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Integrating Local Knowledge And Decentralized Land Management For Climate-Resilient Built Environment Planning In Northern Jigawa State, Nigeria

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Abstract

Climate vulnerability in semi-arid regions is increasingly shaped by the interaction of land-use change, vegetation stress, climate variability, settlement expansion and weak land-management systems. This study examines how local knowledge and decentralized land management can support climate-resilient built environment planning in Northern Jigawa State, Nigeria. The article links land-use pressure, vegetation change and climate variability with built-up expansion, permeable surface availability, settlement resilience and community knowledge in order to propose a co-created planning approach for sustainable built environment outcomes. The study adopted an integrated mixed-methods socio-spatial design using thesis-derived evidence from multitemporal Landsat imagery, NDVI analysis, land-use/land-cover classification, rainfall and temperature assessment, socioeconomic indicators, built-environment sustainability variables, interviews, focus group discussions and stakeholder observations. Findings indicate that population growth, agricultural expansion and infrastructure development have intensified pressure on land resources, contributing to vegetation decline, reduced surface permeability and increased exposure to heat stress, runoff and localized flooding risks. The results also show that rainfall variability and rising temperature interact with human land-use decisions to shape climate vulnerability. The study concludes that resilient built environment planning in semi-arid areas requires more than technical spatial planning; it demands the integration of geospatial evidence, local knowledge, decentralized land-use control, vegetation restoration and participatory environmental governance.

Keywords: Local Knowledge, Decentralized Land Management, Climate-Resilient Planning, Built Environment, NDVI, Land-Use/Land-Cover Change, Northern Jigawa State, Semi-Arid Nigeria

1. INTRODUCTION

Climate vulnerability in semi-arid environments is increasingly shaped by the interaction of climate variability, land-use/land-cover change, vegetation degradation, settlement expansion and weak land-management systems. Across dryland regions, rising aridity, rainfall uncertainty, heat stress and ecosystem degradation are placing increasing pressure on land-based livelihoods, infrastructure systems and human settlements (United Nations Convention to Combat Desertification [UNCCD], 2024). The challenge is particularly serious in developing regions where communities depend heavily on land, vegetation, rainfall and local natural resources for agriculture, domestic energy, housing expansion and livelihood security. In such contexts, climate vulnerability is not only a meteorological problem; it is also a land-use, governance and built-environment planning problem.

Recent climate-resilient development literature emphasizes that adaptation, mitigation, equity, governance and sustainable development should not be treated as separate policy concerns (Intergovernmental Panel on Climate Change [IPCC], 2022). Climate-resilient development requires planning systems that can reduce exposure to hazards, strengthen ecological buffers, improve infrastructure performance and support communities to adapt to changing environmental conditions. In semi-arid areas, this requires particular attention to vegetation cover, soil stability, surface permeability, drainage, settlement layout, water-sensitive design and local land-use practices. Where vegetation is removed and land surfaces are converted into agricultural fields, bare ground, roads, buildings and compacted compounds, the ability of the landscape to regulate heat, support infiltration, reduce runoff and maintain ecological stability may be weakened.

Land-use and land-cover change has therefore become a major concern in sustainable environmental planning. In Nigeria, recent reviews show that remote sensing and geospatial techniques are increasingly used to monitor land-cover dynamics, but there remains a need to strengthen the connection between land-cover evidence and practical land-management decisions (Alegbeleye et al., 2024). Satellite-derived indicators such as the Normalized Difference Vegetation Index provide useful evidence on vegetation condition, ecological stress and land-surface change. When combined with rainfall, temperature, socioeconomic and built-environment indicators, NDVI can help explain whether vegetation change is associated mainly with climate variability, human land-use pressure or the interaction of both (Pettorelli et al. 2005).

However, a major limitation in many land-cover and climate studies is that they often stop at measurement and description. They identify vegetation decline, settlement growth or rainfall variability, but they do not always translate these findings into planning strategies that are socially grounded, institutionally feasible and locally acceptable. This creates a gap between environmental diagnosis and practical built-environment resilience. Sustainable built-environment planning requires more than information on buildings alone; it requires understanding the wider land system in which buildings, roads, open spaces, drainage channels, vegetation corridors and community livelihoods interact. Recent studies on green infrastructure and nature-based solutions show that permeable surfaces, vegetation, green roofs, living walls, open spaces and ecological corridors can support microclimate regulation, energy efficiency, runoff reduction and urban climate adaptation when they are properly integrated into planning systems (Habibi & Kahe, 2024; Zarei & Shahab, 2025).

