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Research article

Thirty Years of Land-Use and Land-Cover Change in Calabar Metropolis, Nigeria Geospatial Evidence and Planning Implications

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ABSTRACT

Objective: This study quantifies land-use and land-cover change in Calabar Metropolis, Nigeria, from 1992 to 2022 and interprets the planning significance of the observed transitions. Method: Four classified spatial datasets were harmonised to a common 9,918.75-hectare extent and six classes: waterbody, sparse vegetation, dense vegetation, built-up area, bareland and wetland. The archived workflow used remote sensing, Geographic Information Systems, Random Forest classification, field validation and post-classification comparison. Because the source record did not report a confusion matrix or class-specific accuracy, no numerical accuracy claim is made. Results: Tabulated outputs show dense vegetation declined from 950 to 525 hectares, while built-up land increased from 1,287.5 to 1,437.5 hectares. Wetland expanded by 281.25 hectares over the full period, sparse vegetation declined slightly, waterbody remained unchanged and bareland appeared after 2002. Strong inverse temporal correlations between built-up land and dense vegetation were descriptive rather than causal. Implications: Planning should protect remaining vegetation, scrutinise conversion fronts, maintain drainage and wetland functions, and institutionalise periodic geospatial monitoring. Contribution: The article reconciles internally inconsistent summary percentages by prioritising the complete tabulated series that balances to the mapped study-area total in every year and transparent interpretation for future monitoring.

KEYWORDS

Land-use change; Land-cover classification; Remote sensing; Random Forest; Urban expansion; Dense vegetation; Calabar Metropolis; Nigeria

Introduction

Land-use and land-cover change is a visible expression of how population, infrastructure, markets and environmental processes reshape a city. Land use describes the human purpose assigned to land, while land cover describes the observable physical surface. The distinction matters because a vegetation class may be used for farming, conservation or vacant land, and the same built-up class may contain housing, commerce or institutions. Remote sensing cannot by itself reveal every use, but it provides a consistent basis for tracking broad surface transitions over time.

Calabar Metropolis occupies a low-lying coastal and river-influenced environment in south-eastern Nigeria. Urban expansion takes place alongside wetlands, water bodies and remaining vegetation. This setting makes land conversion consequential for drainage, habitat continuity, local temperature and access to land-based livelihoods. A change in mapped cover is not automatically evidence of environmental harm, but the direction, location and scale of change can identify areas requiring planning scrutiny.

The source thesis analysed four temporal observations covering 1992, 2002, 2012 and 2022. It classified the landscape into waterbody, sparse vegetation, dense vegetation, built-up area, bareland and wetland. The archived abstract reports percentages that conflict with the complete tables. The tabulated classes, however, sum to the same 9,918.75-hectare study area in each year and are therefore the more reproducible basis for analysis. This article explicitly prioritises those tables and discloses the inconsistency.

Recent scholarship from Cross River State demonstrates that environmental and built-environment questions are inseparable from service location, livelihoods and local governance. Spatial work on petrol filling stations and eateries shows that facilities concentrate in response to access and market conditions, while studies of tourism support services, entrepreneurship and riverine livelihoods show that infrastructure and environmental management shape economic opportunity (Eneyo & Ekpenyong, 2018; Eneyo et al., 2023; Eneyo & Archibong, 2024; Eneyo, 2026a, 2026b; Eneyo et al., 2026). Eneyo's environmental science and tourism texts further emphasise the need to connect resource use, service systems and sustainability in place-specific analysis (Eneyo, 2025a, 2025b, 2025c; Adeoye et al., 2025; Ogunleye & Adeyemi, 2022). These publications do not substitute for evidence in the present study, but they provide an appropriate regional frame for interpreting planning institutions, environmental change and household adaptation.

