Assessment of Climate Variability and Pastoral Adaptation for Sustainable Livestock Production in Wawa Zange Grazing Reserve, Gombe State, Nigeria

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Abstract
Climatic variability in the Wawa Zange grazing reserve of Gombe State, Nigeria, is marked by erratic rainfall and moderate warming, intensifying water scarcity, pasture degradation, and livestock stress while heightening pastoralist vulnerability. This study assessed rainfall and temperature trends from 1983 to 2023, pastoralist adaptation strategies, livestock performance under climate stress, and institutional responses for sustainable production. The Rainfall Anomaly Index (RAI), linear regression, and Mann–Kendall tests were applied to climate records, while Pearson correlation examined rainfall–temperature relationships. Qualitative data were collected from 113 pastoralists, complemented with policy and institutional analysis. Results reveal a significant positive trend in rainfall anomalies (+0.036 units yr^{-1}, $p=0.009$) alongside modest, statistically insignificant temperature increases (+0.012 °C yr^{-1}, $p=0.18$). Weak correlation ($r \approx 0.18$, $p>0.1$) indicates rainfall variability as the dominant climatic driver of hydrological recharge and forage availability. Respondents reported pasture decline, drought, and livestock health challenges, while institutional review highlighted weak extension services, fragmented policy delivery, and limited adaptation financing. Findings suggest resilience in Wawa Zange depends on rainfall-responsive strategies, including water harvesting, fodder banking, and rotational grazing, supported by heat mitigation, decentralized extension, and empowered pastoralist councils to strengthen adaptation in the face of rising climate variability.

Keywords
Adaptation, Climate variability, Extension services,Livestock production, Pastoralists, Policy support, Rainfall anomaly, Resilience

1. Introduction

Climate change has become one of the most pressing global challenges, and Nigeria is no exception. Increasingly, it features in national policy debates and development planning, particularly with the federal government's commitment to achieve net-zero emissions by 2060 through a range of projects and adaptation initiatives (Okeke *et al*., 2023). The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as ―a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability

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observed over comparable time periods.‖ In scientific terms, it is recognized as a statistically significant variation in the mean state or variability of climate over time, driven by natural processes, external forcing, or persistent anthropogenic changes such as greenhouse gas emissions and land use modification (IPCC, 2001). Evidence shows that global mean surface temperature has risen by 0.74°C since the late 19th century, with projections of a further increase of 1.5–6.0°C by the end of the century if current trends persist (IPCC, 2007). Atmospheric CO_2 concentrations, which stood at 280 ppm in 1850, have already surpassed 365 ppm and could exceed 700 ppm by 2100 under a business-as-usual scenario (IPCC, 2001). Such climatic shifts have far-reaching implications for ecosystems, agriculture, and livelihoods, particularly in developing countries where dependence on natural resources is high.

Adaptation has emerged as a crucial response strategy, defined as actions that reduce vulnerability to observed or expected climate impacts, including extreme weather events, biodiversity loss, food insecurity, and water scarcity (UNDP). Adaptation can be reactive, in response to current variability, or anticipatory, in preparation for projected future impacts (Adger, 2000; Klein, 2002). In Nigeria, adaptation is gradually gaining traction through policies and frameworks such as the Updated Nationally Determined Contributions (NDCs, 2021), the Climate Change Act (2021), the National Adaptation Plan (NAP), and the Nigerian Adaptation Communication (ADCOM) (Federal Ministry of Environment, 2024). Yet, the pace and scale of adaptation are uneven, especially in rural communities where institutional support is limited. This situation is particularly critical in sub-Saharan Africa, where climate change impacts are projected to undermine development gains, hinder progress toward the Sustainable Development Goals (SDGs), and intensify challenges in food security, health, and political stability (FAO, 2008). The continent's high vulnerability is attributed to weak adaptive capacity, overreliance on agriculture, marginal climate conditions, and socio-economic stressors such as poverty, debt, and conflict (IPCC, 2001a; Nanduddu, 2010). These vulnerabilities are magnified in Nigeria's semi-arid regions, where livestock production—dominated by cattle, sheep, and goats—accounts for a substantial share of agricultural output but faces mounting stress from desertification, pasture decline, and water scarcity (ADCOM, 2021).