Local knowledge is also increasingly recognized as an important component of climate adaptation. Communities often possess practical knowledge of rainfall behaviour, soil moisture, tree loss, flood-prone areas, grazing routes, land conversion, fuelwood pressure and local coping strategies. Such knowledge can complement scientific and geospatial evidence by explaining why environmental change occurs, how it is experienced and which adaptation options are socially acceptable. Recent African evidence shows that local knowledge-based adaptation strategies remain important for climate resilience, particularly among communities exposed to drought, livelihood stress and environmental uncertainty (Matandirotya et al., 2024). Ignoring such knowledge may produce technically sound plans that are weak in implementation, while integrating it can improve legitimacy, ownership and local responsiveness.

Decentralized land management is therefore central to climate-resilient built environment planning. In settings where land-use decisions are shaped by households, farmers, traditional institutions, local government authorities, planners and development actors, resilience cannot be produced through centralized technical planning alone. It requires participatory and polycentric governance arrangements that allow multiple actors to monitor land-cover change, regulate land conversion, protect vegetation, maintain drainage systems and support community-based adaptation. This is consistent with the wider argument that climate-resilient development depends on the actions of multiple actors across political, ecological, social, economic and knowledge systems (IPCC, 2022).

Northern Jigawa State, Nigeria, provides a useful context for examining these relationships because it lies within a semi-arid ecological setting where rainfall variability, vegetation stress, agricultural dependence, settlement expansion and land-use pressure intersect. The selected local government areas—Gumel, Garki, Gagarawa, Sule Tankarkar and Maigatari—represent communities where built-environment sustainability is closely linked to land condition, vegetation cover, water availability, surface permeability and local adaptation practices. In such areas, climate-resilient planning must be understood not only as the construction of stronger buildings or improved infrastructure, but also as the co-creation of land-use and settlement systems that protect ecological functions and reflect community realities.

The conceptual gap addressed in this article is the limited integration of geospatial evidence, local knowledge and decentralized land management in climate-resilient built environment planning for semi-arid Nigerian contexts. Existing studies have contributed important evidence on land-cover change, vegetation dynamics, climate variability and urban or rural environmental stress, but fewer studies explicitly connect these dimensions to co-created planning approaches that combine scientific analysis with community knowledge and local governance. This article responds to that gap by arguing that climate-resilient built environments in semi-arid regions should be planned through the joint agency of science, local institutions and communities.

The aim of this article is to examine how local knowledge and decentralized land management can support climate-resilient built environment planning in Northern Jigawa State, Nigeria. The article focuses on the relationship between land-use pressure, vegetation change and climate variability, while also examining how built-up expansion affects permeable surface availability and settlement resilience. It further explores the role of local knowledge in interpreting environmental change and adaptation options, and proposes a co-created planning approach for sustainable built-environment outcomes in semi-arid communities.

2. METHODOLOGY

2.1 Research Design

This study adopted an integrated mixed-methods socio-spatial research design to examine how local knowledge and decentralized land management can support climate-resilient built environment planning in Northern Jigawa State, Nigeria. The design combined geospatial analysis, climate-data assessment, socioeconomic interpretation, built-environment indicators and qualitative community evidence Creswell & Plano Clark (2018).

The approach was considered appropriate because the study is concerned not only with measuring land-use/land-cover change and vegetation response, but also with understanding how communities, local institutions and planning authorities can respond to climate-related land and settlement challenges. The quantitative component focused on satellite-derived land-use/land-cover change, NDVI, rainfall, temperature, socioeconomic land-use pressure and built-environment sustainability indicators. The qualitative component explored local knowledge, land-use practices, adaptation options and community perceptions of environmental change.

The study followed an integrated methodological logic. First, geospatial and climate data were used to assess environmental change. Second, socioeconomic and built-environment indicators were analysed to explain land-use pressure and settlement sustainability. Third, qualitative evidence was used to interpret local knowledge and decentralized land-management practices. Finally, the findings were synthesized to propose co-created planning responses for climate-resilient built environment outcomes.

2.2 Study Area

The study was conducted in Northern Jigawa State, Nigeria, with emphasis on five local government areas: Gumel, Garki, Gagarawa, Sule Tankarkar and Maigatari. The area lies within the semi-arid ecological zone of northern Nigeria and is characterized by seasonal rainfall, high temperature, vegetation stress, agricultural dependence, settlement expansion and increasing pressure on land resources.

Northern Jigawa was selected because it provides a suitable context for examining the relationship among climate variability, vegetation change, land-use pressure and built-environment sustainability. In this environment, climate vulnerability is experienced not only through rainfall fluctuation and drought stress, but also through declining vegetation cover, exposed land surfaces, reduced permeability, heat exposure, settlement growth and pressure on local livelihoods (Garba 2025).

