

Assessing Land-Cover Transformation and Seasonal High-Wind Exposure in the Context of Climate Change in Bauchi, Nigeria: A Multi-Source Geospatial Analysis

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ABSTRACT

Reliable local evidence on wind-related hazards remains limited in many rapidly changing West African landscapes. This study assessed seasonal high-wind exposure, land-cover transformation and hydroclimatic variability in Bauchi Local Government Area, Nigeria, using a multi-source geospatial design. Monthly NASA POWER maximum wind speed at 10 m was used to construct a high-wind proxy, defined as the number of months per year with $WS10M_MAX \geq 8.0 \text{ m s}^{-1}$, for 1985–2024. Landsat classifications for 1984, 1994, 2004, 2014 and 2024 quantified land-cover change, while gridded rainfall and temperature series for 2005–2025 described recent hydroclimatic variability. High-wind months were strongly seasonal and concentrated in December–May. The mean annual proxy frequency varied from 4.2 months in 1985–1994 to 5.0 months in 2005–2014 before declining to 4.5 months in 2015–2024; the linear trend was weak and not statistically significant ($0.013 \text{ months year}^{-1}$, $p = 0.481$). In contrast, land-cover change was substantial: forest declined from 531.83 to 154.60 km^2 (–70.9%), cropland increased from 2641.38 to 2975.25 km^2 (+12.6%), and built-up land expanded from 33.85 to 72.27 km^2 (+113.5%). Rainfall was highly variable, including an unusually wet phase in 2020–2022, while the 2005–2025 temperature trend was not significant. The findings show that hazard exposure in Bauchi is shaped less by a simple long-term increase in regional wind speed than by recurrent seasonal high-wind conditions interacting with rapid land-surface transformation. Vegetation protection, climate-sensitive development control and locally validated wind monitoring are therefore central to risk reduction.

Keywords: wind hazard; land-use and land-cover change; NASA POWER; Landsat; climate risk; Bauchi

INTRODUCTION

Wind-related hazards are recurrent features of tropical and semi-arid environments, where convective systems, squall lines, gust fronts and dry-season wind regimes can generate damaging near-surface winds. Although individual events may be short-lived and spatially localised, their cumulative effects can be substantial where settlements contain vulnerable buildings, exposed utility networks and limited emergency-response capacity. In West Africa, organised mesoscale convective systems are especially important because they combine intense rainfall, cold-pool outflows and strong surface winds. Satellite evidence indicates that extreme rainfall and the frequency of the most intense Sahelian convective systems have increased in recent decades, while modelling and field studies link storm intensification to regional thermal gradients, wind shear and convective cold pools (Panthou et al. 2014; Taylor et al. 2017; Fitzpatrick et al. 2020; Bergametti et al. 2022).

The environmental consequences of strong winds are mediated by land-surface condition. Vegetation increases aerodynamic roughness, reduces the continuity of exposed surfaces, intercepts moving sediment and helps retain soil moisture. Conversely, the conversion of woodland and savanna to cropland, settlements and degraded surfaces can increase openness and reduce ecological buffering. Land–atmosphere interactions are not one-directional: heterogeneous soil-moisture and vegetation patterns can modify convergence, atmospheric instability and wind shear, thereby influencing convective development (Klein and Taylor 2020). Changes in forest cover can also alter surface energy and moisture exchanges over areas much larger than the sites of clearing (Alkama and Cescatti 2016). These processes do not mean that vegetation loss directly causes every windstorm, but they establish a plausible pathway through which land-cover transformation can increase the exposure and sensitivity of people, infrastructure and soils to high-wind conditions.

Bauchi Local Government Area (LGA) is a useful case for examining this interaction. The LGA contains Bauchi metropolis and extensive agricultural and peri-urban land. Over recent decades, population growth, cultivation, infrastructure development and biomass demand have transformed the landscape. At the same time, the area lies within the wider West African monsoon domain, where strong seasonal contrasts in temperature, moisture and convection influence wind conditions. Reports of roof failure, fallen trees, disrupted electricity supply and crop damage have increased public concern about windstorms in Bauchi, yet continuous, quality-controlled event inventories and dense anemometer networks are not readily available. This data constraint is common across many African cities and makes it difficult to separate meteorological trend, land-surface change and changing exposure.

Previous studies of West African storms have mainly operated at regional or continental scales, while Nigerian land-cover studies often focus on urban growth, vegetation decline or agricultural expansion without integrating a wind-hazard indicator. Local assessments sometimes compensate for missing event records by treating gridded maximum wind speed as a proxy for potentially hazardous conditions. Such an approach is useful for climate screening, but it must not be confused with an observed disaster-event series. NASA POWER meteorological products are based primarily on MERRA-2 and are distributed at approximately $0.5^\circ \times 0.625^\circ$ resolution, making them suitable for regional climatological interpretation rather than street-level wind modelling (Gelaro et al. 2017; NASA POWER 2026). A defensible local assessment therefore requires transparent proxy definition, careful interpretation and independent attention to land-cover change.

