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ARTICLE

Urban Expansion, Green Infrastructure Decline, and Windstorm Vulnerability in Bauchi: Mapping, Matrix, and Correlation Analyses

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ABSTRACT

Rapid urbanization across the Global South has led to a substantial decline in urban vegetation, increasing the exposure of cities to climate-related hazards. In Sub-Saharan Africa, this trend has heightened vulnerability to extreme weather events, particularly windstorms. Bauchi, a fast-growing city in Nigeria, has recently experienced severe and recurring windstorm damage, raising concerns about the role of urban expansion in shaping disaster risk. This study investigates the relationship between urban growth and windstorm vulnerability using a multi-method quantitative approach. Spatio-temporal analysis of land use/land cover (LULC), an urban vulnerability matrix, and linear correlation analysis were integrated to examine changes in urban green infrastructure (UGI) and expansion dynamics over 20 years (2004–2024). The findings indicate rapid urban expansion accompanied by a significant transformation of vegetation structure. Dense and moderately dense vegetation declined by 59% and 26%, respectively, while sparse vegetation increased by 51%, expanding from 122 km^2 to 250 km^2. This shift reflects a progressive degradation of UGI, resulting

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in the loss of natural wind-buffering capacity and increased exposure of the built environment to windstorm impacts. The study proposes a conceptual framework that repositions UGI as a strategic tool for enhancing urban resilience. The findings underscore the urgent need to embed UGI strategies into revised urban master plans to reduce risk, protect infrastructure, and support a more resilient and sustainable urban future for Bauchi.

Keywords: Vegetation; Green Infrastructure; Windstorm; Risk

1. Introduction

The foundational component of urban green infrastructure (UGI) is vegetation, with its health and density typically categorized as dense vegetation (high canopy cover, multilayered forests), moderately dense vegetation (scattered trees, shrubs, and grasslands), and sparse vegetation (low-cover areas, lawns, or early-successional patches), which largely influence the magnitude and consistency of these services [1,2]. Vegetation health, measured through the Normalized Difference Vegetation Index (NDVI), chlorophyll content, and physiological stress, determines the functional climate resilience of UGI under urban pressures such as pollution, storms, drought, and land use change [3,4].

The effectiveness of Urban Green Infrastructure (UGI) fundamentally depends on the density and health of its vegetation. These qualities are used to measure and categorize an ecosystem's ability to provide essential environmental services [5,6]. Remote sensing indices provide a standardized approach for assessing vegetation characteristics, enabling scientists to evaluate greenness from a spatial perspective [7]. At the upper end of this ecological hierarchy is dense vegetation, which represents key components of urban green infrastructure, typically consisting of mature urban forests or multilayered parks [8,9]. These areas are characterized by high NDVI values, generally above 0.6, and substantial canopy cover exceeding 70% [1]. This level of vegetation density maximizes environmental benefits, including enhanced windstorm mitigation, improved urban cooling, and increased biodiversity.

The moderately dense vegetation, which often forms the accessible backbone of a city's green network [10]. This category includes common features such as street trees, green corridors, urban forests, urban farms, and managed shrublands. Their metrics fall into a solid intermediate range: an NDVI between 0.4 and 0.6 and a canopy cover between 40% and 70% [5]. While they may not offer the benefits of dense vegetation, their widespread distribution ensures broad service delivery across neighborhoods.

Additionally, the sparse vegetation represents the essential, yet less impactful, green elements integrated into highly urbanized environments. This group encompasses features such as green roofs, expansive lawns, and small pocket parks. Their remote sensing signatures are characteristically low, marked by an NDVI of less than 0.4, an LAI of below 2.0, and minimal canopy cover of under 40% [5–7]. While individually less potent, sparse vegetation is often crucial for reducing surface temperatures and managing stormwater in areas where dense plantings are physically impossible.

UGI improves vegetation health by enhancing microclimates, soil conditions, and hydrological systems, while density affects windbreaks, cooling effectiveness, carbon capture, and habitat creation [11]. High-density vegetation maximizes transpirational cooling and pollutant removal but demands intensive maintenance; sparse vegetation allows quick deployment but offers limited long-term advantages [12,13]. Dense vegetation forms the core of effective UGI, providing better ecosystem services and sufficient climate resilience [14].

Rapid urbanization in Sub-Saharan Africa has transformed cities into densely populated, resource-limited environments where natural vegetation is systematically lost to built-up expansion, informal settlements, and infrastructure development [15,16]. This decline in vegetation is not just an ecological issue, it can also be linked with the reduction of cities' ability to withstand increasing climate hazards [18], especially windstorms during the rainy season and gusts that cause widespread roof failures, structural damage, and dust-related health problems [19,20]. In semi-arid urban centers like Bauchi Metropolis, uncontrolled loss of vegetation has left communities more vulnerable, with little natural protection against high-speed winds and related heat island effects.

UGI represents a strategically designed network of vegetation, including urban forests, street trees, shelterbelts, and riparian buffers, that serves as a promising nature-based solution [6,21]. By restoring and managing vegetation as living infrastructure, cities can reduce wind speeds, dissipate energy, stabilize soils, and enhance overall climate resilience [22,23]. The effectiveness of UGI, however, depends critically on the health and density (e.g., canopy closure, layering) of vegetation [11]. Dense, multilayered vegetation provides superior aerodynamic drag and thermal regulation, while sparse or degraded cover offers only marginal protection [24].