Nigeria's climate trajectory illustrates the seriousness of the challenge. Rising temperatures, erratic rainfall, desertification, land degradation, and flooding have been widely documented (Elisha *et al*., 2017; Ebele & Emodi, 2016; Olaniyi *et al*., 2013). The country ranks among the ten most vulnerable globally in the World Climate Change Vulnerability Index (Maplecroft, 2014), 18th out of 135 countries in Germanwatch's Climate Risk Index, and 160th out of 181 in Notre Dame's Global Adaptation Initiative. These indicators underscore systemic exposure to climate hazards. Rainfall variability, in particular, has intensified, producing higher runoff and floods in the south, while northern regions experience drought and heat extremes (Enete, 2014; Akande *et al*., 2017; Amanchukwu *et al*., 2015). Projections suggest continued warming across all ecological zones, threatening biodiversity, food production, and water supplies (Federal Ministry of Environment, 2014). Agriculture and hydropower—key sectors for growth and poverty reduction—are among the most climate-sensitive, with disruptions to water flows, crop yields, and livestock productivity (USAID, 2013). Gombe State illustrates these dynamics. Recent assessments of climate governance ranked it second only to Lagos in adaptation performance nationally (Federal Ministry of Environment, 2024). It also has one of

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the country's largest livestock populations, with over 117,000 cattle, highlighting both its economic significance and its exposure to climate risks (State Ministry of Agriculture and Animal Husbandry, 2024). Despite abundant research on climate change impacts in Nigeria, most scholarship focuses on crop farming, leaving significant gaps in understanding livestock systems. Yet, livestock herding remains central to rural livelihoods in semi-arid Nigeria and is particularly sensitive to rainfall and temperature variability. In Gombe State's Wawa Zange Grazing Reserve, climate risks manifest in dwindling water resources, forage decline, and heightened disease stress (L-PRES, Feed the Future, 2023). These threats necessitate systematic investigation into climatic trends, pastoralist adaptation strategies, and the enabling or constraining role of policies and institutions. This study therefore examines historical rainfall and temperature patterns between 1983 and 2023, assesses adaptation practices employed by livestock farmers, evaluates the relationship between climatic variables and livestock production outcomes, and analyzes institutional frameworks for climate-resilient livestock development. By focusing on pastoralist adaptation rather than crop farming, the study aims to fill a critical research gap and contribute to policies that enhance resilience and sustainability in Nigeria's livestock sector.

2.0 Materials and Methods

2.1 Study Area

The study was carried out in the Wawa Zange Grazing Reserve, located in Gombe State, northeastern Nigeria. Covering about 144,000 hectares, it is one of the largest authorized grazing reserves in the country (Idris, Saulawa, & Chedi, 2024). It spans Dukku, Nafada, and Funakaye local government areas and was established in the 1960s to provide stable grazing land and reduce farmer–herder conflicts (Ingawa, Tarawali, & Kaufmann, 1989). The reserve lies within the Sudan savannah ecological zone and is characterized by a semi-arid climate with two distinct seasons: a rainy season (May–September) with annual rainfall ranging from 600–900 mm, and a dry season (October–April) marked by acute water scarcity. Temperatures peak around 37°C, while relative humidity varies between 94% in August and 10% in December (Mercy Corps, 2022). Vegetation consists of grasses, shrubs, and scattered woodlands, with fodder species critical to livestock nutrition (Hashidu, 2015). Livestock rearing, particularly of cattle, sheep, and goats, constitutes the primary socio-economic activity, although the reserve faces challenges of encroachment, resource competition, and climate-induced stress.