This study addresses that need by integrating a seasonal high-wind proxy with multi-epoch Landsat land-cover classification and recent rainfall–temperature variability. Its aim is to determine how the temporal structure of high-wind conditions and the scale of land-cover transformation jointly shape environmental risk in Bauchi LGA. Specifically, the study: (1) characterises the seasonality and long-term behaviour of high-wind months; (2) quantifies major land-cover transitions between 1984 and 2024; (3) evaluates recent hydroclimatic variability; and (4) identifies implications for vegetation-based risk reduction, urban planning and local monitoring. The study contributes a transparent, data-limited framework that can be replicated in other secondary cities where direct windstorm-event records remain incomplete.

MATERIALS AND METHODS

Study Area

Bauchi LGA is located in Bauchi State, north-eastern Nigeria, and includes the state capital and surrounding rural and peri-urban landscapes. The classified study boundary covers approximately 3689 km². The terrain is generally upland, with local rocky hills and drainage systems that create topographic variation within the broader Sudan–Sahel transition. Rainfall is strongly seasonal, while the late dry season and the transition to the rainy season are associated with intense surface heating, atmospheric instability and convective activity. Land use is dominated by cultivation, with forest, shrubland, settlements and water bodies forming smaller but environmentally important components.

Fig. 1 shows the position of Bauchi LGA within Bauchi State and Nigeria. The combination of a growing urban core, extensive cropland and fragmented natural vegetation makes the area particularly relevant for examining the interaction between land-surface change and seasonal high-wind exposure.

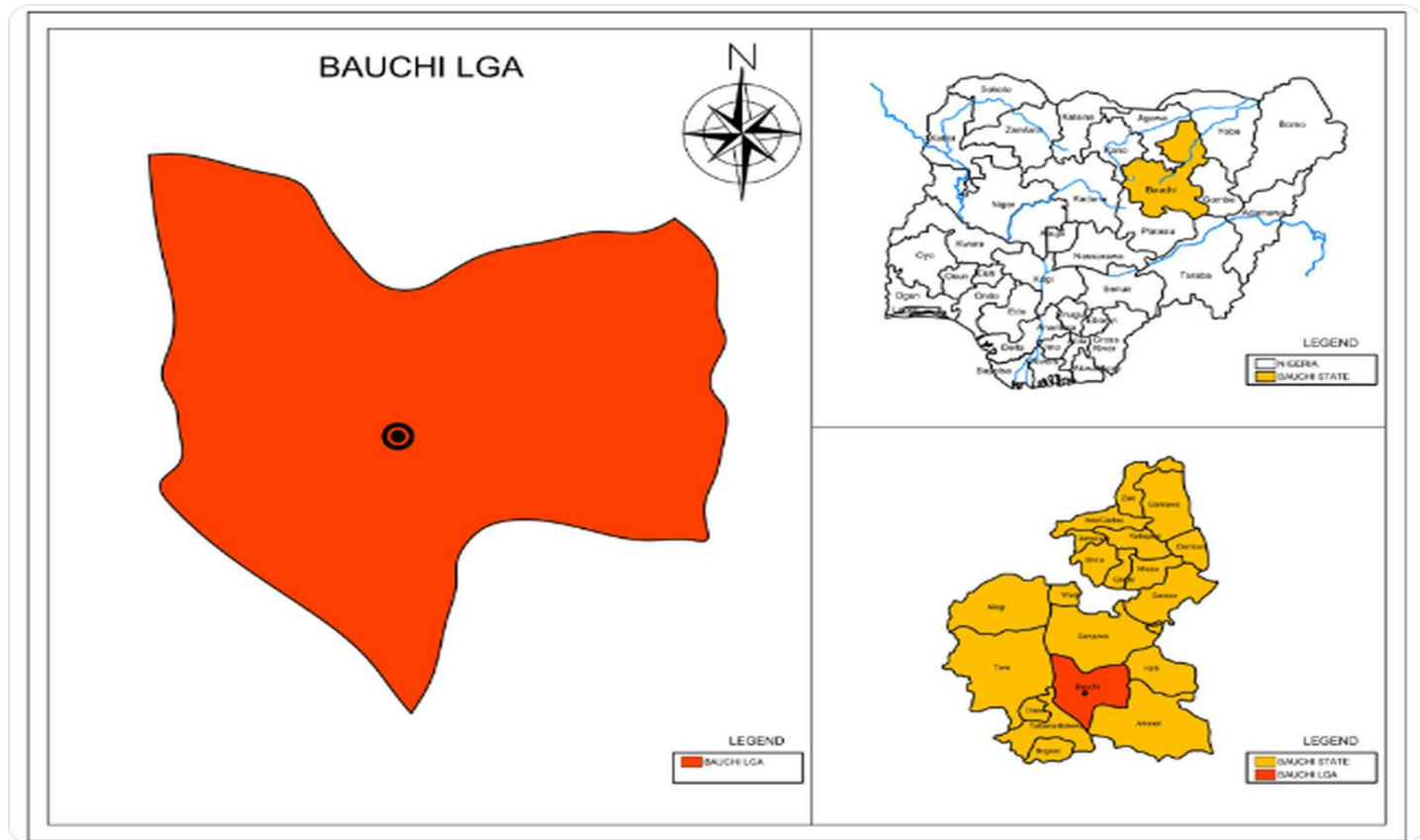


Fig. 1 Location of Bauchi Local Government Area within Bauchi State and Nigeria (source: study thesis map)

The analysis builds on the thesis dataset (Aliyu 2026) and combines reanalysis-derived meteorological variables, multi-epoch satellite imagery and administrative geospatial data (Table 1). The use of multiple temporal windows reflects data availability: the long Landsat archive supports land-cover reconstruction from 1984, whereas the quality-controlled hydroclimatic tables used for this article cover 2005–2025.