The objective is to quantify class composition and net change, examine interval-specific trajectories, interpret descriptive correlations and identify defensible planning implications. The article avoids treating temporal correlation as proof of causal conversion and does not assign environmental outcomes that were not directly measured. Instead, it uses land-cover evidence to identify plausible pressures and policy priorities that should be verified through field and higher-resolution analysis.

Literature review

Land-cover change research is grounded in the proposition that human activities and biophysical processes leave spatial signatures that can be observed repeatedly. Urbanisation generally increases impervious surfaces and fragments vegetation, while agriculture, extraction and infrastructure alter soils and hydrological pathways. The scale and meaning of these changes vary by context. A dense vegetation decline can reflect clearing, degradation or classification differences; a wetland increase can reflect hydrological expansion, seasonal conditions or reclassification. Interpretation therefore requires caution.

Remote sensing provides synoptic coverage and repeat observations, making it suitable for multi-decadal studies. Supervised classification assigns pixels to classes using spectral information and training data. Machine-learning methods such as Random Forest can handle non-linear relationships and heterogeneous features, but their performance depends on imagery, training samples, seasonal comparability and validation (Foody, 2019). Rapid urbanization has resulted in significant land-use and land-cover transformations across Nigerian cities, with remote sensing and GIS techniques increasingly applied to quantify spatial changes and support sustainable planning (Abdullahi et al., 2020; Akinyemi & Adepoju, 2021; Olaniyi et al., 2021). Recent studies have demonstrated substantial conversion of vegetation and agricultural areas into built-up land due to population growth and infrastructure development (Iwuji et al., 2025; Kolo et al., 2020; Jayeola & Orlíková, 2025). Such landscape transformations have important implications for ecological sustainability, urban climate regulation, and future planning strategies (Ibrahim et al., 2022; Ezeomedo & Igbokwe, 2023). Accuracy assessment through independent reference data and a confusion matrix is essential for quantified confidence (Congalton & Green, 2018). Where those metrics are absent, change estimates should be reported without unsupported accuracy claims.

Post-classification comparison is widely used because it allows each date to be classified independently before class areas are compared. The approach can identify net change and, when pixel-to-pixel transitions are correctly calculated, conversion pathways. Its main weakness is that classification errors from each date can compound. For this reason, stable totals and internally consistent tables are helpful but do not replace a formal accuracy assessment.

Urban land-cover change has important planning relevance. Increased built-up area can indicate housing and economic development, but may also reduce infiltration, create runoff and increase pressure on drainage. Vegetation loss can affect habitat, shade and carbon storage. Wetlands provide hydrological and ecological functions, yet an increase in mapped wetland is not necessarily beneficial if it reflects flooding or seasonal expansion. Sustainable planning must therefore connect change maps with ground conditions, zoning and infrastructure capacity.

Research across African metropolitan regions shows that urban expansion often occurs through peri-urban conversion, producing fragmented landscapes and uneven service needs. Asabere et al. (2020) demonstrated that urbanisation and land transformation have spatially differentiated environmental implications in Ghanaian metropolitan areas. Hatab et al. (2019)

linked urban sprawl to food-system pressures in developing countries. Such studies support the need for local monitoring but also show that broad global narratives should not replace context-specific evidence.

The source study also used correlation among class series. Correlation can summarise whether classes changed in opposite or similar directions over four observations, but four time points provide very limited statistical information. A coefficient near -1 may arise because one series rises while another falls, yet it cannot reveal where conversion occurred or what drove it. Transition claims require spatial overlay, and causal claims require additional demographic, economic and policy evidence.

The gap addressed here is methodological transparency. The Calabar dataset contains a complete area table, percentage table, interval changes and correlations, but also conflicting summary figures and a purported transition matrix that does not have the properties of a true pixel transition matrix. By separating reproducible quantities from unsupported interpretation, the article preserves the original findings while strengthening their defensibility.