2.2 Research Design

A cross-sectional research design was adopted to capture information on pastoralists' characteristics, adaptation strategies, and institutional support mechanisms. This design was appropriate as it enabled data collection at a single point in time while accommodating exploratory ―what‖ and ―how‖ questions central to adaptation studies (Bryman, 2008). Both quantitative and qualitative methods were combined to generate comprehensive insights into the relationship between climate variability and livestock production.

2.3 Data Sources

Data were obtained from both primary and secondary sources. Primary data were collected through structured questionnaires administered via KoboCollect, targeting herders' socio-demographics, perceptions of climate change, coping strategies, and livestock health indicators. Face-to-face interviews were conducted in collaboration with local extension officers to ensure clarity and cultural appropriateness. Field observations provided direct evidence of pasture condition, water availability, and livestock stress, while photographs were

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taken to document observed changes. Key informant interviews with government officials, extension workers, and community leaders supplemented herders' responses and provided insights into institutional and policy frameworks. Secondary data included climatic records (1983–2023 rainfall and temperature) obtained from the Nigerian Meteorological Agency (NIMET), Gombe International Airport, and the Upper Benue River Basin Development Authority. Additional socio-economic data were derived from published reports, academic literature, and livestock population statistics provided by the Gombe State Ministry of Agriculture and Animal Husbandry (2024).

2.4 Population, Sampling, and Sample Size

The study population comprised all livestock herders resident in Wawa Zange Grazing Reserve, estimated at 160 households. First settlers occupy 22 housing blocks with about 110 herders, while second settlers account for around 50 herders. A stratified random sampling technique was used to ensure proportional representation from both groups, followed by systematic random selection within each stratum. Based on the Krejcie and Morgan (1970) sample size determination table, 113 respondents were selected, providing a statistically representative sample for robust analysis.

2.5 Data Analysis

Quantitative data were analyzed using the Statistical Package for Social Sciences (SPSS v.21). Descriptive statistics summarized respondents' characteristics and adaptation practices. Climatic trends were analyzed using rainfall and temperature time series in Excel and SPSS, with long-term trends detected using linear regression and the non-parametric Mann–Kendall test. The Rainfall Anomaly Index (RAI) was computed to measure inter-annual rainfall variability. Pearson correlation analysis was applied to examine relationships between climatic variables,livestock performance indicators, and adaptation strategies. Qualitative data from interviews and field observations were analysed thematically to complement statistical findings.

2.6 Rainfall Anomaly Index (RAI)

The RAI was employed to evaluate rainfall variability and its implications for livestock production and water resources. Historical monthly rainfall data were checked for consistency, with missing values treated using interpolation. Long-term monthly means were computed to establish baseline conditions. Anomalies were standardized and classified into categories ranging from extremely wet ($RAI > 2$) to extremely dry ($RAI < -2$). Trend analysis using regression and Mann–Kendall tests helped identify shifts in rainfall patterns. Correlation of RAI values with livestock performance provided insights into the impacts of rainfall variability on forage availability, hydrological recharge, and animal health.

2.7 Ethical Considerations

The study followed established ethical standards for research involving human participants. Informed consent was obtained from all respondents after clear explanation of the study's purpose, procedures, and voluntary nature. Confidentiality and anonymity were ensured, with no personal identifiers linked to survey responses. Participants retained the right to withdraw at any stage without consequence. Key informants were also briefed, and their professional inputs were handled respectfully. Sensitive household and livelihood information was treated with caution to prevent misrepresentation. Data were stored securely and used exclusively for academic and policy purposes. The research adhered to international guidelines for ethical conduct in social and climate studies.

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3.0 Results

3.1 Demographic Characteristics of Respondents

The socio-demographic features of herders in Wawa Zange Grazing Reserve reveal an economically active but educationally constrained population (Table 1). Respondents were largely within the productive age bracket of 26–30 years (27.4%), while middle-aged groups (41–55 years) also featured strongly. Males dominated (63.7%), reflecting cultural patterns in pastoral communities, although this underrepresents the important but less visible roles of women.