Table 1 Datasets, temporal coverage and analytical use

Dataset	Variable/product	Coverage	Resolution/units	Analytical use
NASA POWER / MERRA-2	WS10M_MAX	1985–2024	$0.5^{\circ} \times 0.625^{\circ}$; m s^{-1}	High-wind proxy; seasonal and annual frequency
NASA POWER / gridded tables	Corrected precipitation and mean air temperature	2005–2025	Daily-equivalent rainfall; $^{\circ}\text{C}$	Annual anomalies and linear trends
USGS Landsat surface reflectance	TM, ETM+ and OLI imagery	1984, 1994, 2004, 2014, 2024	30 m	Supervised land-cover classification and change detection
Administrative GIS layer	Bauchi LGA boundary	Current boundary	Vector polygon	Masking, area calculation and map production

WS10M_MAX denotes maximum wind speed at 10 m. Meteorological products are regional-scale fields and do not resolve building-scale gusts.

High-Wind Proxy and Seasonal Analysis

The available wind record consisted of monthly WS10M_MAX values rather than a verified catalogue of windstorm disasters. A high-wind month was therefore defined as a month in which WS10M_MAX was at least 8.0 m s^{-1} . The annual proxy frequency is the count of threshold-exceeding months in each year. This indicator measures the recurrence of regionally elevated wind conditions; it does not measure the number of individual storms, peak building-level gusts, damage or casualties.

Monthly observations were grouped into four climatological seasons: December–February (DJF), March–May (MAM), June–August (JJA) and September–November (SON). Decadal means were calculated to reduce year-to-year noise and reveal changes in seasonal structure. Linear least-squares trends were estimated for annual and seasonal frequency and for annual maximum wind speed. Statistical significance was evaluated at $\alpha = 0.05$. The original thesis also proposed Mann–Kendall and Sen-slope analysis, which are suitable for non-normal hydroclimatic series (Mann 1945; Sen 1968); however, the article reports the trend statistics retained with the validated threshold-derived series.

Land-Cover Classification and Change Detection

Landsat surface-reflectance imagery was used because it provides a consistent multi-decadal archive at 30 m spatial resolution. Collection 2 Level-2 surface reflectance products are atmospherically corrected and designed for multi-date surface analysis (US Geological Survey 2026). Representative images were classified for 1984, 1994, 2004, 2014 and 2024. Six classes were retained: bare surface/degraded land, built-up land, cropland/cultivated land, forest/woodland, shrubland/grassland and waterbody.

A supervised classification and post-classification comparison procedure was applied. Class areas were calculated in square kilometres and percentages of the LGA, and net change was computed as the 2024 area minus the 1984 area. Percentage change was calculated relative to the 1984 class area. Forest and shrubland were also combined as ‘natural woody cover’ to provide a broader measure of potential surface roughness and ecological buffering.

NDVI maps in the thesis were reviewed as supporting visual evidence in line with established vegetation-index applications (Tucker 1979; Pettorelli et al. 2005), but their tabulated annual trajectory was not used for inferential analysis because the underlying annual rasters and validation files were not retained with the submitted thesis package. Standard remote-sensing practice requires accuracy assessment through an error matrix and class-specific measures (Congalton 1991; Foody 2002). Consequently, the land-cover estimates are reported as map-derived results and should be independently revalidated against archived reference samples before final submission.

Hydroclimatic Variability

Annual rainfall and mean air temperature were summarised for 2005–2025 from the gridded climate tables available for the study. Anomalies were computed relative to the series mean, and standardised anomalies were calculated to permit visual comparison between variables with different units. Ordinary least-squares slopes, coefficients of determination and two-sided p values were used to describe monotonic tendencies. These short records are treated as recent variability indicators rather than evidence of long-term climate change.

Spatial climate surfaces retained in the thesis were used qualitatively to identify the broad moisture–temperature gradient across the study region. Because NASA POWER fields are coarse relative to the LGA, no neighbourhood-scale or building-scale inference was made.

Integrative Interpretation and Research Integrity

The three evidence streams were integrated descriptively rather than through causal attribution. The analysis examined whether periods and zones characterised by reduced natural cover also showed greater

environmental exposure to high-wind and hydroclimatic stress. No claim was made that land-cover change alone generated windstorms; atmospheric circulation and convection remain the primary meteorological drivers. The integrative interpretation instead focuses on how land-surface transformation can modify vulnerability, near-surface roughness, soil protection and the consequences of recurrent high-wind conditions.

A generative artificial-intelligence tool was used during manuscript preparation to assist with restructuring, language refinement and document formatting. It was not treated as an author. All numerical values were traced to the thesis or associated climate tables, and the human authors remain responsible for verifying the data, references, interpretations and final wording before submission.

RESULTS

Seasonal Pattern and Trend of High-Wind Months

High-wind exposure was strongly seasonal. DJF and MAM together accounted for most threshold-exceeding months, while JJA contributed very little and SON was secondary (Table 2; Fig. 2). The annual proxy frequency averaged 4.2 months per year in 1985–1994, 4.3 in 1995–2004, 5.0 in 2005–2014 and 4.5 in 2015–2024. The sequence therefore shows a mid-period increase followed by partial easing, rather than a continuous acceleration.