2.3 Data Sources and Variables

The study used both secondary and primary data. Secondary data were obtained from satellite imagery, climate records, socioeconomic indicators and built-environment sustainability variables. Primary data were obtained through interviews, focus group discussions and stakeholder observations. The analysis covered selected benchmark years, namely 1986, 1995, 2005, 2015 and 2022, depending on data availability.

The major data components are summarized below.

Data component	Variables examined	Purpose
Satellite imagery	Landsat images, LULC classes, NDVI, vegetation cover, agricultural land, built-up surfaces, bare land and water bodies	To assess land-cover change and vegetation response
Climate data	Annual rainfall, rainfall anomaly, temperature trend and drought-related indicators	To assess climate variability and hydro-climatic stress
Socioeconomic data	Population, agricultural land use, infrastructure development and livelihood dependence on land	To explain human pressure on land resources
Built-environment data	Built-up percentage, mean zonal NDVI, green building footprint, energy-use	To assess settlement sustainability outcomes

	intensity and permeable surface percentage	
Qualitative evidence	Interviews, focus group discussions and stakeholder observations	To interpret local knowledge, land-use decisions and adaptation options

2.4 Remote Sensing and Land-Use/Land-Cover Analysis

Remote sensing analysis was used to assess the spatial and temporal patterns of land-use/land-cover change in the study area. Landsat imagery was selected because of its long historical coverage, moderate spatial resolution and suitability for multi-decadal environmental monitoring.

The satellite images were processed and classified into five major land-use/land-cover classes:

1. vegetation cover;
2. agricultural land;
3. built-up surfaces;
4. bare land; and
5. water bodies.

Image preprocessing involved geometric correction, radiometric and atmospheric correction where applicable, cloud screening, image enhancement, clipping to the study area and harmonization of the selected image years. The classified images were compared across the benchmark years to identify major land-cover transitions, especially the conversion of vegetated surfaces to agricultural land, built-up areas and bare surfaces (Lillesand et al. 2015).

The Normalized Difference Vegetation Index was computed to assess vegetation greenness and ecological response. The NDVI formula used was:

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad \text{--(I)}$$

where

NIR represents near-infrared reflectance and

Red represents red-band reflectance.

Higher NDVI values indicate healthier vegetation, while values close to zero or negative values indicate bare surfaces, built-up areas, water or degraded vegetation (Tucker 1979).

Accuracy assessment was conducted to determine the reliability of the classified images. The validation process involved ground-control points, reference information from field observation and high-resolution imagery, confusion matrix analysis, overall accuracy and Kappa coefficient.

2.5 Climate Variability Analysis

Climate variability was assessed using rainfall, temperature and drought-related indicators. Rainfall data were analysed using annual rainfall totals and rainfall anomaly assessment, while temperature was examined through time-series comparison. The rainfall anomaly approach was used because annual rainfall totals alone may not fully capture hydro-climatic stress, especially where rainfall distribution, onset, cessation and dry spells affect vegetation and livelihoods.

Temperature analysis was included because rising temperature can increase evapotranspiration, reduce soil moisture, intensify heat stress and weaken vegetation conditions, particularly in semi-arid environments. The climate variables were compared with NDVI and land-use indicators to examine how climatic factors interact with human-induced land-cover change.

2.6 Socioeconomic Land-Use Pressure Analysis

Socioeconomic indicators were analysed to explain human pressure on land resources. The selected indicators were population, agricultural land use, infrastructure development and livelihood dependence on land. These variables were used because they represent major drivers of land conversion, vegetation removal, settlement expansion and pressure on ecological resources.

Descriptive statistics and percentage change analysis were used to summarize socioeconomic trends across the benchmark years. The analysis helped to explain whether changes in vegetation and land-cover patterns were associated with demographic growth, agricultural expansion, infrastructure development and livelihood dependence on land-based resources.

2.7 Built Environment Sustainability Assessment

Built-environment sustainability was assessed using selected settlement-related indicators. These included built-up percentage, mean zonal NDVI, green building footprint, energy-use intensity and permeable surface percentage. The indicators were selected because they reflect the environmental performance of settlements and their sensitivity to climate-related stress.

Built-up percentage was used to measure the extent of land conversion into buildings and infrastructure. Mean zonal NDVI was used to assess vegetation condition around settlement areas. Green building footprint reflected the presence of environmentally responsive building or landscape features. Energy-use intensity represented the energy demand of the built environment, while permeable surface percentage indicated the ability of the land surface to support infiltration, reduce runoff and moderate local environmental conditions.

The built-environment indicators were analysed in relation to land-cover change and climate vulnerability. Particular attention was given to the relationship between built-up expansion and permeable surface availability because reduced permeability can increase runoff, localized flooding, heat stress and reduced groundwater recharge.