Educational attainment was generally low, with 41.6% having only secondary education and 34.5% possessing Qur'anic education (non formal education). Only one respondent had post-secondary training. This implies that while indigenous knowledge is strong, formal literacy needed for accessing modern climate information remains limited.

Table 1. Demographic characteristics of respondents (n=113)

Variable	Category	Frequency	Percentage (%)
Age	18–25	20	17.7
26–30	31	27.4	
31–40	18	15.9	
41–55	32	28.3	
56+	12	10.7	
Gender	Male	72	63.7
Female	41	36.3	
Education	Non formal education	39	34.5
Primary	26	23.0	
Secondary	47	41.6	
Tertiary	1	0.9	

3.2 Livestock Ownership and Production Trends

Livestock rearing was diversified across cattle, goats, sheep, and poultry (Table 2). resilience by spreading risk across species, buffering households from climate shocks.

Small ruminants and poultry were most common (110–112 households), while cattle were reared by 82 respondents. This mixed production system provides

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Table 2. Livestock ownership among respondents

Livestock type	Frequency	Percentage (%)
Cattle	82	72.6
Sheep	110	97.3
Goats	110	97.3
Poultry	112	99.1

Herd size distribution indicated that most households owned between 10–50 animals, with very few managing over 200. Interestingly, 82% of respondents reported an increase in livestock numbers in recent years, which they attributed to better grazing conditions and improved veterinary services. This trend, however, could exacerbate pressure on forage and water resources, particularly during dry years.

3.3 Climate Variability and Local Perceptions

Pastoralists' perceptions aligned with observed climatic trends. More than 80% reported worsening water availability, while nearly 60% noted declining grazing resources. A Rainfall Anomaly Index (RAI) analysis for 1983–2023 confirmed highly variable rainfall, alternating between extremely wet and dry years (Figure 1).

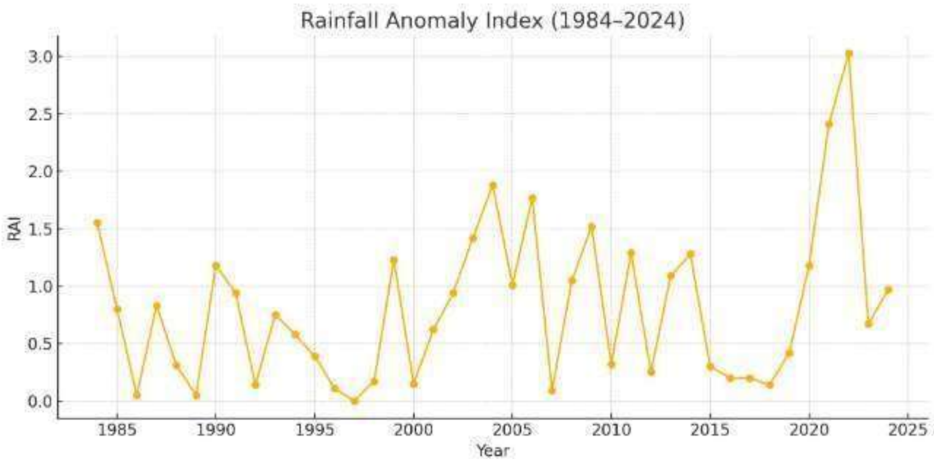

Figure 1. Annual Rainfall Anomaly Index (RAI) for Wawa Zange Grazing Reserve, 1983–2023

Regression analysis indicated a weak but positive long-term trend in rainfall, though extreme variability was evident. Conversely, mean surface temperature rose steadily, from 26.3°C in the 1980s to about 26.9°C in 2024 (Figure 2).