The annual frequency slope was positive but small ($0.013 \text{ months year}^{-1}$) and not statistically significant ($p = 0.481$). MAM showed the clearest upward tendency ($0.016 \text{ months year}^{-1}$), although it also fell short of the 0.05 significance threshold ($p = 0.092$). The annual maximum WS10M_MAX slope was slightly negative ($-0.020 \text{ m s}^{-1} \text{ year}^{-1}$; $p = 0.091$). The main empirical signal is therefore seasonal recurrence, especially during the late dry and pre-rainy transition, rather than a robust monotonic increase in regional maximum wind speed.

Table 2 Decadal high-wind proxy and retained trend statistics

Period/metric	DJF	MAM	JJA	SON	Annual frequency	WS10M_MAX / slope	p value
1985–1994	2.1	1.6	0.1	0.4	4.2	10.30 m s^{-1}	—
1995–2004	2.0	1.7	0.0	0.6	4.3	9.64 m s^{-1}	—
2005–2014	2.3	2.1	0.3	0.3	5.0	9.98 m s^{-1}	—
2015–2024	1.9	2.1	0.0	0.5	4.5	9.57 m s^{-1}	—
Linear trend	−0.001	+0.016	−0.001	−0.001	+0.013 yr^{-1}	−0.020 $\text{m s}^{-1} \text{ yr}^{-1}$	0.481*; 0.091†

Values for seasonal and annual frequency are mean numbers of high-wind months per year. *p value for annual proxy-frequency trend; †p value for annual maximum-wind-speed trend. MAM trend $p = 0.092$.

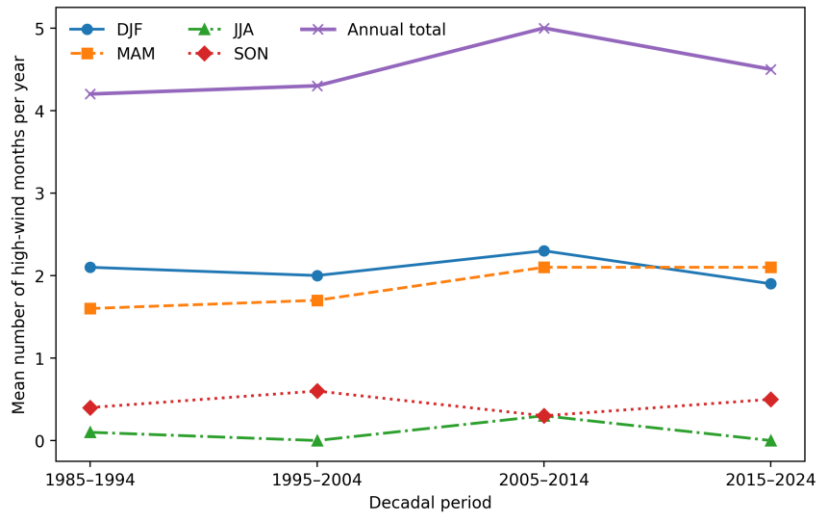


Fig. 2 Decadal seasonality of the high-wind proxy derived from monthly $WS10M_MAX \geq 8.0 \text{ m s}^{-1}$

Land-cover transformation, 1984–2024

Land-cover change was much larger and more directional than the wind-speed trend. Cropland occupied 71.7% of the LGA in 1984 and 80.7% in 2024. Its mapped area increased by 333.87 km², equivalent to 12.6% of its 1984 area. Built-up land more than doubled, increasing from 33.85 to 72.27 km² (+113.5%), although it remained less than 2% of the total mapped area in 2024.

Forest loss was the most pronounced ecological change. Forest/woodland declined from 531.83 km² in 1984 to 154.60 km² in 2024, a net reduction of 377.23 km² or 70.9%. Shrubland remained broadly stable in aggregate, increasing slightly from 470.52 to 479.60 km², although this net figure may conceal spatial turnover and degradation within the class. Combined natural woody cover fell from 1002.35 to 634.20 km², a decline of 36.7%. Fig. 3 illustrates the visible contraction and fragmentation of forest patches and the expansion of cropland and the Bauchi urban footprint.