Despite growing concern over the decline of UGI and the numerous ecosystem services it provides [5,11,25], unchecked urbanization continues to threaten cities across Sub-Saharan Africa [26,27]. Although several studies have examined the impacts of urbanization and climate change, particularly in relation to slum proliferation and vegetation loss [28–30], limited attention has been given to the direct relationship between urban growth and UGI decline. Furthermore, no known study has employed a comprehensive multi-method approach that integrates spatiotemporal, matrix, and correlation analyses to understand urban expansion and UGI dynamics.

Therefore, this study addresses these gaps by utilizing remote sensing for a multitemporal analysis of urban growth and NDVI-based UGI trends in Bauchi over the past two decades. It further employs matrix analysis to assess UGI and urban vulnerability, as well as linear correlation techniques to examine the effects of urban expansion on UGI dynamics. This integrated approach provides a comprehensive evidence-based pathway for informed decision-making and supports the development of an effective urban resilience framework.

2. The Study Area

The study was conducted in Bauchi Metropolis, the capital of Bauchi State, Nigeria. Metropolitan Bauchi lies approximately between latitudes 10°15′ N and 10°22′ N and longitudes 9°45′ E and 9°55′ E (see **Figure 1**). Covering an estimated area of about 120–150 km^2, the metropolis serves as the administrative, commercial, and economic hub of the state, with a rapidly growing population projected at approximately 881,600 in 2024, and an average annual growth rate of 3.3% [15]. This demographic pressure has accelerated the expansion of informal settlements, land-use conversion, and vegetation loss, creating conditions of heightened environmental vulnerability.

Bauchi experiences a tropical savanna climate with distinct wet and dry seasons [31]. The wet season, which runs from May to October, brings moderate rainfall (annual average ≈ approximately 1,000–1,300 mm), while the dry season (November–April) is characterized by prolonged hot, dry conditions with Harmattan winds and occasional squall lines. Mean annual temperatures range from 17 °C to 41 °C, with peak daytime highs frequently exceeding 40 °C during the dry season [32]. These climatic patterns, particularly the strong, dust-laden Harmattan winds and sudden gusts during squall events, pose significant risks to structural integrity, soil stability, and human health in areas where vegetation cover has been depleted [33].

Geologically, Bauchi Metropolis is underlain by the Precambrian Basement Complex, dominated by granitic gneisses, schists, migmatites, and biotite-muscovite granites. The resulting soils are predominantly sandy loam, with moderate to low water-retention capacity and susceptibility to erosion under high wind and limited vegetative protection. Topographically, the area forms part of the gently undulating Northern Nigerian Plateau at elevations of approximately 600–700 m above sea level, dissected by seasonal streams (wadis) and punctuated by occasional inselbergs and residual hills [34]. This rolling landscape, combined with the Sudan savanna vegetation zone, creates a gradient of wind exposure: open plains and elevated sites are more vulnerable to gust acceleration, while valley floors and riparian corridors offer natural shelter when vegetated.

Vegetation in Bauchi Metropolis belongs to the Sudan savanna ecological zone, characterized by a parkland mosaic of tall annual grasses (e.g., *Hyparrhenia rufa*, *Pennisetum pedicellatum*) interspersed with drought- and fire-resistant woody species, including *Acacia nilotica*, *Adansonia digitata* (baobab), *Anogeissus leiocarpus*, *Balanites aegyptiaca*, *Khaya senegalensis*, and *Piliostigma thonningii* [35]. These species historically provided structural windbreaks, soil stabilization, and microclimate moderation. However, two decades of rapid urbanization have significantly reduced vegetation density and health, shifting the landscape toward sparse, degraded cover and increasing the metropolis's exposure to windstorm hazards. The combination of a semi-arid climate, erodible soils, undulating topography, and ongoing vegetation decline makes Bauchi an ideal case study for examining the role of green infrastructure in mitigating windstorm risk in Sub-Saharan African urban settings.

