, integrating climatic data with household survey insights and migration statistics. The research aims to identify the drivers of mobility and propose evidence-based policy interventions focused on land use planning, climate adaptation, and humanitarian response. Ultimately, the study seeks to support the development of more resilient communities in one of Nigeria's most vulnerable regions.

2. Materials and Methods

2.1. Study Area

North-eastern Nigeria covers approximately 279,203 km^2 between latitudes 6˚30'N - 14˚00'N and longitudes 8˚30'E - 15˚00'E. This study focuses on Adamawa, Borno, and Gombe due to their ecological sensitivity, socio-economic vulnerability, and strategic relevance (Figure 1). The region experiences a tropical continental climate with wet and dry seasons [17] [18]. The terrain is generally flat with scattered hills and is characterized by savanna vegetation zones [19] [20].



Source: [2].

Figure 1. The study area.

2.2. Data Sources and Design

This study utilized a mixed-methods approach, integrating quantitative and qualitative data to analyze the relationship between climate variability and human migration. Gridded monthly rainfall and temperature datasets from the NASA POWER database (1981-2021), and net migration data (accessed August 2024) obtained from the World Bank's open data platform (http://data.worldbank.org) for 1981-2021 at ten-year intervals were utilized. Spearman's rank correlation was used to determine relationships among the study variables. Net migration data were utilized for regional studies because they provide a reliable and consistent measure of overall population movement where detailed migration flows are unavailable. They also allow for long-term trend analysis, are less affected by data gaps common in data-scarce regions, and effectively indicate whether a region is a net sender or receiver of population.

2.3. Primary Data Collection and Sampling

385 structured questionnaires were administered across the study area in 2023. The sample size was determined using a standard sample size calculator based on

the total population. A purposive sampling technique was employed. The questionnaire was designed to capture key dimensions, including demographic characteristics; drivers of migration (environmental, economic, and social); livelihood impacts and vulnerabilities; and attitudes toward migration and migration patterns at both origin and destination.

A test-retest reliability assessment was carried out. Thirty participants were surveyed twice, within a two-week interval. For ordinal Likert-scale items, Spearman's rank correlation coefficient was used; the result shows 0.775, indicating a high level of consistency over time. For continuous variables such as income estimates and household size, Pearson's correlation coefficient produced a value of 0.824 ($p < 0.01$), indicating temporal stability.

2.4. Data Analysis

Descriptive statistics (percentages) were used to summarize responses. Spearman's rank correlation was applied to assess the association between climate variables (rainfall and temperature) and migration-related decisions. Key informant interviews were conducted with local leaders and some community stakeholders. Information drawn from these interviews helped improve the findings.

1) Inverse Distance Weighting Interpolation of Rainfall, Maximum and Minimum Temperature

Inverse Distance Weighting (IDW) interpolation is a deterministic interpolation technique that predicts values at unknown locations by averaging known values from nearby locations with varying weights based on their distance [21] [22]. This method assumes that closer values are more similar than those farther apart. As distance increases, the influence of known values decreases.

The mean annual rainfall, mean annual maximum temperature (Tmax), and mean annual minimum temperature (Tmin) for four distinct periods—a) 1981-1990, b) 1991-2000, c) 2001-2010, and d) 2011-2021—were interpolated from their native grids onto a $0.05^{\circ} \times 0.05^{\circ}$ resolution, aligning with the grid of the observed data. To map the spatial distribution of mean annual rainfall and mean annual maximum and minimum temperatures, the Inverse Distance Weighting (IDW) interpolation method was employed using ArcGIS 10.8. This method allowed the generation of spatial estimates of climate variables, highlighting localized trends. The Sen's slope value was then calculated for each grid point to quantify the rate of change (increase or decrease) in these climatic variables over the study period.

Although NASA POWER data are already gridded, IDW interpolation was used to improve spatial continuity and alignment with the study region's boundaries. IDW served mainly as a resampling and visualization tool, not to create new data, allowing coherent regional analysis without introducing additional statistical assumptions.

2) Sen's Slope Estimator (SSE)

Sen's slope estimator is applied in calculating the magnitude of trends in time series data. The technique is preferred over simple linear regression because it provides a better estimation of the trend. It is often used for estimating significant linear trends in time series data, which is used in research studies. The slope T_i between two points of a time series x is calculated by Equation (1) [23];

$$T_i = \frac{x_j - x_k}{j-1} \quad \text{for} \quad i = 1,2,3,\cdots,n \tag{1}$$

$k = 1$ to $n-1$, $j = 2$ to n, x_j and x_k are data values at times j and k ($j > k$), respectively. If the time series x has n point observations, there will be $N = n(n-1)/2$ slope values. Sen's method estimates the slope as the median of the N values of Q. The Q as a slope estimator can be calculated by (Equation (2)).

$$Q = \begin{cases} T_{(N+1)/2}, N\ odd \\ \dfrac{T_{N-2} + T_{(N+2)/2}}{2}, N\ even \end{cases} \tag{2}$$

3) Shapiro-Wilk Normality Test of the data

The Shapiro-Wilk normality test indicates whether each column's data is normally distributed. The test is more frequently employed for smaller sample sizes (n < 50). It is important because many statistical methods assume normality, and knowing if the data is normally distributed helps in choosing appropriate analytical techniques [24]. A p-value greater than 0.05 suggests normality, while a p-value less than 0.05 suggests non-normality. The test was carried out using various packages in Python software, using functions from libraries such as pandas, NumPy, and SciPy.