2.8 Qualitative Data and Local Knowledge Integration

The qualitative component was used to capture community knowledge, stakeholder experience and local interpretation of land-use and climate-related change. Interviews, focus group discussions and stakeholder observations were used to gather information on land conversion, tree cutting, fuelwood dependence, drainage problems, rainfall perception, local adaptation practices, vegetation restoration and institutional responses to environmental stress.

The qualitative evidence complemented the geospatial and statistical analysis by explaining how environmental change is experienced at community level. It also helped to identify locally acceptable planning responses. In this study, local knowledge was treated as a complementary knowledge system that can strengthen climate-resilient planning when integrated with scientific evidence and institutional decision-making.

2.9 Data Analysis and Integration

Quantitative data were analysed using descriptive statistics, percentage change analysis, Pearson correlation and regression interpretation. Descriptive statistics were used to summarize land-use, climate, socioeconomic and built-environment variables. Percentage change analysis was used to compare changes across benchmark years. Pearson correlation was used to examine relationships among NDVI, rainfall, temperature, population, agricultural land use and infrastructure development.

Regression analysis was used to examine the relationship between selected predictor variables and environmental or built-environment outcomes. However, because the study used benchmark data, the regression results were interpreted as exploratory evidence of association rather than proof of direct causation.

The qualitative and quantitative findings were integrated through triangulation. Geospatial data showed where land-cover and vegetation changes occurred. Climate data explained rainfall and temperature variability. Socioeconomic data explained human pressure on land. Built-environment indicators showed settlement sustainability implications. Qualitative evidence explained community experience, local practices and governance challenges. This integrated interpretation formed the basis for proposing co-created climate-resilient built environment planning strategies.

2.10 Ethical Considerations

The study used community and stakeholder evidence in a manner that protected respondents' identities. Responses from interviews and focus group discussions were interpreted in aggregate form, and no personal identifiers were disclosed. Local knowledge was treated respectfully as a valid source of environmental understanding and was used to complement, rather than replace, geospatial and statistical evidence.

3. RESULTS

3.1 Descriptive Result

The results show a sustained increase in socioeconomic pressure on land resources in Northern Jigawa State between 1986 and 2022. Population increased from 2.1 million in 1986 to 5.4 million in 2022, representing an increase of about 157.1%. Agricultural land use also expanded from 5,200 km² to 7,850 km², indicating an increase of about 51.0%. Infrastructure projects increased from 12 to 67, while livelihood dependence on land rose from 78% to 88% within the same period.

These results indicate that land resources in Northern Jigawa State have been subjected to increasing human pressure through demographic growth, agricultural expansion, settlement development and infrastructure provision. In a semi-arid environment, this pattern is significant because land conversion may reduce vegetation cover, expose soil surfaces, increase runoff and weaken ecological buffers needed for climate-resilient settlement planning. The increasing pressure on land resources is presented in Table 1, showing population growth, agricultural expansion, infrastructure increase and rising livelihood dependence on land.

Table 1. Socioeconomic Drivers of Land-Use Pressure in Northern Jigawa State, 1986–2022

Year	Population million	Agricultural land use km²	Infrastructure projects	Livelihood dependence on land %
1986	2.1	5,200	12	78

1995	2.9	5,850	24	81
2005	3.7	6,500	37	84
2015	4.6	7,100	52	86
2022	5.4	7,850	67	88

The pattern in Table 1 suggests that climate vulnerability in Northern Jigawa is not only a climatic issue but also a land-management and development-planning issue.

3.2 Vegetation Response and Climate Variability

The NDVI trend shows a clear decline from 1986 to 2015, followed by partial recovery by 2022. The decline suggests increasing vegetation stress, while the partial recovery may reflect improved rainfall, vegetation restoration, land-management interventions or natural regeneration in some parts of the study area. However, because the 2022 NDVI value remained below the 1986 value, the recovery should be interpreted as incomplete.

This finding is important for built-environment planning because vegetation performs several climate-regulating functions. It provides shade, supports evapotranspiration, reduces surface temperature, stabilizes soil, improves infiltration and reduces runoff. Where vegetation is degraded, settlements become more exposed to heat stress, dust, erosion, localized flooding and reduced environmental comfort. Therefore, vegetation restoration should not be treated only as an ecological intervention; it should be treated as a built-environment resilience strategy. AVegetation and climate indicators reveal a coupled pattern of vegetation decline, rainfall reduction, warming and increased drought frequency. Mean NDVI declined from 0.34 in 1986 to 0.25 in 2015, before partially recovering to 0.29 in 2022. This represents a decline of about 26.5% between 1986 and 2015 and a net decline of about 14.7% between 1986 and 2022.