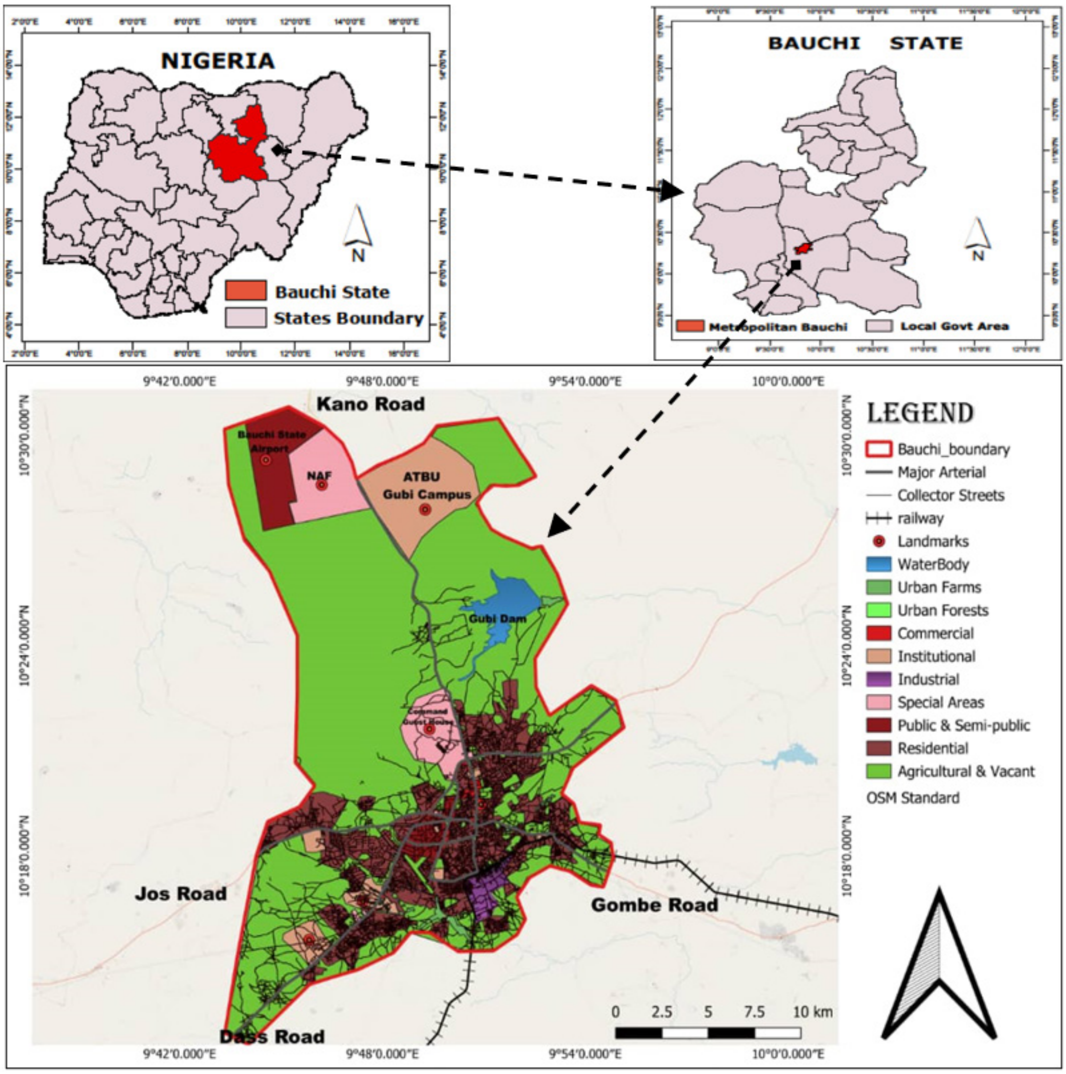


Figure 1. Maps of the Study Area.

3. Methodology

This study employs a multi-temporal, geospatial, and field-integrated methodology to evaluate the state of vegetation in UGI in Bauchi Metropolis [36,37]. To assess the condition of UGI within the study area, the Normalized Difference Vegetation Index (NDVI) was computed for each set of multi-date satellite images [38]. The analysis covers the period 2004 to 2024, providing insights into two decades of changes in vegetation health and density. Landsat multi-date imagery was used for NDVI generation [39,40]. Priority in data acquisition was given to dry-season imagery (November–February) to minimize cloud interference (less than 10% cloud cover) and to reduce the misclassification of seasonal crops as UGI.

To examine the trends in urban growth and their relationship with vegetation dynamics in Bauchi, Landsat 5 TM data were used to analyze NDVI and built-up expansion for 2004, while Landsat 7 ETM+ imagery was employed for the 2014 assessment. Furthermore, Landsat 8 OLI data were utilized to evaluate urban growth and vegetation dynamics for 2024 (see **Table 1**).

Table 1. Landsat Satellite Imagery Metadata.

Spacecraft	Sensor	Spectral Bands	Spatial Resolution	Source
Landsat 5	TM	1–7	30 m	
Landsat 7+	ETM+	1–8	30 m	USGS http://earthexplorer.usgs.gov/
Landsat 8	OLI	1–11	30 m	

3.1. Preprocessing

To ensure data integrity and consistency, all satellite imagery was subjected to preprocessing procedures using ArcGIS 10.8. The preprocessing steps included radiometric and atmospheric corrections, which were applied to improve image quality and enhance comparability across datasets [41]. These corrections normalized variations in reflectance and digital number (DN) values caused by sensor differences and atmospheric effects, thereby ensuring reliable multi-temporal analysis.

3.2. Image Processing for Urban Expansion Trend

Image classification was performed using a supervised classification approach in ArcGIS 10.8, with emphasis on accurately extracting the built-up land use/land cover class. The Maximum Likelihood Classification (MLC) algorithm was adopted due to its robustness and widespread application in urban land cover mapping [28,42]. Training samples representing built-up areas were carefully selected through visual interpretation of high-resolution reference imagery and field knowledge of the study area. Given that the focus of this study is on urban growth dynamics, the classification was restricted to a single land use/land cover class (built-up) to improve classification accuracy and minimize spectral confusion with other land cover categories [43].

3.3. Normalized Difference Vegetation Index

To understand the windstorm vulnerability of Bauchi Metropolis, the Normalized Difference Vegetation Index (NDVI) was employed to assess vegetation health and density, which are important components of UGI that serve as windbreaks to mitigate windstorm exposure and impacts during strong winds [38].

The NDVI was calculated using the red and near-infrared spectral bands of satellite imagery, according to the formula:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \ .$$

Where:

- NIR is the reflectance value in the near-infrared band (which strongly reflects vegetation).
- Red represents the reflectance value in the red band (which strongly absorbs vegetation) [38].

NDVI Classification

To assess the windstorm resistance level of urban green infrastructure (UGI), particularly vegetation, the study classified NDVI values within the range of 0 to 1, although the theoretical NDVI range is −1 to +1 [7]. For this study, all negative NDVI values are considered as brown areas representing dried shrubs, bare land, and built-up areas and therefore excluded from the analysis. The classification of vegetation based on NDVI values was as follows:

1) Dense vegetation (NDVI > 0.45): Mature trees with a closed canopy,
2) Moderately dense vegetation (NDVI 0.25–0.45): Scattered trees and shrubs,
3) Sparse vegetation (NDVI 0.10–0.25): Stressed grasses and early regrowth.