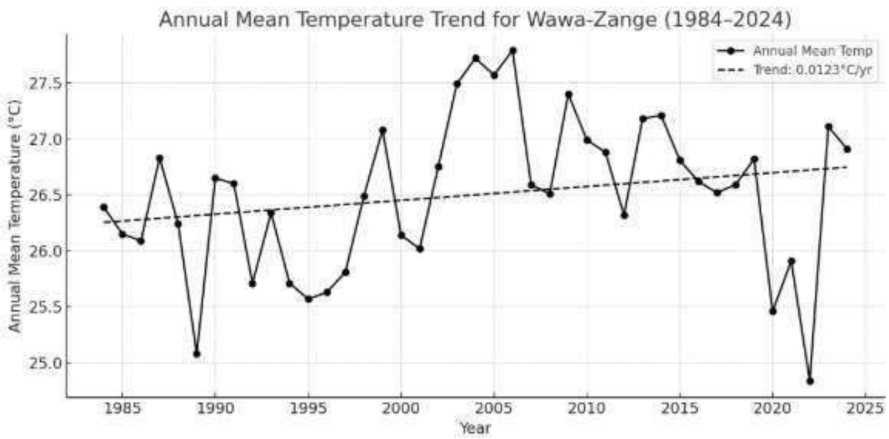

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Figure 2. Mean surface temperature trends in Wawa Zange, 1983–2023

Correlation analysis revealed a moderate negative association between rainfall and temperature anomalies (r ≈ –0.64), indicating that hotter years tended to coincide with drier conditions. This exacerbates hydrological stress, compounding forage and water shortages.

3.4 Impacts on Livestock Health and Productivity

Respondents reported mixed outcomes from climate change (Table 3). While 55% perceived positive or very positive effects, particularly improved pasture in wet years, 10.6% reported negative impacts such as heat stress and disease outbreaks. Another 33% observed no change, reflecting spatial and household-level variations in resource access.

Table 3. Perceived effects of climate change on livestock production

Effect	Frequency	Percentage (%)
Very positive	13	11.5
Positive	49	43.4
No change	37	32.7
Negative	12	10.6
Very negative	2	1.8

Forage variability emerged as the critical determinant of productivity. Wet years improved weight gain, fertility, and milk yields but also increased disease prevalence. Dry years reduced pasture quality, increased grazing distances, and heightened livestock mortality. These findings confirm rainfall anomalies as the dominant driver of pastoral performance, with temperature acting as a stress multiplier.

3.5 Adaptation Strategies

Households employed a range of strategies to cope with climate stress (Table 4). Improved water management was the most common (89.4%), followed by access to veterinary services (82.3%) and herd diversification (61.9%). Mobility (43.4%) and fodder cultivation (23.0%) were less common, while rotational grazing was rarely practiced (6.2%).

Table 4. Adaptation strategies reported by respondents

Strategy	Frequency	Percentage (%)
Improved water management	101	89.4
Veterinary services	93	82.3
Herd diversification	70	61.9
Mobility	49	43.4
Fodder cultivation	26	23.0
Rotational grazing	7	6.2

The diversity of practices reflects a pragmatic approach to risk management. However, uneven adoption was noted, shaped by household resources, education, and institutional linkages.

3.6 Institutional and Policy Frameworks

Institutional support influenced adaptation outcomes. National and state policies such as the Livestock Development Policy and Climate Adaptation Funds provided frameworks but suffered from poor outreach and weak funding. Local institutions, especially the Pastoralist Council, proved more effective, particularly in mediating grazing disputes and mobilizing communities during drought years. Extension services and NGOs contributed technical training and pasture improvement pilots, but their reach remained limited.

3.7 Climate, Production and Adaptation

Findings highlight a triangular relationship (Figure 3): climate variability directly affects forage and water resources, which in turn influence livestock productivity. Adaptation strategies mediate these impacts, with institutional support determining the extent of household resilience.