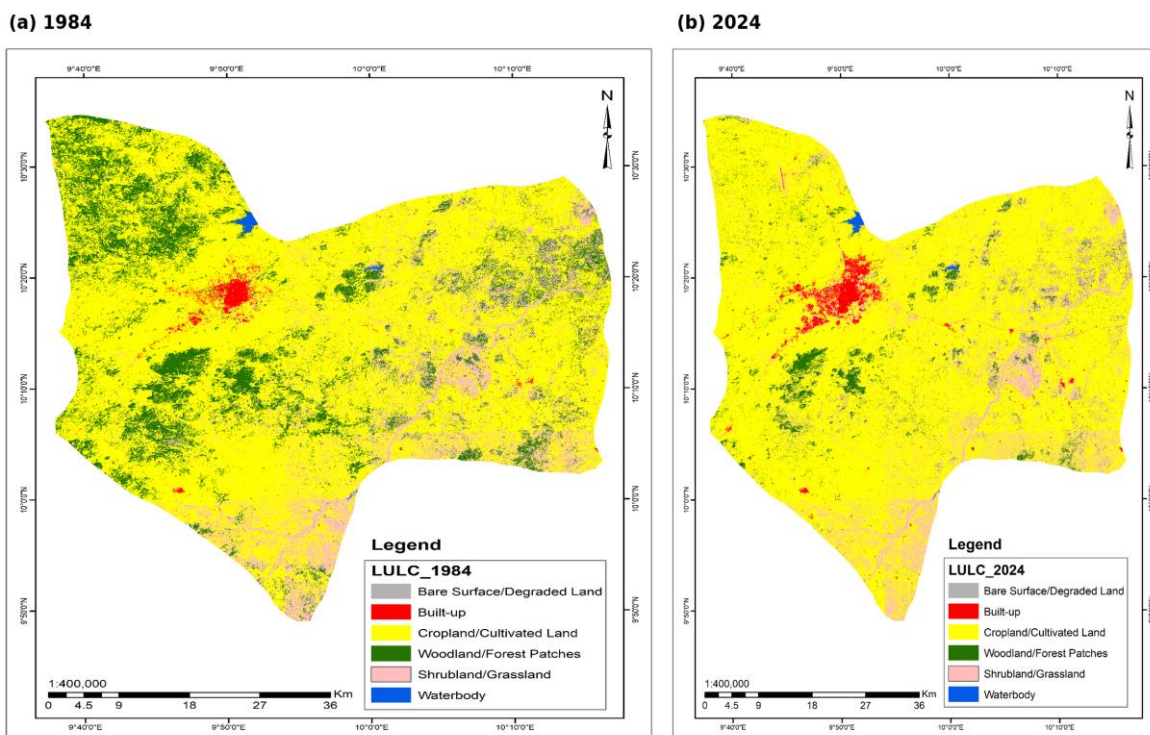


Fig. 3 Land-use and land-cover classification for (a) 1984 and (b) 2024 (source: Landsat classifications)

in the study thesis)

Table 3 Net land-cover change in Bauchi LGA, 1984–2024

Class	1984 area (km ²)	2024 area (km ²)	Net change (km ²)	Relative change
Bare surface	0.09	0.63	+0.54	+600.0%
Built-up	33.85	72.27	+38.42	+113.5%
Cropland	2641.38	2975.25	+333.87	+12.6%
Forest	531.83	154.60	-377.23	-70.9%
Shrubland	470.52	479.60	+9.08	+1.9%
Waterbody	6.54	6.95	+0.41	+6.3%
Natural woody cover	1002.35	634.20	-368.15	-36.7%

Natural woody cover is the sum of forest and shrubland. Minor differences in mapped total area among epochs reflect raster-edge and rounding effects.