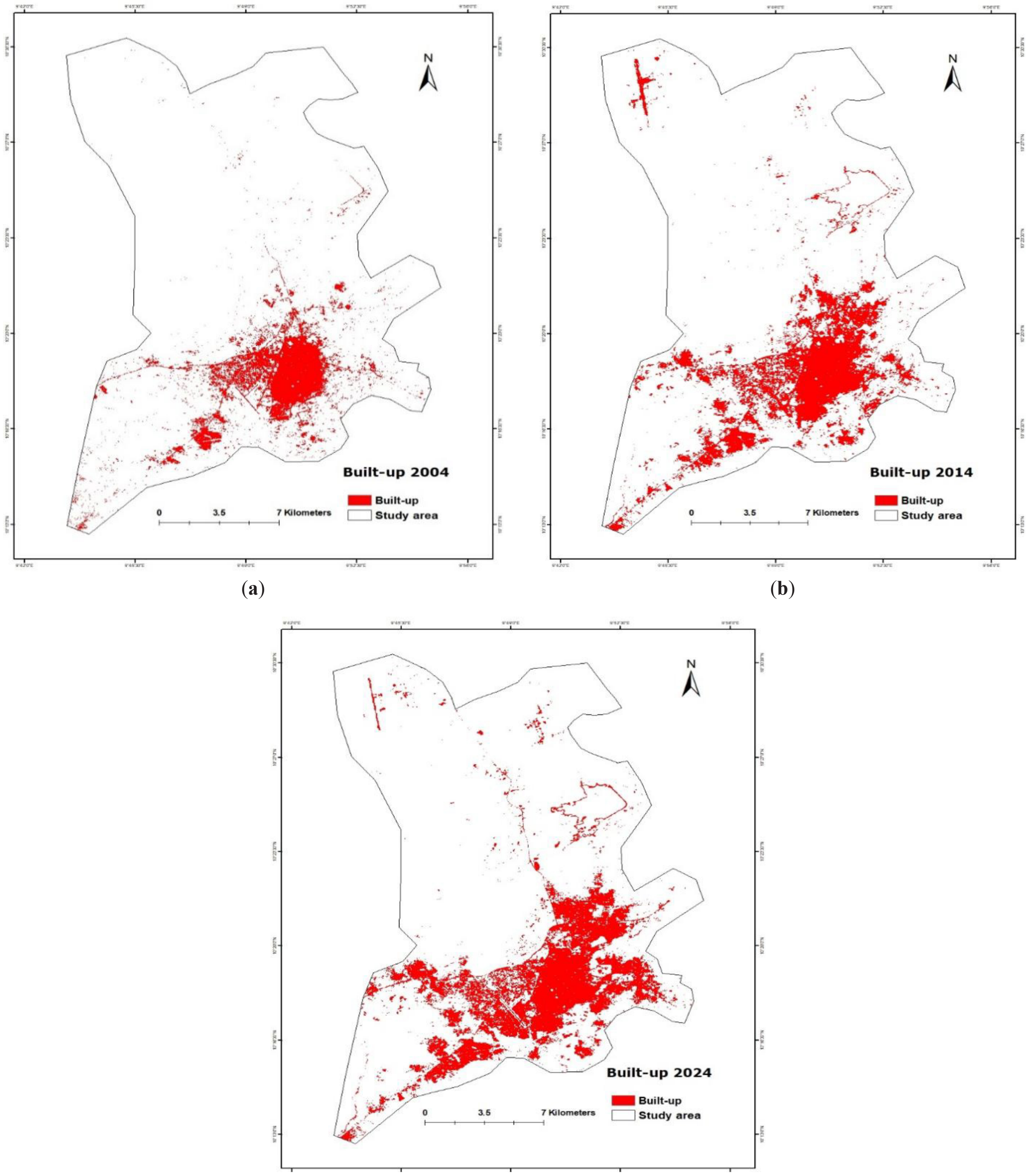
3.4. Correlation Analysis

To understand the relationship between changes in urban vegetation and Bauchi's urban growth, a linear correlation analysis was conducted over the 20-year period from 2004 to 2024. Vegetation conditions derived from the two dates served as the dependent and independent variables to quantify the correlation between urban expansion and windstorm vulnerability. To compute the linear correlation, a total of 243 evenly distributed points were generated using Fishnet within the GIS environment. Furthermore, a multi-value extraction procedure was carried out to extract the DNVI values for both dependent (2004) and independent variables [15]. The linear correlation was computed to evaluate both the strength and direction of this relationship. This analysis provided clear quantitative evidence of how temporal urban expansion trends have driven the decline of urban green infrastructure (UGI) and, consequently, heightened the city's vulnerability to windstorms.

4. Results

4.1. Bauchi Urban Growth Trend

To understand the dynamics of urban growth in Bauchi, the study conducted a land use/land cover (LULC) analysis with a specific emphasis on built-up land cover over two decades (from 2004 to 2024) (see **Figure 2**). The results indicate a substantial and continuous expansion of built-up areas, increasing from 74.4 km^2 in 2004 to approximately 123 km^2 in 2014 and further rising to about 169 km^2 by 2024 (see **Table 2**).



(c)

Figure 2. Bauchi Urban Growth Revealing Observed Built-Up for (**a**) 2004; (**b**) 2014; (**c**) 2024.

Table 2. Built-up and Vegetation Changes from 2004 to 2024.