Annual rainfall decreased from 720 mm in 1986 to 610 mm in 2015, before increasing to 650 mm in 2022. Average temperature increased from 28.1°C in 1986 to 29.6°C in 2015, before moderating slightly to 29.1°C in 2022. Drought frequency increased from one event per decade in 1986 to four events per decade in 2015, before declining to three events per decade in 2022.

3.3 Land-Use Pressure as a Driver of Climate Vulnerability

The results show that climate vulnerability in Northern Jigawa State is strongly linked to land-use pressure. Population growth, agricultural expansion and infrastructure development increased substantially between 1986 and 2022. These changes are not necessarily negative in themselves because population growth and infrastructure provision are part of development. However, the environmental concern arises when such development occurs without adequate land-use control, vegetation protection, drainage planning and green infrastructure.

The strong negative correlation between NDVI and population, agricultural land use and infrastructure suggests that vegetation decline is closely associated with land conversion. In practical terms, this means that climate vulnerability in the area is not only driven by rainfall and temperature variability; it is also produced through human decisions about land clearance, settlement expansion, cultivation, fuelwood extraction and infrastructure development. This supports the central argument of the article that climate-resilient spaces must be co-created through both scientific analysis and local land-management decisions. These results suggest that 2015 represented the most environmentally stressed benchmark year in the dataset. Table 2 presents the vegetation and climate indicators used to assess the environmental stress pattern in Northern Jigawa State.

Table 2. Vegetation and Climate Indicators in Northern Jigawa State, 1986–2022

Year	Mean NDVI	Annual rainfall mm	Average temperature °C	Drought frequency events/decade
1986	0.34	720	28.1	1
1995	0.31	680	28.6	2
2005	0.27	640	29.2	3
2015	0.25	610	29.6	4
2022	0.29	650	29.1	3

The table shows that vegetation decline occurred alongside reduced rainfall, increased temperature and increased drought frequency, indicating a land-climate system under stress.

3.4 Rainfall-Temperature Regression Pattern

The rainfall-temperature regression results show seasonal differences in the strength and direction of the relationship between temperature and rainfall. January, March, April and October recorded weak or very weak relationships, suggesting that temperature alone does not strongly explain rainfall behaviour during dry or transitional months. May recorded a moderate inverse relationship, while June recorded a moderate positive wet-season relationship.

The peak rainy-season months of July, August and September showed stronger inverse relationships. August recorded the strongest relationship, with an R^2 value of 0.5997, indicating that rainfall-temperature interaction was most pronounced during the core rainy season. At the annual scale, the model produced an R^2 value of 0.5475, suggesting that about 54.75% of annual rainfall variability was explained by temperature in the model, while the remaining variation may be linked to atmospheric circulation, humidity, land-surface moisture and wider climate-system drivers. The seasonal and annual rainfall-temperature regression outputs are summarized in Table 3.

Table 3. Summary of Rainfall-Temperature Regression Outputs

Scale/month	Regression slope	R^2	Interpretation
January	-0.8989	0.1116	Weak inverse relationship
March	0.9408	0.0045	Very weak positive relationship
April	-0.5613	0.0067	Very weak inverse relationship
May	-12.6100	0.3697	Moderate inverse relationship
June	25.7850	0.4968	Moderate positive wet-season relationship
July	-33.2620	0.4419	Strong inverse wet-season relationship
August	-55.3580	0.5997	Very strong inverse wet-season relationship
September	-35.7750	0.3761	Strong inverse wet-season relationship
October	-2.7903	0.1276	Weak inverse relationship

Annual	-201.4200	0.5475	Moderately strong annual inverse relationship

The annual model confirms that temperature is an important explanatory factor in rainfall variability, although rainfall behaviour is also influenced by other atmospheric and land-surface processes.

3.5 Correlation Results

The correlation results show strong relationships between socioeconomic land-use pressure and vegetation conditions. Population was strongly and negatively correlated with NDVI r = -0.91, while agricultural land use was also negatively correlated with NDVI r = -0.88. Infrastructure projects had a negative correlation with NDVI r = -0.85. These relationships indicate that vegetation condition declined as population, agricultural land use and infrastructure development increased.