4) Spearman's Rank Correlation Coefficient Analysis

Spearman's rank correlation analysis was used to establish the correlation between net migration and climate parameters (Equation (3)) in the study location using various packages in Python software with functions like pandas, numpy, scipy, matplotlib, pyplot, and seaborn.

Spearman's Rank Correlation is a non-parametric measure of the strength and direction of association between two ranked variables. It evaluates a monotonic relationship and can capture both linear and non-linear associations. The Spearman correlation coefficient is denoted as ρ_s. The formula for it is:

$$\rho_s = 1 - \frac{6\Sigma \mathrm{d}_i^2}{n\left(n^2-1\right)} \tag{3}$$

where d_i is the difference between the ranks of corresponding variables and n is the number of observations. The Spearman correlation coefficient ranges from −1 to 1. A value of 1 indicates a perfect positive relationship, −1 indicates a perfect negative relationship, and 0 indicates no relationship. It is widely used where data may not be normally distributed or where the relationship between variables is not linear [25].

Due to the violation of normality in one of the variables, as indicated by the Shapiro-Wilk test, Spearman's rank correlation coefficient was selected as the appropriate statistical method.

5) Relationship between Climate Change and Migration

To determine the impact of climate change (using rainfall and temperature data) and migration (using net migration data), a correlation coefficient analysis was conducted. Before that, the Shapiro-Wilk normality test was performed.

3. Result

3.1. Rainfall, Maximum and Minimum Temperature

1) Mean Annual Rainfall

Table 1 presents the mean annual rainfall values across four decadal intervals along with the Sen's slope estimates for the period 1981-2021 across the study area. The Sen's slope estimate for Adamawa State is +0.853, indicating a moderate upward trend. In contrast, Borno State exhibits a negative slope of −2.401, suggesting a slight but consistent decline in rainfall. Gombe State records a positive slope of +1.896, also indicative of a moderate increase. When averaged across the three states, the mean Sen's slope is −0.442, suggesting a general but modest decline in mean annual rainfall for the entire region during the 41-year period [2].

Table 1. Mean annual rainfall.

State	1981 to 1990	1991 to 2000	2001 to 2010	2010 to 2021	Slope from 1981 to 2021	Remark
Adamawa	1140.29	1091.7	926.62	1019.33	0.853	Moderate Increase
Borno	628.65	652.72	548.75	697.22	−2.401	Low Decrease
Gombe	954.78	988.63	753.91	1033.83	1.896	Moderate Increase
Mean Total	871.56	871.59	721.5	874.63	−0.442	Low Decrease

2) Mean Annual Maximum Temperature

Table 2 summarizes the mean annual maximum temperature values for the same time intervals, alongside Sen's slope estimates from 1981 to 2021. Adamawa State recorded a Sen's slope of +0.060, signifying a moderate increase. Borno State, with a slope of +0.035, indicates a slight increase. Gombe State shows a similar trend, with a slope of +0.046, reflecting a low to moderate rise in maximum temperatures. The regional mean Sen's slope across the three states is +0.046, pointing to an overall warming [2].

Table 2. Mean annual maximum temperature.

State	1981 to 1990	1991 to 2000	2001 to 2010	2011 to 2021	Slope from 1981 to 2021	Remark
Adamawa	40.53	41.56	42.22	42.27	0.060	Moderate Increase
Borno	43.18	43.56	44.27	44.11	0.035	Low Increase
Gombe	41.22	41.75	42.4	42.54	0.046	Low Increase
Mean Total	41.87	42.51	43.19	43.16	0.046	Low Increase

3) Mean Annual Minimum Temperature

Table 3 displays the mean annual minimum temperature, along with Sen's slope values. Adamawa State shows a slight increase in minimum temperatures, with a Sen's slope of +0.005. Borno and Gombe States exhibit minor negative trends, with slope values of −0.010 and −0.008, respectively, both suggesting very minimal decreases in minimum temperatures. The average Sen's slope across the three states is −0.005, implying a negligible overall decrease in minimum temperature in the region over the study period [2].

Table 3. Mean annual minimum temperature.

States	1981 to 1990	1991 to 2000	2001 to 2010	2011 to 2021	Change 1981 to 2021	Remark
Adamawa	12.21	12.33	12.41	12.13	0.005	Low Increase
Borno	11.48	11.01	10.94	10.87	−0.010	Very low decrease
Gombe	11.64	11.34	11.75	11.09	−0.008	Low Decrease
Mean Total	11.77	11.54	11.62	11.36	−0.005	Low Decrease

3.2. Factors Influencing Migration

The socio-demographic profile of migrants (Table 4) shows that over 80% are aged between 15 and 45, with a significant male representation of 64.06%. Most are married (53.15%) and have varied education levels, though 22.80% lack formal education. Economically, 60% earn below ₦52,000 a month, and 16.56% report no income, indicating financial vulnerability.