Year	Built-up Area (km²)	Change (%)	Unit	Vegetation			Total Area (km²/%)
				Dense	Moderately	Sparse	
2004	74.4		Area (km²)	139.7	171.6	122.4	433
			%	32.2	39.6	28.2	100
2014	122.7	39.4	Area (km²)	126.2	192	114.8	433
			%	29.1	44.4	26.5	100
2024	170	37.8	Area (km²)	57.2	126.7	249	433
			%	13.2	29.2	57.6	100

This growth represents a significant transformation of the urban landscape, with built-up land increasing from about 17% of the total land area of the study region to approximately 39% within two decades. The observed trend underscores the increasing conversion of other land cover types into built-up areas [33].

4.2. Windstorm Destruction of Urban Built-Up

To understand the extent and magnitude of windstorm damage within the built-up areas of metropolitan Bauchi, this study referenced the findings of Kafi et al. [44]. In their study, they employed the Enhanced Fujita (EF) scale, a conventional framework for estimating wind speed and its corresponding damage ratings [45]. As shown in **Table 3**, the results indicate a varying degree of damage across different land use types, with residential and commercial areas experiencing the most severe destruction during the 2018 windstorm [46]. These findings highlight the vulnerability of urban infrastructure and buildings in Bauchi to windstorm events [38].

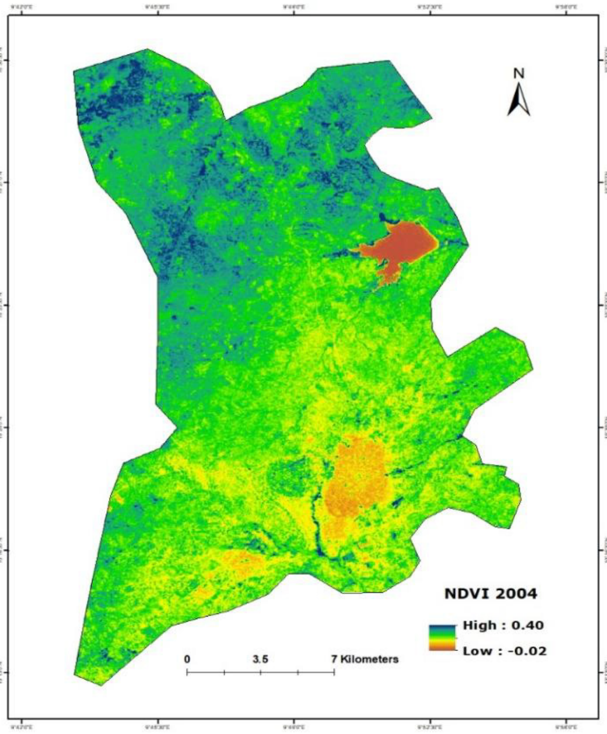
Table 3. Damage Severity Levels across Different Land Use Types from the 2018 Windstorm in Bauchi.

Land use	≥F0	≤F1+	≤F2+	≤F3+	≤F4+	F5	Total	(%)
Residential	15	799	357	659	219	72	2,121	91.0
Commercial	0	42	23	17	9	5	96	4.1
Institutional	0	20	16	13	10	4	63	2.7
Public	0	7	4	1	3	0	15	0.6
Semi-Public	0	6	3	2	4	2	17	0.7
Industrial	0	4	3	0	2	0	9	0.4
Recreational	0	2	1	0	2	0	5	0.2
Total	15	880	407	692	249	83	2,326	100.0

Source: Kafi et al. [44].

4.3. Vegetation Transition in Bauchi

The vegetation dynamics reveal a clear shift from dense to sparse cover between 2004 and 2024, largely driven by rapid urban expansion and complex urban processes such as population growth and land-use conversion [41,47] (see **Figure 3**). Dense vegetation declined markedly from 139.7 km^2 in 2004 to 57.2 km^2 in 2024, while moderately dense vegetation decreased from 171.6 km^2 to 126.7 km^2. In contrast, sparse vegetation increased significantly from 122.4 km^2 to 249 km^2 (see **Table 2**). These changes indicate a progressive degradation of vegetation structure, with dense and moderately vegetated areas transitioning into sparse cover, alongside the loss of previously vegetated land [47]. The expansion of built-up areas, road networks, and residential developments has fragmented continuous green spaces and contributed to a decline in overall vegetation health across the metropolis.



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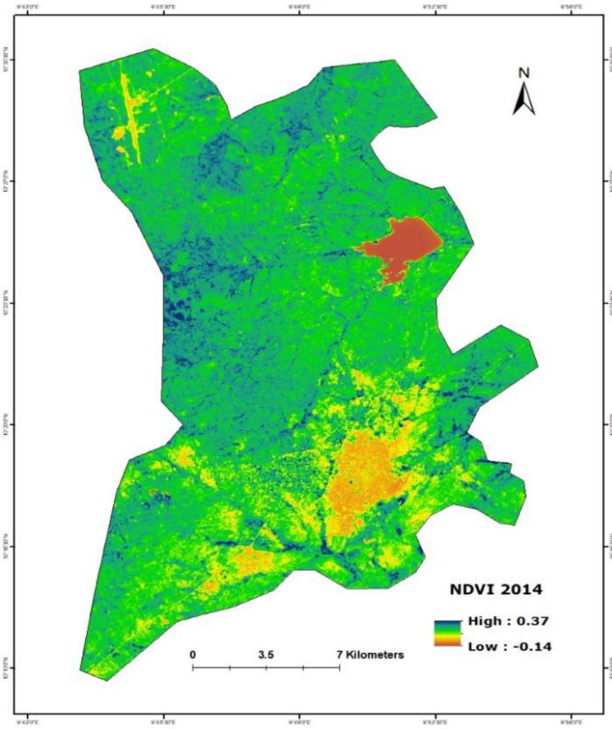