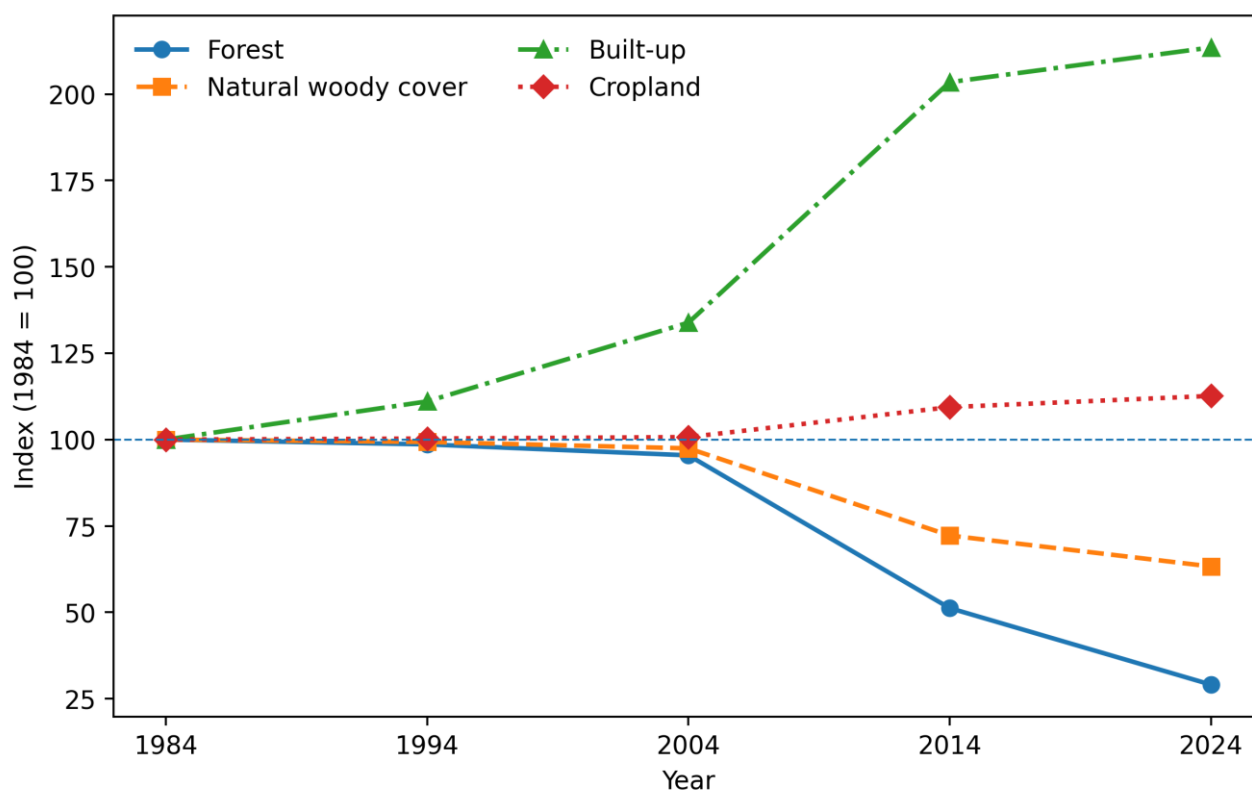


Fig. 4 Indexed trajectories of selected land-cover classes, with 1984 set to 100

Recent Rainfall and Temperature Variability

The 2005–2025 rainfall series was highly variable. Mean rainfall was 2.490 mm day⁻¹, with a minimum of 1.455 mm day⁻¹ in 2006 and a maximum of 6.572 mm day⁻¹ in 2021. The fitted rainfall slope was +0.087 mm day⁻¹ year⁻¹ ($R^2 = 0.177$; $p = 0.057$). This near-significant positive slope was strongly influenced by the wet phase from 2020 to 2022 and should not be interpreted as a stable long-term trend.

Mean temperature was 26.402 °C. The minimum annual value occurred in 2022 (24.557 °C) and the maximum in 2025 (27.327 °C). The fitted temperature slope was $-0.027\text{ °C year}^{-1}$ ($R^2 = 0.054$; $p = 0.311$), indicating that interannual variability dominated the short record. Standardised anomalies show the coincidence of wet and relatively cool conditions during 2020–2022, followed by a return to warmer and drier conditions in parts of 2023–2025 (Fig. 5). Spatially, the retained gridded surfaces indicate a relatively hotter and drier north/north-east and a cooler, wetter south-western sector.

Table 4 Summary statistics and linear trends for recent hydroclimatic variables, 2005–2025

Variable	Mean	Minimum (year)	Maximum (year)	Slope per year	R ²	p value
Rainfall	2.490 mm day ⁻¹	1.455 (2006)	6.572 (2021)	+0.087 mm day ⁻¹	0.177	0.057
Temperature	26.402 °C	24.557 (2022)	27.327 (2025)	-0.027 °C	0.054	0.311

The hydroclimatic series is too short to represent multi-decadal climate change and is interpreted as recent variability.