Table 4. Demographic characteristics of respondents.

Variable	percentage
Age	
Below 15 years	5.83
15 - 25 years	22.50
26 - 35 years	33.46
36 - 45 years	24.13
46 - 55 years	9.20
56 and above	4.88
Sex	
Male	64.06
Female	35.94
Marital Status	
Single	41.06
Married	53.15
Divorced	2.73
Widowed	3.06

Continued

Education Level	
No Formal education	22.80
Primary	11.39
JSS	6.06
SSS	22.76
Tertiary	28.26
Others	8.73
Monthly Income	
Less than 26,000 Naira	28.00
26,001 - 52,000 Naira	32.00
52,001 - 104,000 Naira	16.02
104,001 - 156,000 Naira	3.96
156,001 - 260,000 Naira	1.56
Above 260,000 Naira	1.90
No earnings	16.56
Household Size	
Single	27.03
2 - 5	33.96
6 - 10	31.16
11 - 20	5.60
21 - 30	1.83
31 - above	0.42

Source: Field work, 2023.

Most migration occurs within states (individual states of the study area) and the north-eastern regions, highlighting internal displacement rather than cross-border movements (**Figure 2**). In **Figure 3**, the primary motivations include insecurity (32.86%), job-seeking opportunities (35%), and educational pursuit (20.73%), with environmental factors being less significant (4.46%). Despite challenges—such as (**Figure 4**) high transportation costs (28.36%)—83% feel their livelihoods improve post-migration (**Figure 5**).

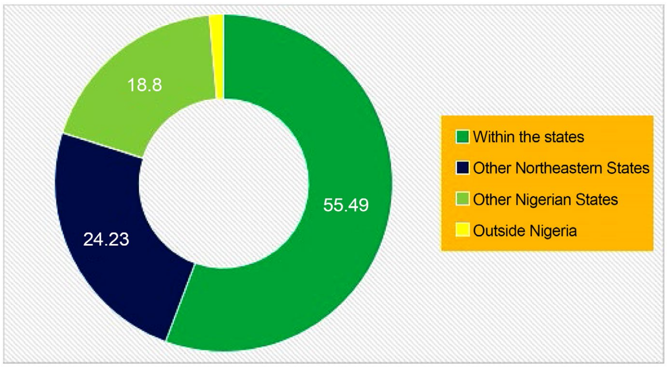


Figure 2. Migrants' origins.

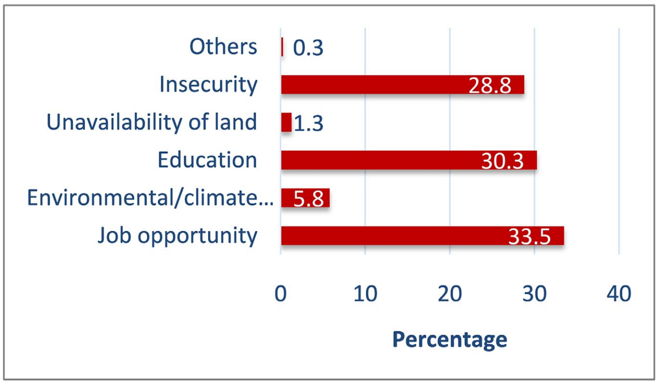


Figure 3. Reasons for Migration.

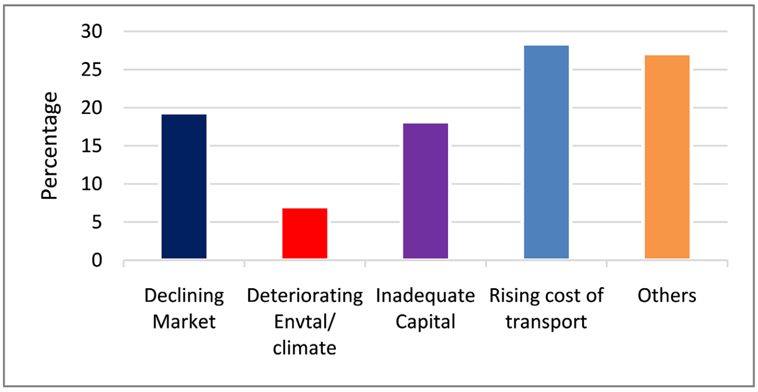


Figure 4. Barriers to the main livelihood.

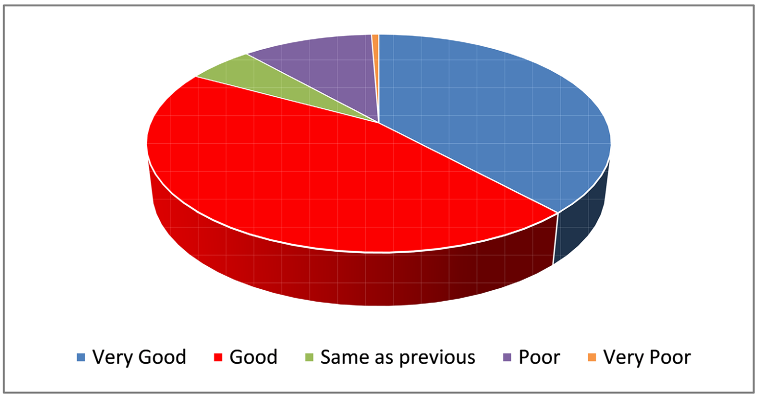


Figure 5. Comparison of livelihoods between at present location and previous location.