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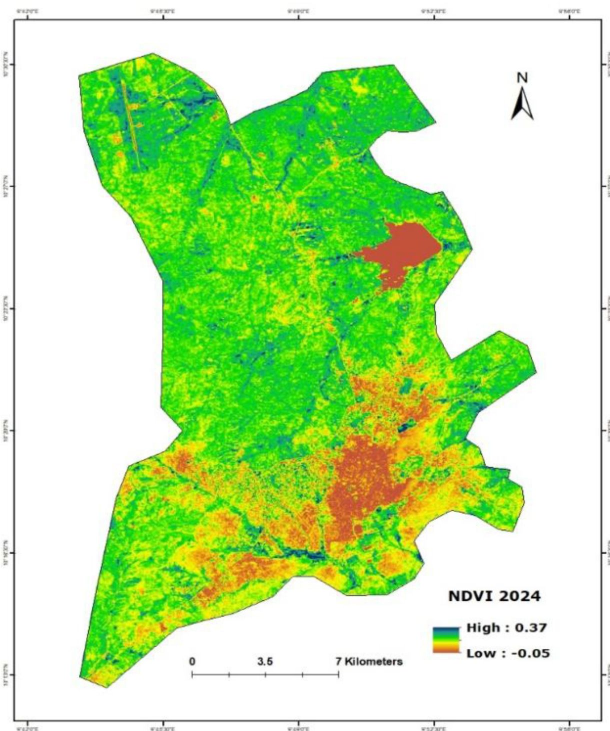

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Figure 3. Normalized Difference Vegetation Index of Bauchi for (**a**) 2004; (**b**) 2014; (**c**) 2024.

4.4. Bauchi Urban Growth and Windstorm Vulnerability

To understand the relationship between Bauchi urban growth and windstorm vulnerability, the study performed linear correlation and matrix analyses of NDVI dynamics against multi-temporal dates in Bauchi (see **Figures 4** and **5**). The linear correlation result indicates a strong relationship between urban expansion and the decline of urban green infrastructure (UGI) in Bauchi. An R^2 value of 0.709 suggests that approximately 71% of the variation in UGI decline (as captured by NDVI dynamics) is explained by the increase in built-up areas over the study period (2004–2024) (see **Figure 4**). This relatively high coefficient of determination demonstrates that urban expansion is a dominant driver of vegetation loss and degradation within the metropolis.

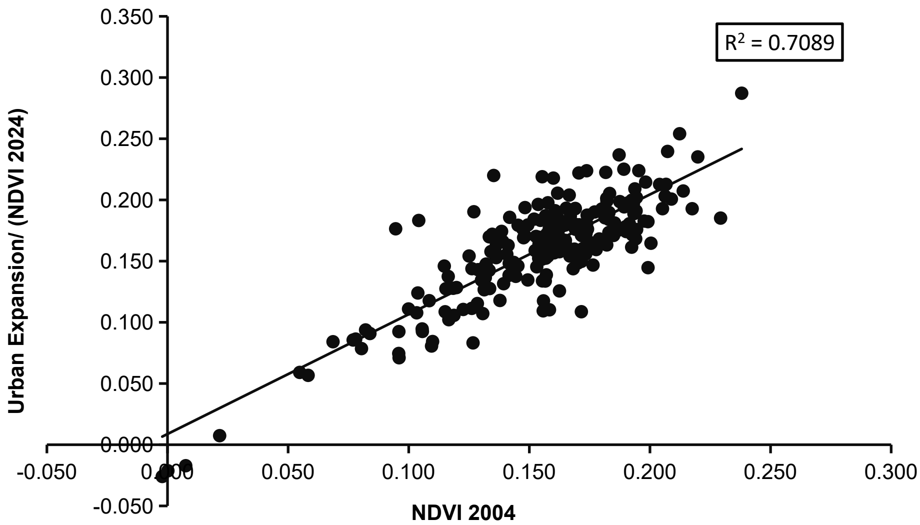

Figure 4. Linear Correlation between Urban Expansion and the Decline of Urban Green Infrastructure (UGI) Derived from NDVI Dynamics in Bauchi from 2004 to 2024.

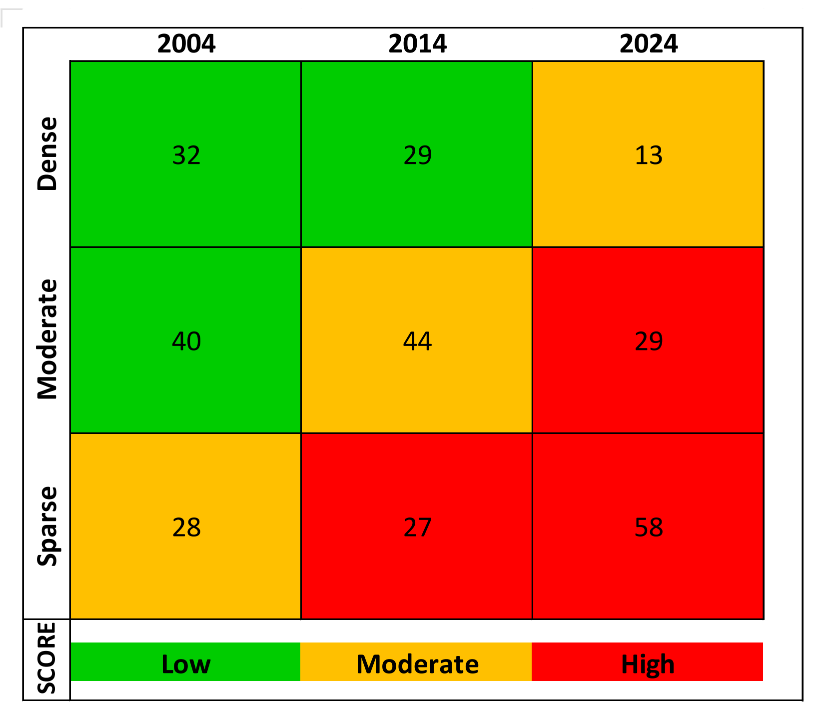

Figure 5. Windstorm Vulnerability Matrix.