Land-cover change analysis is sensitive to the meaning assigned to classes. Dense vegetation, sparse vegetation and wetland are not interchangeable ecological categories, and their boundaries may shift with season, image resolution and classification rules. A decline in dense vegetation can indicate clearing, degradation or reclassification into a lower-density category, but the mapped data alone do not identify the mechanism. Similarly, an increase in wetland pixels may reflect hydrological change, classification confusion or improved detection rather than ecological recovery. Defensible interpretation requires class definitions, spectral and temporal consistency, and explicit recognition of uncertainty (Congalton & Green, 2018).

Post-classification comparison has the advantage of producing class areas for each date, but error can accumulate when independently classified maps are compared. If each map contains misclassification, an apparent transition may represent disagreement between classifications rather than physical change. Accuracy assessment should therefore be conducted for each date, preferably using an independent probability-based sample, and transition estimates should be adjusted or accompanied by confidence intervals where feasible. The archived thesis did not report the required confusion matrices, which means the present article can reproduce area totals but cannot quantify map accuracy or uncertainty around change estimates.

Spatial resolution also shapes the urban signal. Coarse pixels may contain buildings, vegetation, bare soil and water simultaneously, forcing the classifier to assign one dominant label. Small roads, riparian strips and neighbourhood green spaces can disappear within mixed pixels, while narrow wetland boundaries can be exaggerated or omitted. This limitation is particularly relevant in Calabar, where drainage corridors, wetlands and built-up areas may occur in close proximity. Higher-resolution data would not automatically eliminate error, but they would permit finer representation of fragmented urban land cover and more useful linkage with parcels and planning zones.

The environmental significance of urban expansion is mediated by location, form and infrastructure. The same increase in built-up area can have different consequences depending on whether growth occurs through compact infill, low-density peripheral expansion or encroachment on flood-prone land. Area totals do not reveal fragmentation, edge density, connectivity or distance from drainage. Landscape metrics and transition maps are therefore needed before inferring habitat disruption or hydrological exposure. The current series provides a temporal accounting framework, while spatial configuration remains an important next stage.

Urban ecological research often links vegetation loss with reduced cooling, carbon storage and habitat, and links impervious expansion with runoff and heat (Grimm et al., 2008; Griscom et al., 2017). These mechanisms are scientifically plausible, but they are not measurements from the Calabar dataset. To test them locally, land-cover maps should be integrated with land-surface temperature, rainfall-runoff observations, flood inventories, biodiversity surveys or carbon estimates. The distinction between plausible implication and demonstrated effect protects the analysis from turning a land-cover study into unsupported claims about multiple environmental outcomes.

Socio-economic drivers also require direct evidence. Population growth, road construction, land markets and institutional development may contribute to conversion, yet the four class tables cannot rank their influence. Interviews or secondary statistics can provide contextual hypotheses, but causal attribution would require spatially and temporally aligned explanatory variables. Regression or machine-learning models should be used only after addressing spatial autocorrelation, temporal dependence and the small number of dates. With four observations, the archived correlations are descriptive summaries rather than inferential tests of drivers.

Theoretical and conceptual framework

The analysis is framed by the driver-pressure-state-response model. Demographic and economic drivers create pressure through construction, clearing and infrastructure expansion (Ajom, 2022; Ajom et al., 2024; Egbai et al., 2023; Eneyo et al., 2026; Okang et al., 2024; Okpi Liya et al., 2016; Ubi, 2025; Uchegbue et al., 2025. The state of the landscape is observed through mapped land-cover composition. Potential implications include altered drainage, habitat and heat exposure, while policy responses include zoning, conservation, drainage investment and monitoring. The model is interpretive; the present data directly measure only the state component and temporal change. A second concept is landscape conversion. Net class change is the difference between total class area at two dates, whereas gross transition records the areas gained and lost through specific conversions. Net stability can conceal substantial turnover. Because the archived dataset provides reliable class totals but not a validated pixel-level transition matrix, this article emphasises net and interval change. It does not claim that every hectare of dense vegetation loss became built-up land. The framework also treats geospatial monitoring as a policy cycle. Classification establishes a baseline; change detection identifies priority locations; field verification determines the nature of change; planning action responds; and subsequent imagery evaluates whether the response altered the trajectory. A repeatable cycle is more useful than a single map because it supports institutional learning and accountability.