In Figure 6, many migrate individually (38.80%) or with family (29.26%), facing financial strain (49.56%) and housing issues (26.76%) at their destinations (Figure 7). Positive impacts of migration at destination areas include new ideas and increased labor supply; however, concerns arise from unemployment, overcrowding, and resource strain (Figure 8). At the origin, migration reduces pressure on amenities but leads to labor depletion and diminished competitiveness, contributing to community degradation (Figure 9).

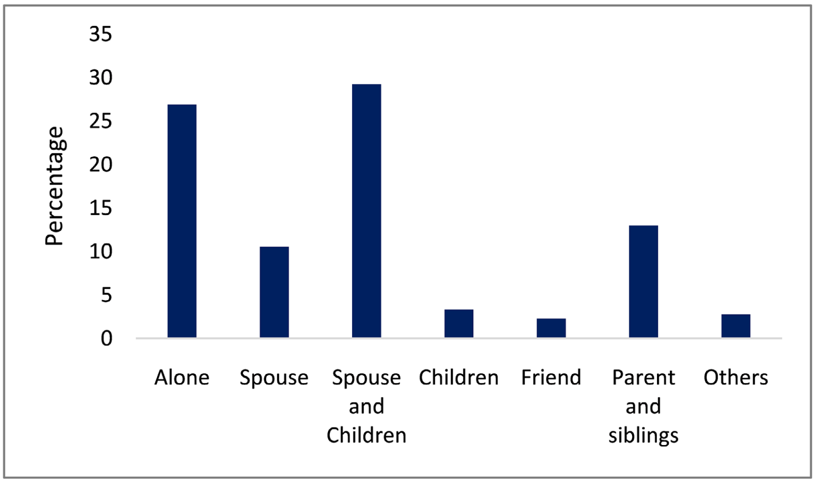


Figure 6. Migration companions.

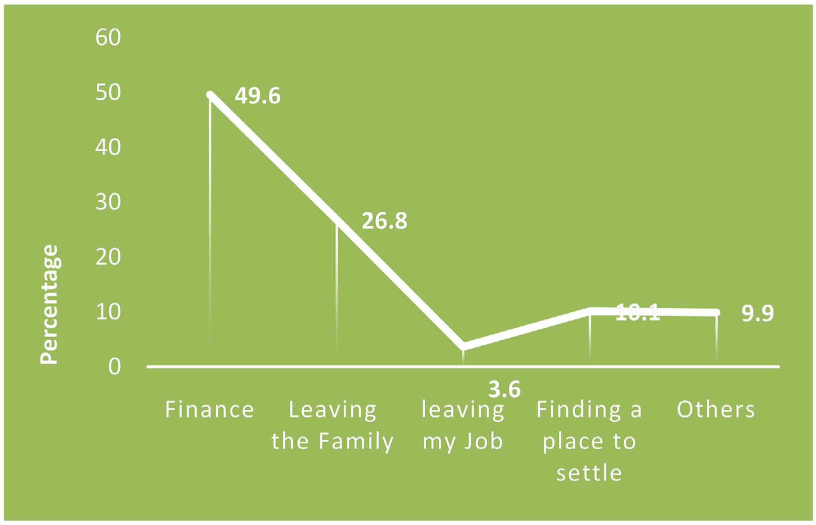


Figure 7. Challenges of leaving one's origin.

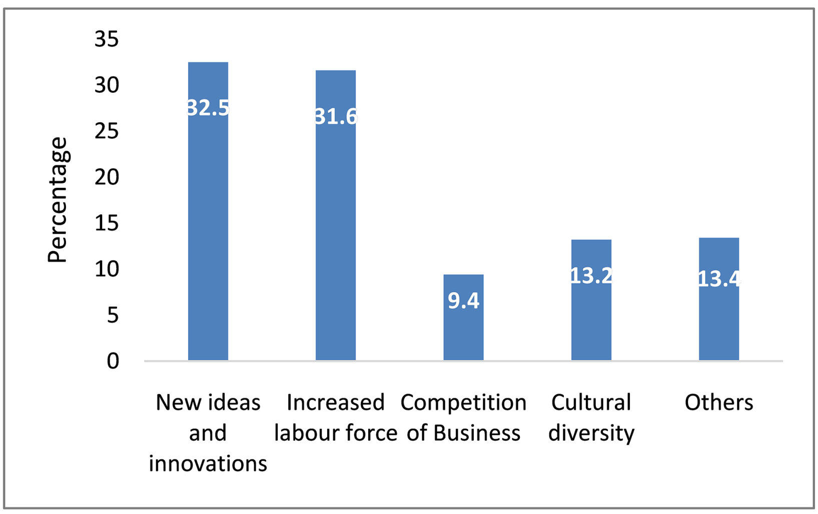


Figure 8. Positive effect of migration on the destination.