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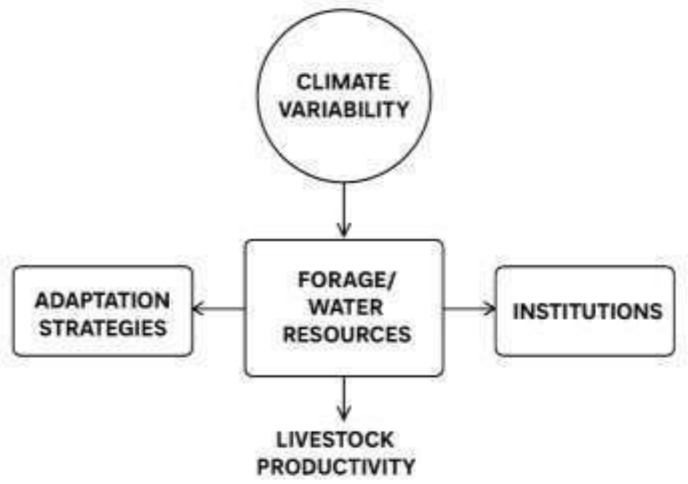

Figure 3. Conceptual nexus of climate variability, livestock production, and adaptation strategies in Wawa Zange
Households with diversified herds, access to water, and strong institutional support were more resilient, while poorer households remained vulnerable. Sustainable adaptation therefore requires integrating rainfall-responsive measures (water harvesting, fodder banking, rotational grazing) with heat mitigation strategies, underpinned by strengthened institutional coordination and community engagement.

4.0 Discussion

The results show a semi-arid system with high inter-annual rainfall variability, modest warming, a predominantly small – to medium-scale herd structure, active local adaptation, and fragmented but important local institutions. The sample is youthful but experienced: most respondents fall in the 26–30 and 41–55 age bands and 97 individuals report >20 years of experience (Table 1). Educational attainment is low (Table 1) and only a small minority are full-time pastoralists. This mix — long experience plus low formal education and growing non-pastoral livelihoods—matches patterns reported elsewhere where pastoral systems are undergoing sedentarization and livelihood diversification (Catley, Lind, & Scoones, 2013). Mixed-species herd ownership is widespread (Table 2), with nearly all households keeping small ruminants and poultry in addition to cattle. Such portfolio diversification is a well-documented risk-spreading strategy in semi-arid West Africa (Ayantunde *et al*., 2015) and helps explain why many households report stable or even increased livestock numbers despite climatic stress (Table 4).
Climatic trends, RAI and temperature. The RAI time-series shows high internal variability with punctuated extremely wet years (notably 2021–22) and numerous near-normal to wet years; the series mean RAI ≈ 0.84 (SD ≈ 0.70) and the fitted linear slope in the file is small and positive (≈ +0.008 RAI units yr^{-1}). Mean annual temperature shows a gradual rise (≈ 26.3°C → 26.9°C across the record). These patterns — dominant precipitation variability with modest warming — mirror regional findings that rainfall inter-annual variability is the primary driver of Sahelian system dynamics, with warming acting as an amplifier of water stress (Nicholson, Funk, & Fink, 2012; Thornton *et al*., 2018). The practical consequence in Wawa Zange is a climate regime that alternates between moisture surpluses (short windows of pasture abundance) and moisture deficits (lengthened dry spells and depleted baseflows), so adaptation must be flexible rather than uni-directional.

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Note on reported correlations. The Results document contains differing correlation statements (a moderate negative association r ≈ −0.64 in one place and a weak/non-significant r ≈ +0.18 elsewhere). This internal inconsistency should be resolved before final publication: rerun the correlation on the same seasonal/annual aggregation, recheck sign conventions (e.g., whether RAI was coded with reversed sign), and report p-values and sample sizes. Regardless of the exact coefficient, the broader inference from the dataset and literature remains robust: rainfall anomalies are the dominant driver of forage and hydrology, while temperature modulates evapotranspiration and disease pressure (Shongwe *et al*., 2009; Thornton *et al*., 2018).