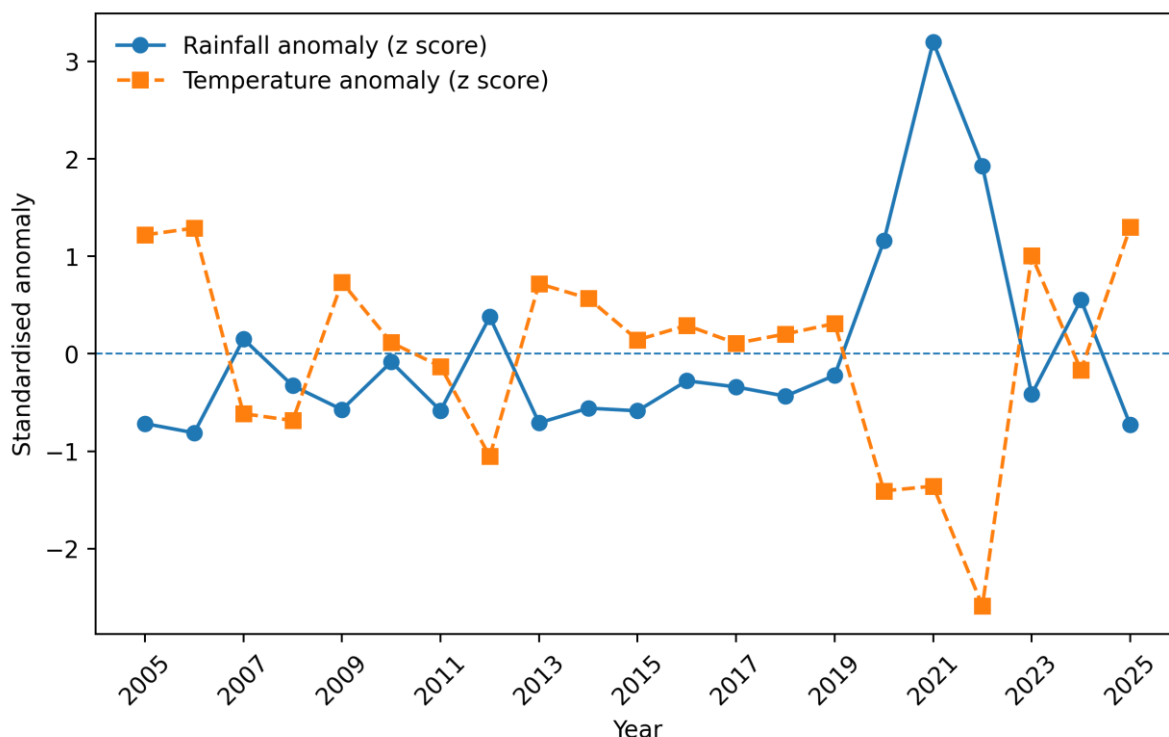


Fig. 5 Standardised annual rainfall and temperature anomalies for 2005–2025

Integrated Environmental-Risk Signal

Taken together, the results identify two different temporal signals. The regional high-wind proxy is recurrent and strongly seasonal but shows no significant monotonic increase. Land-cover transformation, by contrast, is large, persistent and spatially visible. The decline in forest and natural woody cover means that comparable high-wind conditions now occur over a substantially more cultivated, fragmented and urbanised surface than in the 1980s. This distinction is important for risk interpretation. An increase in reported impacts can occur without a statistically significant increase in regional maximum wind speed if exposure and sensitivity rise. More buildings, utility lines, farms and people are now located within the hazard footprint, while reduced woody cover can diminish shelter, soil protection and ecological resilience. The evidence therefore supports an exposure-amplification interpretation rather than a simple claim that windstorms have continuously intensified.

DISCUSSION

Seasonal High-Wind Exposure in the West African Monsoon Environment

The concentration of high-wind months in DJF and MAM is consistent with the seasonal transition experienced across northern Nigeria. DJF includes dry-season northeasterly flow and dust-bearing conditions, while MAM combines intense surface heating with the onset of convective storms. The MAM tendency is especially relevant for preparedness because early-season thunderstorms can produce strong downdrafts and gust fronts before soils and vegetation have fully recovered from the dry season. Sahelian studies show that mesoscale convective cold pools can generate the strongest surface winds and play a major role in dust mobilisation (Bergametti et al. 2022).

The absence of a statistically significant upward trend in the Bauchi proxy does not contradict regional evidence that the most intense Sahelian convective systems have become more frequent (Taylor et al. 2017). The indicators measure different phenomena and operate at different spatial scales. Taylor et al. tracked the intensity and frequency of large convective systems across the Sahel, whereas the present analysis counts monthly threshold exceedances in a coarse regional wind field. A month can contain several damaging gust events but still contribute only one threshold count, and local topography, storm tracks and urban roughness are unresolved. The result is therefore best read as evidence of persistent seasonal hazard windows rather than proof of meteorological stability at all scales.

This finding has practical value. Local authorities do not need to wait for a statistically significant long-term trend before strengthening seasonal readiness. Roof inspection, tree maintenance, protection of power infrastructure, emergency communication and public warnings can be scheduled before the March–May transition and maintained through other locally high-risk months. A seasonal risk calendar may be more actionable than a single annual trend line.

Land-Cover Transformation as an Exposure Multiplier

The scale of forest loss is the most consequential environmental finding. A 70.9% reduction in mapped forest area over four decades indicates a major change in surface structure, habitat continuity and ecosystem function. Even when shrubland is included, natural woody cover declined by more than one-third. Cropland expansion absorbed most of this change, while the built-up footprint more than doubled. The indexed trajectories show that urban and agricultural expansion were not marginal adjustments but sustained structural transformations.

Vegetation affects wind-related risk through several mechanisms. Trees and shrubs increase surface drag, interrupt long fetches, protect soil and crops, and provide shade and moisture-retention benefits. At the same time, poorly managed or structurally weak trees can themselves become hazards during storms. Risk reduction therefore requires strategic vegetation management rather than indiscriminate tree planting. Shelterbelts, riparian buffers, urban green corridors and properly selected street trees can reduce exposure, but they must be designed for local soils, rooting space, maintenance capacity and prevailing wind directions.

The land-cover result also changes how windstorm impacts should be interpreted. If similar regional wind conditions recur over an increasingly built and cultivated landscape, total damage can rise because more assets are exposed. This is consistent with the broader disaster-risk framework in which hazard, exposure and vulnerability interact (IPCC 2022). The finding cautions against attributing all recent damage to climate-driven increases in wind speed. It also demonstrates why land-use planning is a core component of climate adaptation rather than a separate development issue.

The apparent stability of shrubland warrants caution. Net class area can remain stable while the location, density and ecological quality of shrub cover change. Post-classification totals cannot fully reveal transitions among forest, shrubland and degraded cropland, especially when spectral signatures overlap. Independent

accuracy assessment and transition matrices should therefore be completed before final journal submission. Nevertheless, the magnitude and direction of forest, cropland and built-up change are sufficiently large to justify immediate management attention.

Hydroclimatic variability and compound stress

The rainfall and temperature series underline the importance of variability rather than a simple linear narrative. The wet phase of 2020–2022 strongly influenced the rainfall slope, while temperature oscillated without a significant monotonic tendency over the short period. In a monsoon environment, such year-to-year variability can alter vegetation growth, fuel loads, soil moisture and the timing of agricultural operations. Wet years may temporarily increase greenness and biomass, whereas subsequent dry and hot periods can leave stressed vegetation and exposed soils.

Land-surface moisture can also influence convection. Experimental and observational research shows that dry soil patterns may intensify mesoscale convective systems by enhancing convergence, instability and wind shear (Klein and Taylor 2020). This does not establish a direct causal link for Bauchi, but it reinforces the need to consider wind, moisture and land-cover change as a coupled system. The hotter and drier northern/north-eastern sector identified in the gridded surfaces may be particularly sensitive because sparse vegetation, lower moisture and open land can coincide.