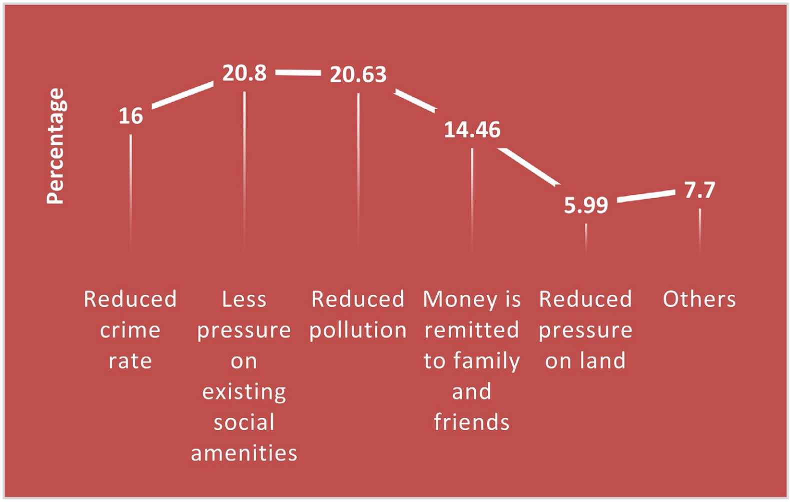


Figure 9. Positive effect of migration on origin.

3.3. Relationship between Net Migration and Rainfall, Tmax, and Tmin

1) Shapiro-Wilk test

Table 5 displays the Shapiro-Wilk test results, indicating that Net Migration, Tmax, and Tmin follow normal distributions ($p > 0.05$), while Rainfall does not ($p = 0.0023$).

Table 5. Shapiro-Wilk test.

Variable	W-statistic	P-value	Normal
Net Migration	0.7793	0.07	Yes
Rainfall	0.6467	0.0023	No
Tmax	0.877	0.3258	Yes
Tmin	0.9954	0.9833	Yes

2) Spearman's Rank Correlation Analysis

A strong negative correlation was observed between net migration and annual rainfall ($p = -0.80$), but it was not statistically significant ($p = 0.20$). The analysis also revealed a moderate positive correlation ($p = 0.40$) between net migration and maximum temperature; the relationship was not statistically significant ($p = 0.60$). Similarly, a moderate positive correlation ($p = 0.40$) was found between net migration and minimum temperature. This association was also not statistically significant ($p = 0.60$).

4. Discussion

1) Rainfall, Maximum and Minimum Temperature Trends

The results indicate a general decline in rainfall over the study period, with a Sen's slope value of −0.0442, signifying a low but consistent decrease (Figure 10). This finding aligns with the regional patterns identified by [26]-[28], who reported spatial variability in rainfall, with decreasing trends in the southern and northern zones of Gombe State and an increasing trend in the central region. In Adamawa State, [29] similarly observed a general reduction in rainfall across most of the territory. However, [30] [31] presented contrasting evidence of increasing rainfall trends in parts of Borno and Adamawa States from 1970 to 2015, suggesting potential decadal variability and spatial heterogeneity across the sub-region.