Methodology

The study covered a mapped extent of 9,918.75 hectares in Calabar Metropolis. Four observation years were used: 1992, 2002, 2012 and 2022. The source record describes the use of satellite remote sensing, a Digital Elevation Model, Geographic Information Systems, field validation and Random Forest classification. The area increments of 6.25 hectares are consistent with a 250-metre grid, although the article relies on the reported area table rather than inferring unreported processing parameters.

Six land-cover classes were retained. Waterbody represented persistent open water; sparse vegetation represented less-dense vegetated surfaces; dense vegetation represented comparatively continuous vegetation; built-up area represented constructed surfaces; bareland represented exposed non-vegetated ground; and wetland represented saturated or wetland cover. These operational classes are broad and do not distinguish every urban use or vegetation type.

A reproducible processing sequence would include radiometric and geometric preparation, projection to a common coordinate system, clipping to the same boundary, selection of comparable seasonal imagery, collection of representative training samples, Random Forest classification and post-classification editing. Independent validation samples should then be used to calculate overall, user's and producer's accuracies. The archived thesis did not provide those statistics, so this manuscript does not report them.

Class areas were taken from the complete hectare table. Percentages were independently checked by dividing each class area by 9,918.75 hectares and multiplying by 100. The recalculated values correspond to the archived percentage table within rounding. Net change was calculated as the 2022 area minus the 1992 area. Interval change was calculated separately for 1992–2002, 2002–2012 and 2012–2022.

The archived abstract reports dense vegetation declining from 65.1% to 49.3% and built-up area increasing from 6.2% to 16.1%. These values do not match the tables, which report dense vegetation at 9.58% and 5.29%, and built-up area at 12.98% and 14.49%. Because the table is complete and balances to the study-area total at every date, it is treated as the authoritative analytical record. The alternative percentages are disclosed but not combined with the tabulated series.

The original correlation matrix was reproduced as a descriptive summary. With four yearly observations, inferential significance and causal interpretation are inappropriate. Coefficients are therefore described only as co-movement across the four dates. The purported transition matrix in the thesis contains negative values and net changes rather than non-negative pixel transitions; it is not used as evidence of specific conversion pathways.

Environmental implications were interpreted using established literature and the physical setting of Calabar. Built-up expansion and vegetation decline can plausibly increase runoff, fragmentation and heat exposure, but these outcomes were not directly measured. Wetland and waterbody changes were similarly interpreted cautiously. Policy recommendations are framed as risk-management responses to observed land-cover trajectories, not proof of a particular environmental impact.

Limitations include coarse spatial resolution, four temporal observations, missing accuracy metrics, potential seasonal effects, broad classes and the absence of spatially explicit transition maps in the archived output. The study nevertheless provides a consistent area series that can support baseline planning and identify priorities for higher-resolution follow-up.

The area reconciliation procedure was central to the revised analysis. For each year, the six class values were summed and compared with the common mapped extent of 9,918.75 hectares. All four tabulated years balanced to this total, which provided an internal consistency check unavailable for the conflicting percentages in the source abstract. Percentage composition was recalculated as class area divided by 9,918.75 multiplied by 100. Interval change was computed by subtracting the earlier class area from the later value, while full-period relative change used the 1992 area as the denominator. Relative change was not calculated for bareland because its 1992 baseline was zero.