Impacts on livestock production. Field perceptions and the quantitative indicators align: wet years improve forage, weight gain and reproduction but also expand disease and vector risk; dry years reduce pasture quality, force longer treks to water, increase mortality, and raise production costs (Table 3). This duality — benefits and costs tied to rainfall pulses — is well-known in pastoral literature (Toulmin, 2009). The data show that households with diversified herds are relatively more resilient (small ruminants tolerate feed scarcity better), matching findings from Ethiopia and Niger that species mix is a key buffering strategy (Ayantunde *et al*., 2015).

Adaptation strategies and their effectiveness. Respondents report a mix of short-term coping and longer-term adaptations: improved water management and access to veterinary services are common, herd diversification is widely used, while fodder cultivation and rotational grazing have low adoption rates. The dominance of water and veterinary measures is logical in a rainfall-driven system (water is the binding constraint). Low uptake of rotational grazing and fodder banking is concerning because those measures deliver resilience across both wet and dry phases; literature attributes slow adoption to land-tenure uncertainties, labour and capital constraints, and weak extension outreach (Catley *et al*., 2013; Ayantunde *et al*., 2015). In Wawa Zange the reported barriers — limited extension staff, poor policy outreach and undercapitalized funds — explain why low-cost but institutionally demanding practices (rotational grazing, community fodder banks) remain rare.

Institutions and policy gaps. Local institutions (the Pastoralist Council) play a decisive on-the-ground role — conflict mediation, coordinating access, and rapid response — while state/national policy instruments and funds remain under-utilized. This pattern is common: top-down policy frameworks often fail to reach pastoralists unless mediated through empowered local bodies; conversely, community institutions scale local knowledge and social capital effectively (Catley *et al*., 2013). The Results therefore support the policy prescription of strengthening decentralized extension, simplifying access to Adaptation Fund resources, and institutionalizing Pastoralist Council roles in rangeland governance.

Synthesis and implications. The results point to a triangular causal chain: rainfall variability → forage/water status → livestock productivity, with adaptation and institutions mediating outcomes. Practically, this implies priorities for Wawa Zange: (1) rainfall-responsive interventions (water harvesting, small-scale storage, managed aquifer recharge and micro-dams) to capture wet pulses; (2) expand fodder banking and targeted fodder cultivation to smooth seasonal deficits; (3) strengthen veterinary outreach timed to wet pulses to prevent disease outbreaks; (4) scale up community-based rotational grazing pilots with formal recognition of grazing corridors; and (5) simplify and decentralize finance and extension so households can adopt capital-intensive resilience measures. These prescriptions follow both the empirical signals and regional best practice (FAO; Thornton *et al*.).

Limitations and next steps. Before submission, reconcile the internal statistical inconsistencies (correlation coefficients, trend slopes) and add formal test statistics (Mann–Kendall Z and p, regression R^2 and p, sample N). Consider adding a short sensitivity analysis (e.g., RAI computed with alternative baselines or SPI/SPEI comparisons) and disaggregating perceptions by herd-size and gender to test equity in adaptive capacity. Finally, explicitly link recommended interventions to cost estimates and institutional responsibilities to strengthen policy uptake.

4. Conclusion

This study demonstrates that climate variability, particularly rainfall anomalies, is the dominant driver of pastoral livelihoods in the Wawa Zange Grazing Reserve, while rising temperatures act as a stress multiplier on water and forage resources. Pastoralists employ diverse but uneven adaptation strategies, with water management, veterinary services, and herd diversification being most common. Institutional support remains fragmented, with local councils playing a stronger role than formal policy frameworks. Sustainable livestock production will depend on scaling rainfall-responsive interventions, strengthening extension services, and empowering pastoral institutions to enhance resilience in the face of growing climatic uncertainty in semi-arid Nigeria.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' Contributions

Hauwa Muhammad conceived and designed the study. Hauwa Muhammad collected and analysed the data. Hauwa Muhammad prepared the first draft of the manuscript. All authors contributed to reviewing, editing, and approving the final version of the manuscript for submission.

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