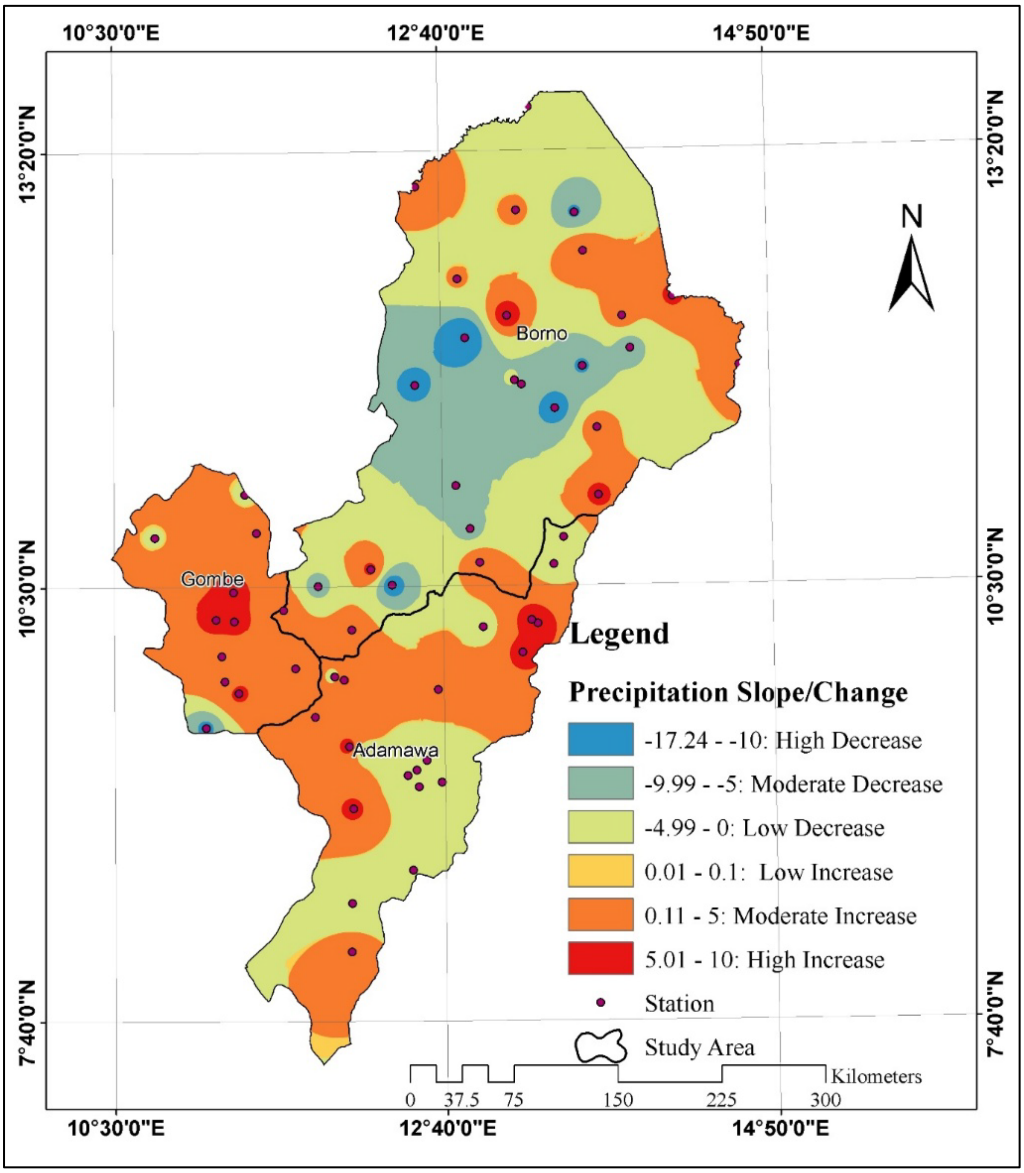


Figure 10. Rainfall (1981 to 2021).

The mean annual maximum temperature showed a Sen's slope value of +0.046, indicating a low but consistent increase over the 40 years (**Figure 11**). This observation is supported by the findings of [26] [28] [32], all of whom reported statistically significant increases in maximum temperature in Gombe State. Similar upward trends have been documented in Adamawa by [29] [33] [34]. These findings confirm that warming conditions are becoming more pronounced in north-eastern Nigeria, consistent with global climate change projections.