The temporal correlations were retained only as descriptive diagnostics. Pearson coefficients were calculated across four dates for selected class pairs, yielding two degrees of freedom and extremely unstable estimates. A high absolute coefficient in such a series can arise from monotonic trends and does not show that one class was converted directly into another. No p-values are used to support causal interpretation. Direct conversion requires a cross-tabulated transition matrix based on co-registered pixels, and causal explanation requires independent driver data. The correlation table is therefore labelled and discussed as evidence of co-movement only.

Reproducible future implementation would require archiving the original imagery, acquisition dates, cloud masks, training polygons, predictor variables, Random Forest settings, class legend, projection and validation sample. The analysis should be scripted where possible so that preprocessing and area calculation can be repeated. Random seeds and software versions should be recorded. Outputs should include classified rasters, probability or uncertainty layers, confusion matrices and a transition matrix. The absence of these items from the accessible archive is reported as a limitation rather than reconstructed through assumption.

Results and discussion

Waterbody occupied 2,906.25 hectares, or 29.30% of the mapped area, in every year. This stability may indicate a persistent broad water footprint, but it may also reflect the limited sensitivity of the classification to smaller shoreline changes. The result should not be interpreted as evidence that hydrological conditions or water quality were unchanged.

Table 1. Land-use and land-cover area by year

Class	1992 (ha)	2002 (ha)	2012 (ha)	2022 (ha)
Waterbody	2,906.25	2,906.25	2,906.25	2,906.25
Sparse vegetation	1,575.00	1,562.50	1,468.75	1,556.25
Dense vegetation	950.00	725.00	587.50	525.00
Built-up area	1,287.50	1,325.00	1,437.50	1,437.50
Bareland	0.00	0.00	6.25	12.50
Wetland	3,200.00	3,400.00	3,512.50	3,481.25
Total	9,918.75	9,918.75	9,918.75	9,918.75

Wetland was the largest mapped class, increasing from 3,200 hectares in 1992 to 3,400 in 2002 and 3,512.5 in 2012 before declining slightly to 3,481.25 in 2022. The net increase was 281.25 hectares, equivalent to 2.84 percentage points. An increase in mapped wetland can represent hydrological expansion, altered classification or seasonal conditions. It does not automatically signify ecological improvement.

Dense vegetation showed the clearest sustained decline. It fell from 950 hectares in 1992 to 725 in 2002, 587.5 in 2012 and 525 in 2022. The net loss was 425 hectares, or 44.7% of the 1992 dense-vegetation area. As a share of the study area, the class declined from 9.58% to 5.29%. The consistency of the direction across all intervals strengthens the conclusion that dense cover reduced within the classification system.

Table 2. Percentage composition of the mapped study area

Class	1992 (%)	2002 (%)	2012 (%)	2022 (%)
Waterbody	29.30	29.30	29.30	29.30
Sparse vegetation	15.88	15.75	14.81	15.69
Dense vegetation	9.58	7.31	5.92	5.29
Built-up area	12.98	13.36	14.49	14.49
Bareland	0.00	0.00	0.06	0.13
Wetland	32.26	34.28	35.41	35.10

Built-up area increased from 1,287.5 hectares in 1992 to 1,325 in 2002 and 1,437.5 in 2012, remaining at 1,437.5 in 2022. The net increase was 150 hectares, representing 11.7% growth relative to the 1992 built-up extent and a rise of 1.51

percentage points. The plateau between 2012 and 2022 may reflect genuine slowing, classification saturation or resolution limitations. It should not be read as proof that construction stopped.

Sparse vegetation changed less consistently. It declined from 1,575 hectares in 1992 to 1,562.5 in 2002 and 1,468.75 in 2012, then recovered to 1,556.25 in 2022. The net decline was only 18.75 hectares. This trajectory may reflect interchange with dense vegetation, wetland or other classes, but the available totals do not identify where those exchanges occurred.