The results also show that rainfall was positively associated with NDVI r = 0.70, while temperature was negatively associated with NDVI r = -0.79. This confirms that vegetation response in Northern Jigawa is shaped by both climatic and socioeconomic pressures. Improved rainfall supports vegetation greenness, while increased temperature and land-use pressure weaken vegetation condition. The relationships among land-use pressure, vegetation response and climate indicators are presented in Table 4

Table 4. Correlation Matrix of Socioeconomic Drivers, Vegetation and Climate Indicators

Variable	NDVI	Rainfall	Temperature	Agricultural land	Infrastructure
Population	-0.91	0.68	0.84	0.95	0.96
Agricultural land use	-0.88	0.61	0.79	1.00	0.93
Infrastructure projects	-0.85	0.58	0.75	0.93	1.00
NDVI	1.00	0.70	-0.79	-0.88	-0.85

.The strong negative correlations between NDVI and land-use pressure indicators suggest that vegetation decline is closely associated with human-induced land transformation.

3.6 Rainfall Variability, Temperature Increase and Drought Stress

The rainfall and temperature results indicate that Northern Jigawa experienced a climate-sensitive stress pattern during the study period. Rainfall declined from 1986 to 2015, while temperature increased during the same period. Drought frequency also increased up to 2015. Although rainfall partially recovered and temperature moderated slightly by 2022, the long-term pattern still indicates climatic instability.

The rainfall-temperature regression results further show that temperature-rainfall relationships are stronger during the peak rainy-season months of July, August and September. This suggests that climate variability in the area is seasonal and that planning responses should pay special attention to wet-season rainfall behaviour, drainage, flood risk, soil moisture and vegetation response. In semi-arid environments, both drought and intense rainfall can create risks: drought weakens vegetation and soil stability, while heavy rainfall on exposed or compacted surfaces can increase runoff and erosion.

3.7 Sustainable Built-Environment Indicators

The built-environment indicators provide a bridge between environmental change and settlement sustainability. The built-environment panel contained 25 zonal observations and included built-up percentage, mean zonal NDVI, green building footprint, energy-use intensity and permeable surface percentage. Built-up percentage had a mean value of 12.612%, while mean zonal NDVI was 0.284. Green building footprint averaged 4.066%, energy-use intensity averaged 232.876 kWh/m²/year, and permeable surface percentage averaged 51.348%.

The variation in permeable surface percentage, from 34.0% to 64.4%, is especially important because permeability influences infiltration, runoff reduction, groundwater recharge, surface cooling and flood moderation. Areas with lower permeability are more exposed to runoff accumulation, heat stress and drainage pressure. The descriptive statistics for the built-environment sustainability indicators are presented in Table 5.

Table 5. Summary Statistics for Sustainable Built-Environment Indicators n = 25

Variable	Mean	SD	Minimum	Median	Maximum
Built-up percentage	12.612	5.078	4.82	13.08	23.66
Mean zonal NDVI	0.284	0.033	0.228	0.288	0.337
Green building footprint %	4.066	2.101	0.48	4.11	8.46
Energy-use intensity kWh/m²/year	232.876	27.163	176.3	235.5	295.5
Permeable surface %	51.348	8.530	34.0	52.4	64.4

The variation in built-up percentage, vegetation condition and permeable surface availability shows that settlement sustainability differs across zones and requires location-specific planning responses.

3.8 Relationship Among Built-Environment Indicators

The correlation results among built-environment indicators show that built-up percentage was strongly and positively associated with green building footprint r = 0.890. This may indicate that green building features are more likely to appear in zones where building development is expanding. However, built-up percentage was strongly and negatively associated with permeable surface percentage r = -0.772, indicating that settlement expansion is linked with the replacement of permeable ground by sealed or compacted surfaces.

Mean NDVI was negatively associated with built-up share r = -0.541 and positively associated with permeable surface percentage r = 0.444. These relationships suggest that vegetation and permeability remain important environmental indicators for climate-resilient settlement planning. Table 6 shows the statistical relationships among the selected built-environment sustainability indicators.

Table 6. Pearson Correlations Among Sustainable Built-Environment Indicators

Variable	Built-up %	NDVI	Green building footprint %	EUI	Permeable surface %
Built-up %	1.000	-0.541	0.890	-0.509	-0.772
NDVI	-0.541	1.000	-0.525	0.341	0.444
Green building footprint %	0.890	-0.525	1.000	-0.551	-0.753
EUI	-0.509	0.341	-0.551	1.000	0.506
Permeable surface %	-0.772	0.444	-0.753	0.506	1.000

The strong negative relationship between built-up percentage and permeable surface percentage indicates that climate-resilient settlement planning must protect infiltration areas, green spaces and unsealed surfaces.

4. DISCUSSIONS

4.1 Built-Environment Sustainability and Permeable Surface Loss

The built-environment results show that settlement expansion is strongly associated with reduced permeable surface availability. This is one of the most important findings for the article because it directly connects land-cover change with sustainable built-environment outcomes. Permeable surfaces allow rainwater to infiltrate into the soil, reduce runoff, recharge groundwater and moderate surface temperature. When these surfaces are replaced by buildings, roads, compacted yards and other impervious surfaces, settlements become more vulnerable to flooding, erosion, heat and drainage failure.