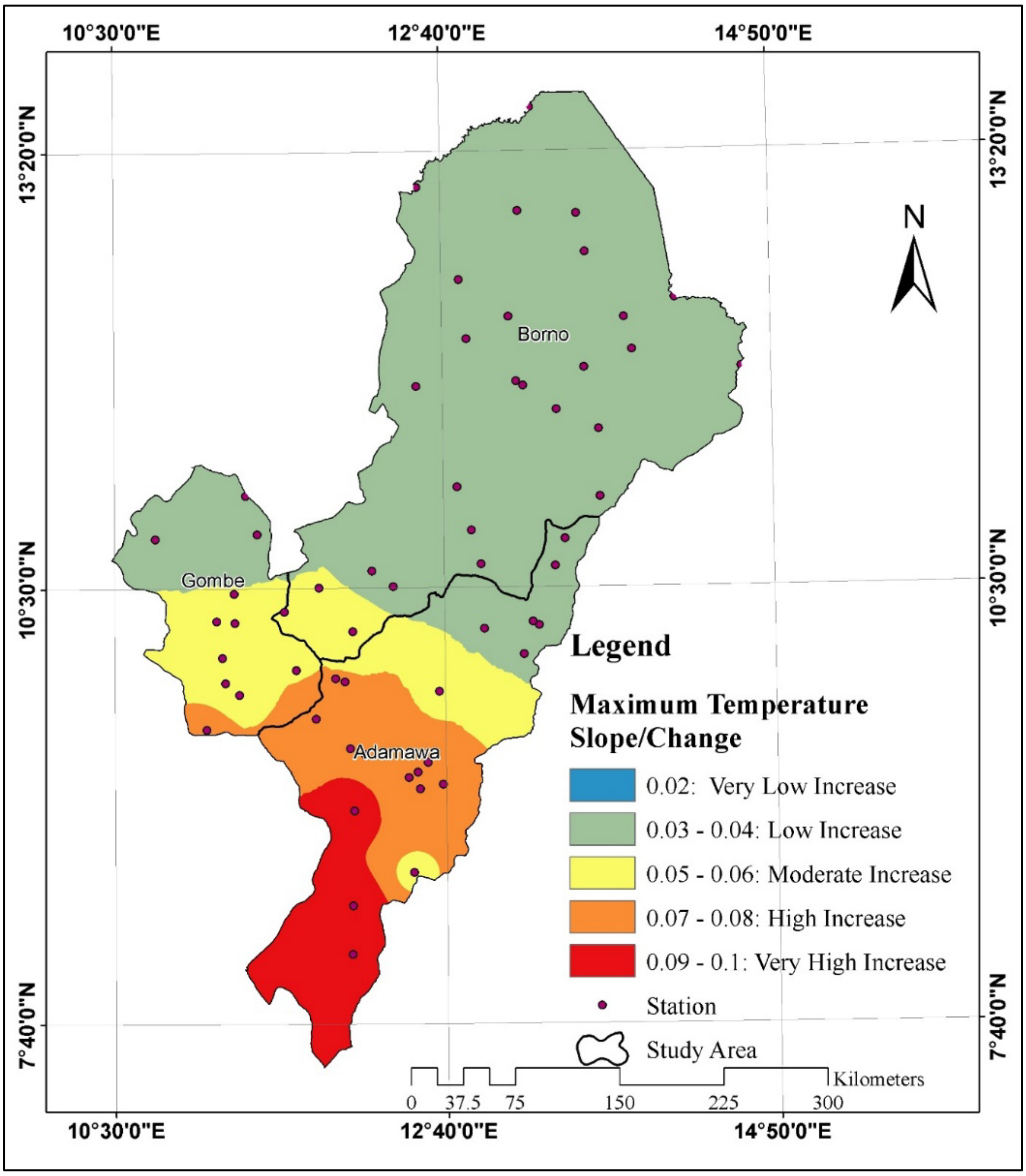


Figure 11. Tmax (1981 to 2021).

The mean annual minimum temperature exhibited a slight negative trend, with a Sen's slope value of −0.005 (**Figure 12**). This suggests a very mild decline in nighttime temperatures, diverging from previous studies. For instance, [26] [35] reported increasing minimum temperatures across Gombe and Adamawa States, while [32] observed a similar upward trend (albeit statistically insignificant) between 1987 and 2016. [34] also found rising minimum temperatures in Borno. The discrepancy observed in this study could be attributed to local microclimatic variations, differences in elevation, vegetation loss, or land cover change effects—factors known to influence nighttime cooling rates.

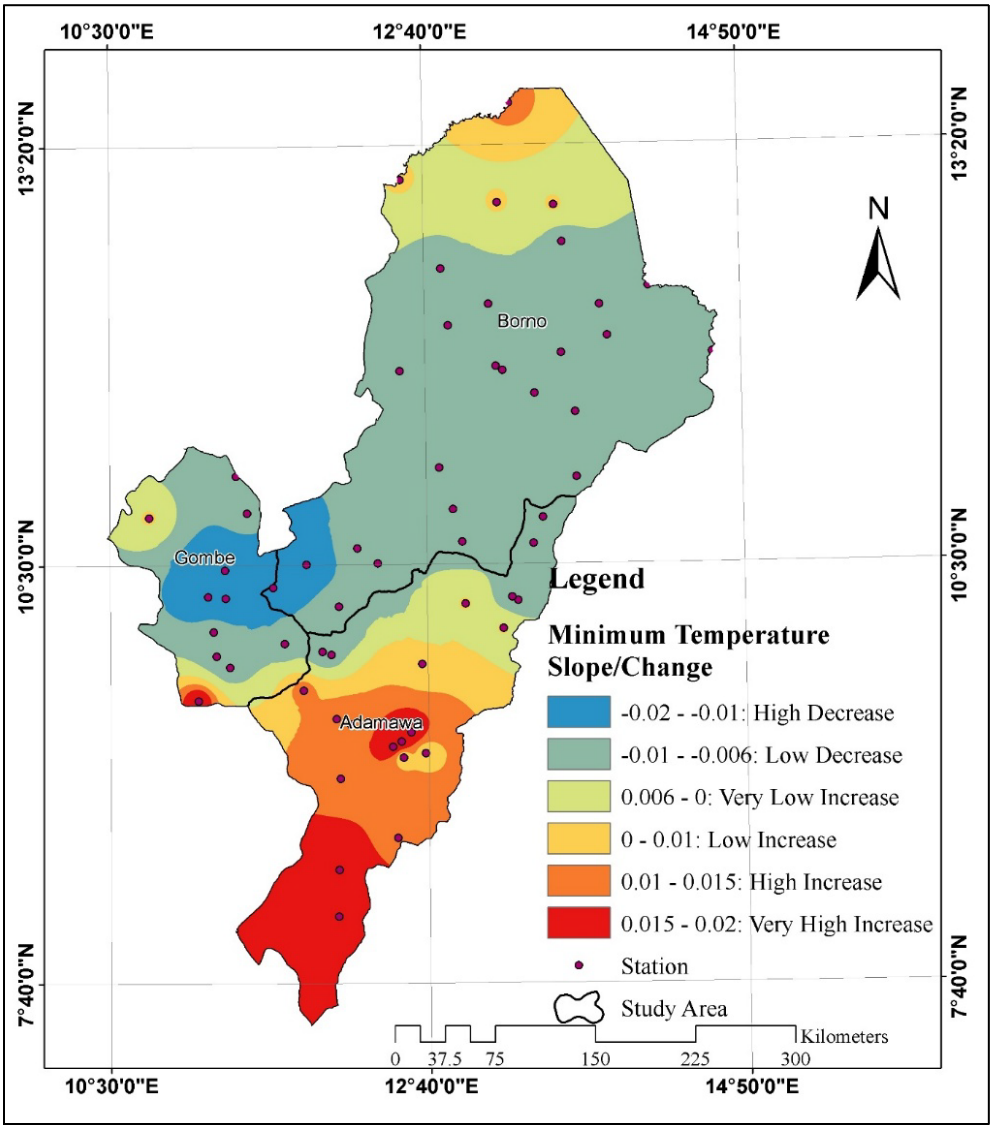


Figure 12. Tmin (1981 to 2021).