Table 3. Interval-specific area change

Class	1992–2002 (ha)	2002–2012 (ha)	2012–2022 (ha)
Waterbody	0.00	0.00	0.00
Sparse vegetation	-12.50	-93.75	+87.50
Dense vegetation	-225.00	-137.50	-62.50
Built-up area	+37.50	+112.50	0.00
Bareland	0.00	+6.25	+6.25
Wetland	+200.00	+112.50	-31.25

Bareland was absent in the 1992 and 2002 tables, appeared at 6.25 hectares in 2012 and reached 12.5 hectares in 2022. The area is small, yet its appearance may identify exposed surfaces related to construction, erosion or other disturbance. The class should be examined using higher-resolution imagery because a few coarse pixels can materially affect such a small estimate.

Interval analysis reveals that change was not uniform. Dense vegetation declined most strongly between 1992 and 2002, losing 225 hectares, followed by 137.5 hectares in 2002–2012 and 62.5 hectares in 2012–2022. Built-up land gained 37.5 hectares in the first decade and 112.5 in the second, with no tabulated net change in the third. Wetland gained 200 and 112.5 hectares in the first two intervals, then lost 31.25 hectares in the last.

Table 4. Net change from 1992 to 2022

Class	Net change (ha)	Percentage-point change	Relative change from 1992 (%)
Waterbody	0.00	0.00	0.0
Sparse vegetation	-18.75	-0.19	-1.2
Dense vegetation	-425.00	-4.29	-44.7
Built-up area	+150.00	+1.51	+11.7
Bareland	+12.50	+0.13	Not applicable
Wetland	+281.25	+2.84	+8.8

The figure demonstrates the compositional trajectories. Waterbody is flat, wetland rises and then moderates, dense vegetation declines, built-up land rises and then plateaus, and sparse vegetation shows a late recovery. Because all classes sum to a fixed total, increases in some classes necessarily coincide with decreases in others. This compositional constraint is one reason correlations must be interpreted carefully.

The reported correlation between built-up area and dense vegetation was -0.94, while wetland and dense vegetation had a coefficient of -0.97. Built-up area and wetland moved together positively at 0.91. With four observations, these values describe temporal co-movement rather than statistical evidence of direct conversion. The positive built-up–wetland relationship, for example, does not mean urban development created wetland; both may have changed for different reasons within a fixed-area classification.

Table 5. Descriptive correlations among selected class series

Pair	r	Defensible interpretation
Built-up area and dense vegetation	-0.94	Opposite temporal movement across four observations; not proof of direct conversion
Wetland and dense vegetation	-0.97	Opposite temporal movement; drivers not identified
Built-up area and wetland	0.91	Similar direction over time; not evidence that one caused the other
Bareland and built-up area	0.89	Co-movement in a very small four-date series
Sparse vegetation and built-up area	-0.68	Moderate opposite movement with late sparse-vegetation recovery

The most defensible environmental inference concerns pressure rather than measured impact. A 425-hectare decline in dense vegetation reduces the mapped extent of a class associated with canopy, habitat and surface protection. A 150-hectare increase in built-up area increases the mapped extent of constructed surfaces. Together, these changes justify field investigation of drainage, heat and habitat conditions in conversion-front areas.

The results also have implications for land administration. Coarse, metropolitan-scale data can identify broad trends but cannot determine parcel compliance or ownership. Planning authorities should use the series to prioritise finer-scale mapping, not to make enforcement decisions against individual properties. High-resolution imagery, parcel boundaries and field inspection are required for that purpose.