The negative relationship between built-up percentage and permeable surface percentage therefore indicates that climate-resilient planning in Northern Jigawa must go beyond conventional building development. It must include open-space protection, drainage-sensitive design, green belts, tree planting, rain gardens, infiltration corridors, community woodlots and limits on uncontrolled land sealing. In other words, the built environment should be planned as part of a wider ecological system.

4.2 Local Knowledge and Co-Creation of Climate-Resilient Spaces

The title of the article emphasizes co-creation, local knowledge and decentralized land management. The quantitative results show where vulnerability is emerging, but local knowledge is needed to explain how people experience and respond to these changes. Community members can identify areas where tree loss has increased heat exposure, where rainfall runoff concentrates, where drainage is blocked, where land conversion is occurring rapidly and where traditional adaptation practices still exist.

This means that local communities should not be treated only as beneficiaries of climate-resilience planning. They should be treated as partners in producing resilient spaces. Co-creation can involve participatory mapping of vulnerable areas, community-based vegetation monitoring, local tree-planting programmes, identification of flood-prone settlement zones, protection of grazing and farming corridors, and agreement on land-clearance rules. When scientific data are combined with local knowledge, planning becomes more realistic, socially accepted and easier to implement.

4.3 Decentralized Land Management and Planning Implications

The results support the need for decentralized land management. Climate vulnerability in Northern Jigawa is locally experienced, but it is produced through multiple interacting processes: household land-use decisions, agricultural expansion, infrastructure planning, rainfall variability, temperature stress and vegetation loss. A centralized planning system alone may not respond quickly enough to these local dynamics (Ostrom 2010).

Decentralized land management would allow local government authorities, traditional institutions, community associations, farmers, planners, environmental officers and researchers to work together in monitoring land-cover change and enforcing climate-sensitive planning rules. Such a system can support local afforestation, land-use zoning, drainage planning, protection of permeable surfaces, and regulation of indiscriminate vegetation clearance. The planning implications of the empirical findings are summarized in Table 7.

Table 7. Implications of Findings for Co-Created Climate-Resilient Planning

Observed result	Climate/built-environment implication	Co-created planning response
Population and settlement pressure increased	Greater demand for land, housing, roads and services	Participatory settlement zoning and compact growth planning
Agricultural land expanded	Reduction of vegetation buffers and open land	Agroforestry, green belts and controlled land conversion
NDVI declined then partially recovered	Reduced shading, cooling, infiltration and ecological protection	Community tree planting, shelterbelts and vegetation restoration
Rainfall declined then partially recovered	Uncertainty for water-sensitive planning	Rainwater harvesting, drainage upgrading and watershed-sensitive design
Temperature increased up to 2015	Higher heat stress and possible energy demand	Passive cooling, reflective materials and shade-tree planning
Drought frequency increased	Stress on soil moisture, crops and settlement water supply	Drought-resilient landscaping and early warning systems
Built-up share reduced permeability	Increased runoff and reduced infiltration	Permeable paving, open-space protection and infiltration corridors
Local knowledge exists on land and climate stress	Scientific data alone may not capture lived experience	Participatory mapping and community-based monitoring

The table shows that climate-resilient spaces require the integration of land-use control, local knowledge, vegetation restoration, permeable surface protection and decentralized environmental governance.

5. CONCLUSION

This article examined how climate-resilient spaces can be co-created through the integration of local knowledge, decentralized land management and sustainable built-environment planning in Northern Jigawa State, Nigeria. The study was based on the understanding that climate vulnerability in semi-arid regions is not caused by climatic factors alone, but by the interaction of rainfall variability, temperature increase, vegetation decline, land-use pressure, settlement expansion, weak land-use control and limited community participation in environmental decision-making.

The findings show that Northern Jigawa State has experienced significant socioeconomic and land-use pressure between 1986 and 2022. Population increased substantially, agricultural land expanded, infrastructure projects increased, and livelihood dependence on land remained very high. These changes indicate growing human pressure on land resources. Although development, infrastructure and agricultural expansion are important for socioeconomic progress, their environmental consequences become serious when they occur without adequate vegetation protection, land-use zoning, drainage planning and sustainable built-environment control.

The vegetation and climate indicators further reveal that the area has experienced ecological and hydro-climatic stress. Mean NDVI declined from 1986 to 2015 before showing partial recovery in 2022, while rainfall declined during the same period before also improving slightly. Temperature increased up to 2015 and later moderated slightly by 2022. Drought frequency also increased before declining slightly. This pattern suggests that Northern Jigawa's environmental system is sensitive to both climatic variation and human land-use pressure. The partial recovery recorded in 2022 is encouraging, but it does not fully reverse the long-term decline in vegetation condition.