As built-up areas increase, vegetated surfaces are either directly converted into urban land uses or indirectly degraded through fragmentation, infrastructure development, and land-use intensification. The strength of the relationship implies a systematic and consistent pattern, rather than a random or weak association. However, the remaining 29% of unexplained variation indicates that other factors also contribute to UGI decline. These may include climate variability, land management practices, socio-economic pressures, and informal development patterns, which are not fully captured by built-up expansion alone. Overall, the result underscores the significant impact of rapid urban growth on green infrastructure, highlighting the need for integrated urban planning strategies that incorporate green space preservation and sustainable land-use management to mitigate further ecological degradation in Bauchi.

Figure 5 depicts the windstorm vulnerability ranking of Bauchi over a two-decade period, derived from UGI dynamic matrix analysis and expressed based on the shift in UGI area percentage. The findings reveal a pattern of windstorm vulnerability, increasing from low to high vulnerability between 2004 and 2024. In 2004, 32%, approximately 140 km^2, of vegetated cover, comprising both dense and healthy vegetation, provided substantial protection against strong winds. However, dense vegetation has experienced a marked decline over time, reducing to 29% (126 km^2) in 2014 and further dropping sharply to only 13%, approximately 57 km^2, by 2024 (see **Figure 5**). This significant loss of dense vegetation has correspondingly reduced the city's natural wind protection capacity and increased overall vulnerability to windstorms [38].

Similarly, moderate-density vegetation exhibited a declining trend over the study period. In 2004, it covered 40% (approximately 171 km^2), increasing to 44% (193 km^2) by 2014, which suggests a transition from dense vegetation. However, by 2024, moderate vegetation had declined significantly to 29% (127 km^2). This reduction indicates continued vegetation degradation and increasing urbanization pressure, contributing to the weakening of Bauchi's natural buffer against windstorms and reinforcing the observed rise in urban vulnerability across the metropolis.

In contrast, sparse vegetation showed a different trajectory over the two decades. In 2004, it covered 28% (approximately 122 km^2), slightly decreasing to 27% (115 km^2) in 2014. However, by 2024, sparse vegetation increased markedly to 58% (approximately 250 km^2) of the total vegetation cover. This sharp rise reflects extensive vegetation thinning and degradation driven by deforestation for livelihood activities, urban expansion, and broader land-use and land-cover change dynamics.

Overall, the vegetation index aggregate score indicates that Bauchi was classified as having low vulnerability and high resistance to windstorm exposure and severity in 2004. By 2014, the decline in urban vegetation had increased the city's exposure to windstorm disasters, resulting in a matrix ranking of moderate vulnerability. Unfortunately, this downward trend continued, further increasing Bauchi's susceptibility to windstorm events, with the aggregate score reaching high vulnerability by 2024 (see **Figure 4**). The observed decline in dense and moderate-density vegetation, coupled with the increasing dominance of sparse vegetation, reflects a reduced resistance capacity of the urban green infrastructure and explains the city's heightened vulnerability to windstorm disasters and related extreme events.

5. Discussion

The observed vegetation dynamics (2004–2024) provide clear evidence of increasing windstorm vulnerability in Bauchi, driven by unchecked urban expansion and ongoing land-use/land-cover transformation. The sharp decline in dense vegetation from 32% in 2004 to 13% in 2024, alongside a simultaneous expansion of sparse vegetation from 28% to 58%, signals a systematic weakening of the city's natural protective landscape structure. This trend reinforces recent findings by Kafi and Ponrahono [38], which, through Explainable AI analysis, identified high housing density, low urban tree cover, and a large population size as key drivers of Bauchi's vulnerability to extreme events.

Dense and moderately dense vegetation typically serves as a natural windbreak by increasing surface roughness, reducing wind velocity, and dissipating wind energy before it reaches built-up areas. The marked 59% reduction in dense vegetation over the two-decade period, coupled with the expansion of sparse cover, has significantly weakened Bauchi's urban resilience by diminishing its wind-buffering capacity. Earlier studies by Kafi [48] further confirm that the city's limited and declining resilient infrastructure—particularly low tree canopy cover and vulnerable building structures—intensifies exposure to windstorm impacts. This reduced buffering capacity is reflected in increasing reports of storm-related roof damage and structural failures across the city [44].

The observed trend aligns with broader savanna-urban studies, where the loss of dense native vegetation reduces soil stability and aerodynamic resistance, thereby increasing windstorm intensity and erosion risk [49]. The strong linear relationship identified through correlation analysis ($R^2 = 0.709$) further supports existing literature indicating that rapid urban expansion, deforestation, and climate-driven desertification collectively degrade high-value urban green infrastructure (UGI). This transition results in landscapes dominated by low-ecological-value surfaces that provide limited protection against wind hazards while also reducing carbon sequestration and soil retention capacity [2,50,51]. Similarly, the NDVI trajectory—from dense to sparse vegetation—mirrors patterns observed in other Nigerian cities, where vegetation loss has contributed to rising surface temperatures and declining resilience to extreme weather events [49,52].