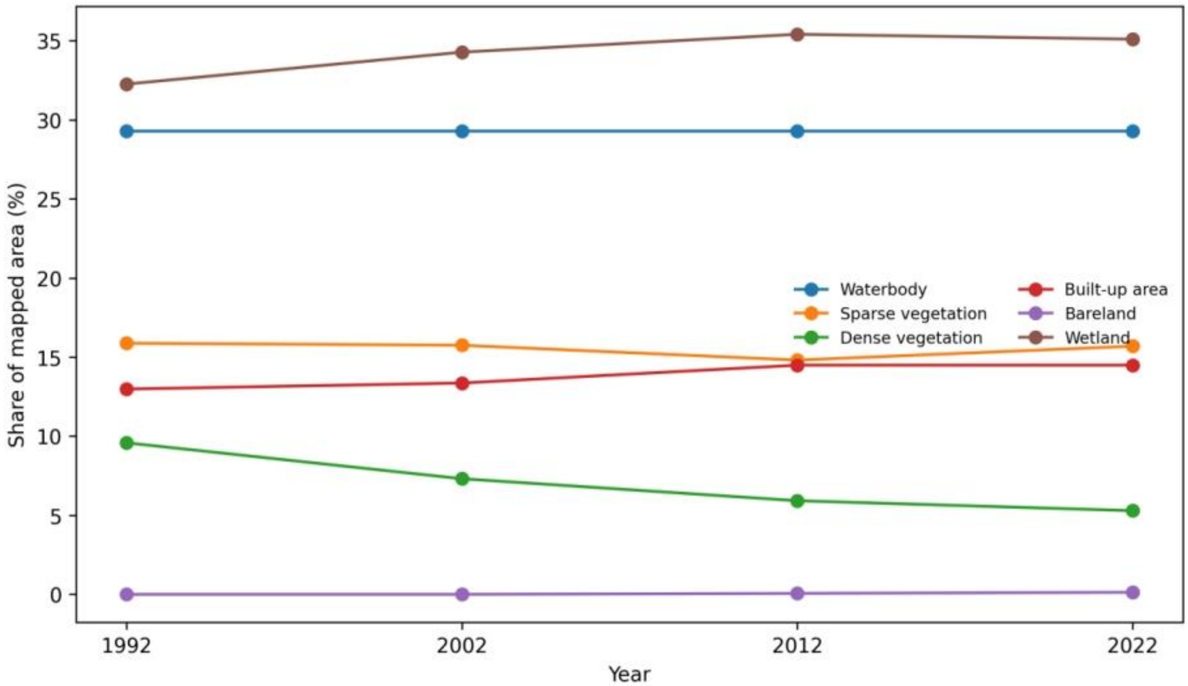

Figure 1. Land-use and land-cover composition in Calabar Metropolis, 1992–2022.

Source: Author's analysis, 2026

The discrepancy between the abstract and the tables is a substantive data-quality issue. Reporting both sets without explanation would create an internally contradictory article. Prioritising the balanced area table preserves the verifiable part of the original research and prevents exaggerated claims. This approach illustrates the importance of reproducible tables, metadata and archived processing outputs in geospatial research.

The Calabar pattern is broadly consistent with literature on urbanising African regions, where built surfaces expand and vegetation becomes fragmented. However, the relatively large and increasing wetland class differentiates the study area and highlights the need for coastal and hydrological interpretation. Planning responses should therefore combine urban growth management with wetland and drainage governance rather than treating the metropolis as a purely terrestrial landscape.

The long-term decline in dense vegetation was both absolute and proportional. The class fell from 950 hectares in 1992 to 525 hectares in 2022, a net reduction of 425 hectares or 44.7% relative to its baseline. The decline slowed across the three intervals, from 225 hectares in the first decade to 62.5 hectares in the last. This deceleration may indicate reduced remaining area, changing conversion pressure or classification differences, but the available series cannot discriminate among these explanations. What the tables support is a persistent downward trajectory, not a measured account of the processes causing it.

Built-up land increased by 150 hectares over the full period, with most recorded growth occurring between 2002 and 2012. The 2012 and 2022 totals were identical. Equality at the class-total level should not be interpreted as an absence of urban change during the final decade. Gains and losses in different locations could offset each other, or the classification could lack sensitivity to small and dispersed development. A pixel-level transition matrix and higher-resolution imagery would be required to determine whether the urban footprint was stable, reorganised or affected by classification saturation.