2) Migration Dynamics, Patterns, Drivers, and Impacts

The study on migration dynamics in North-eastern Nigeria highlights a complex landscape shaped by a young, mobile population battling socio-economic vulnerabilities, environmental stress, and persistent insecurity. Most migrants are young, with over 60% possessing formal education, yet many are low-income earners displaced by conflict, as noted by [36]. Migration patterns are primarily internal, with individuals moving to nearby areas that share cultural ties for better access to services, as observed by [37], and resembling global trends identified by [38].

The main drivers are conflict, terrorism, and climate change, particularly the impacts of insurgency and the shrinking of Lake Chad, as emphasized by [39]. While humanitarian agencies like the government, the International Organization for Migration (IOM), the National Emergency Management Agency (NEMA), the

State Emergency Management Agency (SEMA), and other non-governmental organizations (NGOs) have provided vital assistance, migrants face challenges such as loss of family connections and food insecurity, reflecting the push-pull dynamics discussed by [40] [41]. They also encounter social issues like loneliness and discrimination, with young males often leading migration trends [36]. Environmentally, migration has resulted in pollution and unregulated development at destinations, while causing the abandonment of farmland at origins, consistent with the findings of [42]. Therefore, while migration can provide new opportunities and adaptation strategies, it simultaneously exposes deep vulnerabilities. The findings call for sustainable interventions, including strengthening education and vocational training, improving social protection, investing in climate-resilient agriculture, and better urban planning to transform migration into a choice rather than a last resort for survival.

3) Relationship between Climate Change and Migration

The relationship between climate variability and migration was explored using Spearman's rank correlation analysis, complemented by insights from existing qualitative and survey-based literature. While the statistical analysis provides useful contextual signals, the findings are interpreted cautiously, recognizing that migration decisions are shaped by multiple interacting social, economic, and security-related factors.

The analysis revealed a strong negative correlation between net migration and annual rainfall ($p = -0.80$), suggesting that periods of higher rainfall may be associated with reduced outward migration. This pattern is consistent with qualitative evidence showing that adequate rainfall supports agricultural productivity and livelihood stability, thereby reducing the need for mobility [43]. However, the lack of statistical significance ($p = 0.20$) indicates that rainfall alone cannot be considered a decisive driver of migration. Rather, rainfall variability appears to influence migration indirectly by affecting livelihood security, as also emphasized by [44], who showed that households often adopt migration as a coping strategy when environmental stress interacts with economic vulnerability.

Similarly, moderate positive correlations were observed between net migration and both maximum and minimum temperatures ($p = 0.40$), suggesting a possible association between rising thermal stress and increased migration. Nonetheless, these relationships were not statistically significant ($p = 0.60$), limiting their explanatory power. This finding aligns with [45], which reported that temperature variations did not significantly influence migration decisions in Somalia, largely due to local adaptive capacities and non-climatic constraints.

Qualitative and comparative studies further highlight that climate factors do not operate in isolation. While [46] documented cases in the Global South where rising temperatures have contributed to both voluntary and forced migration, other studies emphasize context-specific responses shaped by governance, economic opportunities, and social networks [47] [48]. [49] similarly observed that migrants may consider climatic similarity when selecting destinations, underscoring the nuanced role of climate as a conditioning rather than a determining factor.

Overall, the findings suggest that climate variability in north-eastern Nigeria functions primarily as a risk amplifier, increasing vulnerability and pressure on livelihoods, rather than acting as a direct trigger of migration. Consequently, qualitative insights and survey-based evidence are essential for understanding how households perceive and respond to climatic stress, while correlation results should be interpreted as indicative patterns rather than causal relationships.

5. Conclusions

This study examines climate trends in north-eastern Nigeria from 1981 to 2021 and finds a clear shift toward lower rainfall and higher temperatures. Although these changes may seem small from year to year, their long-term effects are serious. Reduced rainfall and rising heat are drying soils and shrinking water resources, which threatens food security and the livelihoods of communities that depend on rain-fed farming.

The study also shows that climate change influences migration, but it is not the main reason people move. Instead, economic hardship, insecurity, and the search for education and better opportunities remain the strongest drivers of migration. Climate change mainly increases vulnerability, making these economic and social pressures harder to manage and more likely to push people to relocate.

Growing pressure on limited land and water resources is increasing social tensions and local conflicts, while also limiting people's ability to adapt or move safely. Therefore, policies should not focus solely on climate adaptation. Effective responses must combine climate strategies with economic development, social protection, and youth empowerment to reduce forced migration.

A key limitation of this study is the lack of detailed migration data at the state and local levels. National statistics may miss important local and cross-border movement patterns. Future studies should utilize more detailed migration data and qualitative methods to gain a deeper understanding of how households make migration decisions. Strong climate monitoring systems and evidence-based policies will be essential for reducing displacement risks and supporting long-term stability in the region.

Acknowledgements

The work is part of the Doctoral Research Program on Climate Change and Human Habitat of the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) at the Federal University of Technology Minna, Niger State, Nigeria, sponsored by the German Federal Ministry of Education and Research (BMBF).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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