The correlation results confirm that vegetation condition is strongly affected by land-use pressure. NDVI was negatively associated with population, agricultural land use and infrastructure development, while rainfall had a positive relationship with NDVI and temperature had a negative relationship with NDVI. This means that vegetation decline in the study area cannot be explained by rainfall variability alone. It is also linked to land conversion, settlement growth, agricultural expansion, infrastructure development and human dependence on land-based resources. This supports the argument that climate vulnerability in Northern Jigawa is both an environmental and a governance problem.

The built-environment results are particularly important for climate-resilient planning. Built-up expansion was associated with declining permeable surface percentage, suggesting that settlement growth is replacing natural or semi-natural surfaces with sealed, compacted or impervious surfaces. This has implications for runoff, flooding, groundwater recharge, heat stress and environmental comfort. A built environment that reduces vegetation and permeability may increase vulnerability even when buildings themselves appear structurally sound. Therefore, sustainable built-environment planning in Northern Jigawa must consider land cover, surface permeability, green infrastructure, vegetation corridors, open spaces, drainage systems and community-managed ecological buffers.

The article concludes that climate-resilient spaces cannot be created through technical planning alone. Satellite imagery, NDVI analysis, climate data and statistical models are essential for identifying patterns of change, but they must be combined with local knowledge and decentralized decision-making. Community members understand the lived realities of rainfall changes, tree loss, fuelwood dependence, drainage problems, land conversion, agricultural pressure and settlement vulnerability. When this knowledge is combined with geospatial and climate evidence, planning becomes more grounded, inclusive and practical.

6. RECOMMENDATIONS

6.1 Strengthen Decentralized Land-Use Management: There is a need to strengthen decentralized land-use management across the selected local government areas. Local government authorities, traditional institutions, planning departments, environmental officers, community leaders, farmers and residents should be actively involved in land-use decision-making. This will ensure that land conversion, agricultural expansion, settlement growth and infrastructure projects are properly guided by local environmental realities.

Land clearance, building development and infrastructure expansion should not be approved without considering vegetation loss, drainage pattern, soil exposure, flood risk and surface permeability. Local environmental committees can be established or strengthened to monitor land-use changes and advise planning authorities before major land conversion takes place.

6.2 Integrate Local Knowledge into Climate-Resilient Planning: Local knowledge should be formally integrated into climate-resilient spatial planning. Communities often understand areas that are vulnerable to flooding, erosion, drought stress, vegetation loss, blocked drainage and heat exposure. This knowledge should be collected through participatory mapping, focus group discussions, community consultations and local environmental monitoring.

Planning authorities should not rely only on maps and technical reports. They should combine geospatial analysis with community experience. This will improve the accuracy, acceptance and sustainability of planning interventions.

6.3 Promote Community-Based Vegetation Restoration: Vegetation restoration should be treated as a major climate-resilience strategy in Northern Jigawa State. The decline in NDVI indicates that vegetation cover has been under pressure, and restoring tree cover can help reduce heat stress, improve infiltration, stabilize soil, reduce wind erosion and support ecological recovery.

Community tree planting, shelterbelt development, agroforestry, school-based greening programmes, roadside planting and community woodlots should be promoted. Tree species should be selected based on ecological suitability, drought tolerance, community preference and economic usefulness. Local communities should be involved in planting, protection and maintenance to avoid the failure of restoration projects.

6.4 Protect Permeable Surfaces in Settlement Planning: Since built-up expansion is associated with reduced permeable surface percentage, planning authorities should protect open and permeable spaces within settlements. Building approvals should require adequate setbacks, open spaces, drainage channels, green areas and permeable ground surfaces.

The use of concrete over entire residential compounds should be discouraged where it increases runoff and heat stress. Permeable paving, grassed surfaces, infiltration trenches, soakaway systems, rain gardens and drainage-sensitive landscaping should be promoted. This is especially important in areas prone to flooding or poor drainage.

6.5 Introduce Climate-Sensitive Building and Settlement Guidelines: Northern Jigawa State needs climate-sensitive building and settlement guidelines that respond to semi-arid environmental conditions. Building design should consider ventilation, shading, roofing materials, wall orientation, tree cover, outdoor thermal comfort and energy efficiency.

Settlement layouts should include green corridors, open spaces, drainage networks, pedestrian routes, vegetation buffers and water-sensitive design. Public buildings, schools, markets and health centres should demonstrate climate-responsive design principles, including shade trees, rainwater harvesting and energy-efficient materials.

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