Recent variability also has implications for restoration. Tree-planting targets based only on the number of seedlings may fail if species selection, planting dates, soil-water conservation and aftercare do not account for rainfall uncertainty. Restoration programmes should combine native and climate-tolerant species, assisted natural regeneration, agroforestry and protection of existing mature vegetation. Monitoring survival and canopy development is more informative than reporting planting totals alone.

Implications for planning and disaster-risk reduction

The results support a layered risk-reduction strategy that combines meteorological monitoring, land management and development control. Table 5 translates the evidence into practical actions for Bauchi LGA.

Table 5 Priority actions arising from the study evidence

Evidence	Risk implication	Priority action	Lead actors
High-wind months cluster in DJF–MAM	Predictable seasonal window for damage	Issue seasonal advisories; inspect roofs, schools, markets, trees and utility lines before MAM	NiMet, SEMA, LGA, utilities
Forest declined by 70.9%	Reduced woody cover and ecological buffering	Protect remaining forest patches; restore shelterbelts, riparian strips and urban green corridors	Forestry agencies, LGA, communities
Built-up land more than doubled	More people and assets exposed	Enforce wind-sensitive building standards and development control in expansion areas	Planning authority, professional bodies
Cropland expanded by 333.87 km ²	Longer exposed fetch and soil vulnerability	Promote agroforestry, conservation agriculture and farm windbreaks	Agriculture ministry, extension services
Coarse regional	Local gusts and damage are	Install/maintain automatic weather stations and create a geocoded wind-	NiMet, universities, SEMA

Evidence	Risk implication	Priority action	Lead actors
wind data	unresolved	damage inventory	

Institutional names should be aligned with the final Bauchi State implementation framework before submission.

First, meteorological monitoring should move from a single regional proxy towards a local observing network. Automatic weather stations positioned across urban, peri-urban and rural sectors would capture spatial contrasts in gust speed, direction and storm timing. Second, a standardised event-and-damage database should record date, location, wind estimate, building type, injuries, losses and photographs. Linking this inventory to land cover and building characteristics would allow future studies to model actual risk rather than climatological exposure alone.

Third, development control should explicitly include wind hazard. Building approval and inspection can prioritise roof-to-wall connections, anchorage, material quality and setbacks from hazardous trees or unstable structures. Critical facilities such as schools, health centres, markets and electricity infrastructure should receive targeted audits before the high-risk season. Fourth, vegetation policy should protect existing mature cover while restoring strategically located buffers. Urban greening is most effective when integrated with drainage, road design, open-space planning and maintenance budgets.

Finally, community engagement is essential. Residents often possess detailed knowledge of recurrent storm paths, damaged structures and locally vulnerable locations. Participatory mapping can complement coarse climate data, identify overlooked hotspots and improve the relevance of warnings. Such engagement should be incorporated into a formal evidence system rather than used as a substitute for measurements.

LIMITATIONS AND RESEARCH NEEDS

This study has four important limitations. First, WS10M_MAX is a coarse, reanalysis-derived regional variable and the threshold count is a proxy, not an observed windstorm-event inventory. It cannot resolve short-duration gusts, topographic acceleration or building-scale turbulence. Second, the available wind results were retained mainly as decadal summaries, which limits more advanced time-series diagnostics and attribution.

Third, the underlying land-cover training samples and confusion matrices were not archived with the article-preparation package, preventing independent reproduction of classification accuracy. Fourth, the hydroclimatic record used here covers only 21 years and is strongly affected by recent anomalous years.

These limitations define a clear research agenda. Future work should combine quality-controlled station gust records, radar or satellite storm tracking, high-resolution digital elevation models, field-validated land-cover maps and geocoded damage data. A multi-level statistical model could then distinguish atmospheric hazard from exposure and vulnerability. Building surveys and household data would also permit assessment of differential impacts by housing quality, livelihood and social vulnerability. Until those data are assembled, the current results should be used for strategic screening and preparedness rather than parcel-level risk prediction.

CONCLUSIONS

The study demonstrates that wind-related environmental risk in Bauchi LGA is best understood as the interaction of recurrent seasonal high-wind conditions with rapid land-surface transformation. The high-wind proxy was concentrated in DJF and MAM, but neither annual threshold frequency nor annual maximum wind speed showed a statistically significant monotonic trend. The stronger and more certain change occurred on the ground: forest declined by 70.9%, natural woody cover fell by 36.7%, cropland expanded by 333.87 km² and built-up land more than doubled between 1984 and 2024.

These findings challenge a simple narrative that recent impacts necessarily reflect continuously increasing wind speed. Even where regional wind trends are weak, damage can increase as settlements, infrastructure and cultivated land expand and ecological buffers decline. Risk reduction should therefore combine seasonal early warning with forest protection, strategic restoration, wind-sensitive building control, farm windbreaks and a locally validated monitoring network.

The most urgent scientific requirement is the creation of a geocoded windstorm and damage inventory linked to station-level gust observations. Completing independent land-cover accuracy assessment and depositing the processed datasets in a public repository would also strengthen reproducibility. With these improvements, the framework developed here can support a more rigorous, spatially explicit assessment of windstorm risk in Bauchi and other rapidly changing cities of northern Nigeria.

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