These findings carry urgent policy implications for Bauchi in the context of accelerating urbanization, human-induced environmental change, and climate-amplified hazards. Uncontrolled urban expansion must be urgently addressed through strict enforcement of land-use zoning regulations and urban greening policies that prioritize the protection and restoration of dense vegetation corridors. Urban planners and policymakers should integrate urban UGI frameworks into all development schemes, including mandatory tree-planting requirements in residential developments and the establishment of green belts designed to function as windbreak systems.

Therefore, we developed a UGI conceptual framework for Bauchi that provides an integrated pathway for strengthening urban ecological resilience and reducing exposure to climate- and windstorm-related hazards. Central to this framework are five interlinked components: canopy density, tree coverage, tree connectivity, tree health, and overall landscape functionality (see **Figure 6**). The implementation of this framework will help reverse the declining trend of UGI caused by rapid urban expansion, reduce disaster risk, mitigate the urban heat island effect, and foster a more sustainable, livable, and climate-resilient urban environment.

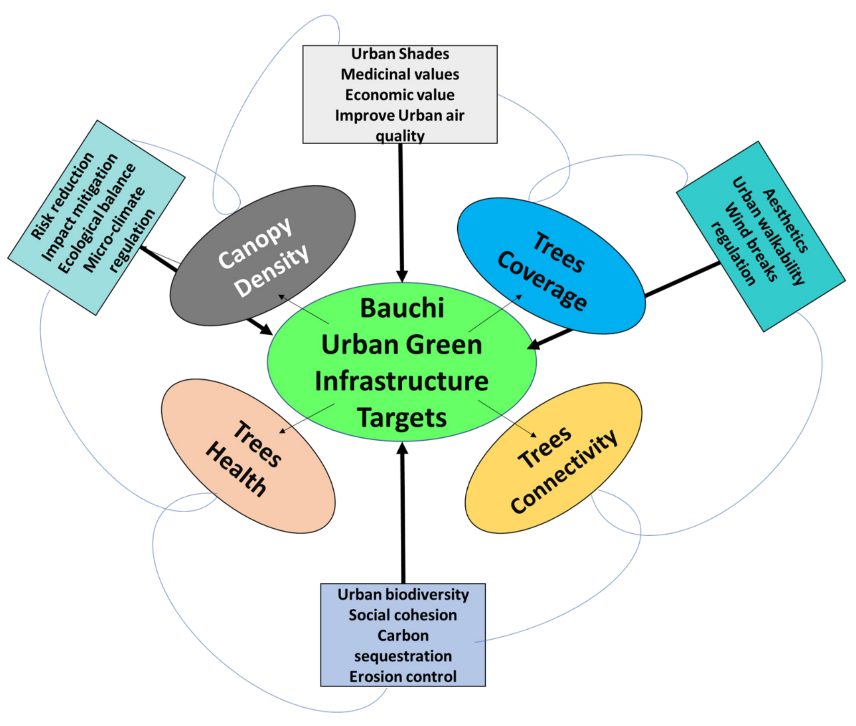

Figure 6. Conceptualized Bauchi Urban Green Infrastructure Framework for City Resilience to Windstorms.

6. Conclusions

The study utilizes a multi-method approach utilizing spatio-temporal analysis of urban expansion and NDVI-based UGI dynamics in Bauchi over the past two decades (2004–2024). In addition, matrix analysis was employed to assess UGI and urban vulnerability to windstorm disasters, while linear correlation techniques were used to examine the relationship between urban expansion and UGI decline.

The findings reveal that Bauchi city expanded by 127% during the study period, accompanied by a rapid shift from dense to sparse vegetation and an overall decline in UGI due to rapid urbanization. Furthermore, the results indicate a rising trend in urban vulnerability to windstorm events driven by these transitions. This highlights that sustained vegetation loss weakens UGI and diminishes the effectiveness of urban windbreaks that buffer strong winds, thereby increasing exposure of the urban fabric and reducing overall urban resilience.

The decline of UGI and rising urban vulnerability highlight the need for a more functional and resilient UGI framework that goes beyond simple vegetation presence [53]. Such a framework should integrate key attributes, including vegetation density, connectivity, coverage, and health, as these guarantee the protection of urban infrastructure and determine the effectiveness of ecosystem services, including mitigation against heavy winds, microclimate regulation, and environmental conservation. The findings further emphasize the need for proactive vegetation restoration, as continued expansion of sparse cover is likely to intensify other environmental and climate-related challenges [54], including the urban heat island effect, desertification, and dust storm frequency, while also increasing economic losses from infrastructure damage, as consistently reported in semi-arid urban studies [46,55].

Author Contributions

Conceptualization, A.A., L.F.B. and K.M.K.; methodology, A.A. and K.M.K.; software, A.A.; validation, L.F.B., and K.M.K.; formal analysis, A.A.; investigation, A.A.; resources, A.A., R.O.O., M.A. and M.A.M; data curation, K.M.K.; writing—original draft preparation, A.A.; writing—review and editing, K.M.K. and M.A.M.; visualization, L.F.B., R.O.O., and M.A.; supervision, L.F.B.; project administration, A.A.; funding acquisition, A.A. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available online.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

AI Use Statement

During the preparation of this work, the authors used QuillBot and Grammarly to improve the grammar of the manuscript. The authors subsequently reviewed and edited the content as necessary and take full responsibility for the final content of the published article.

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