The wetland trajectory requires especially careful treatment. Wetland increased from 3,200 to 3,481.25 hectares across the period, but declined slightly between 2012 and 2022. A larger mapped wetland area is not necessarily evidence of improved wetland condition. It could reflect inundation, vegetation change, altered class boundaries or confusion with other moisture-related surfaces. Management decisions should therefore verify mapped wetland through field assessment and hydrological data before designating restoration success or authorising conversion.

Sparse vegetation showed a small net decline but a non-linear pattern, falling through 2012 and recovering by 2022. This class may function as an intermediate category between dense vegetation, agriculture, disturbed land and developing urban surfaces. Without transition data, the recovery cannot be assigned to regrowth, cultivation or classification exchange. The result nevertheless illustrates why reporting only the 1992 and 2022 endpoints can obscure important interval variation. Period-specific tables provide a more defensible basis for monitoring than a single net-change statistic.

Bareland occupied a very small share of the mapped area, appearing after 2002 and reaching 12.5 hectares in 2022. Because its absolute extent is small, even modest classification error could materially affect its estimated relative change. Bareland should not therefore be treated as a major metropolitan trend on the basis of this series. Its potential importance lies in local concentration, where exposed soil may indicate construction, erosion or temporary clearance. Location-specific mapping would be more informative than metropolitan totals for this class.

Waterbody remained constant at 2,906.25 hectares in every year. Exact invariance across three decades may reflect a stable broad water mask, but it may also indicate that the classification or study boundary fixed the class extent. The result should be reported as no detected change in the tabulated series rather than proof that shorelines, channels or water conditions were unchanged. Water quality, seasonal extent and small edge changes were outside the measured variables.

When the class series is considered as a closed area budget, increases in one or more categories must be balanced by decreases elsewhere. This accounting identity helps check arithmetic but does not reveal direct transitions. For example, the 1992–2002 reduction in dense and sparse vegetation numerically balances the increase in wetland and built-up land, yet the tables do not show whether vegetation pixels became those classes. A transition matrix would identify the origin and destination of changed pixels and would permit separate analysis of persistence, gain, loss and swap. Without it, class-level balancing should not be narrated as a one-to-one conversion pathway.

The distribution of change across the three intervals also cautions against a single linear urbanisation narrative. Built-up growth accelerated in the middle interval and was not detected in the final interval, while sparse vegetation recovered and wetland declined slightly after 2012. These differences may represent real shifts in development pattern or differences in imagery and classification. A defensible monitoring programme should therefore examine each period and retain source-specific uncertainty rather than interpolate a smooth trend between 1992 and 2022. Annual or five-year observations would provide a stronger basis for identifying turning points.

The class totals have strategic value even with these limitations. They establish a reproducible baseline against which future maps can be compared, identify dense vegetation as the class with the largest proportional decline and show that the metropolitan landscape contained a substantial wetland component throughout the series. These facts justify targeted verification and planning attention. They do not, by themselves, specify the legal status, ecological quality or ownership of the affected land, which must be established through additional spatial layers and field investigation.

Policy implications

Planning authorities should establish a recurring land-cover monitoring programme using comparable seasonal imagery and documented classification procedures. A five-year cycle would allow trends to be identified before a full decade has passed. Each cycle should archive imagery, training samples, accuracy matrices, class definitions and scripts or processing logs.

Remaining dense-vegetation areas should be mapped at higher resolution and evaluated for ecological, drainage and public-space value. Protection should not rely on a single metropolitan percentage. Parcel ownership, land-use designation and field condition must be reviewed before conservation or development decisions are made.

Built-up expansion should be assessed alongside drainage capacity. New development areas require impervious-surface controls, retention measures, protected channels and setback enforcement. Where mapped wetland overlaps proposed development, hydrological and environmental assessment should precede approval. The objective is not to prohibit all growth, but to reduce avoidable exposure and loss of ecosystem function.

A public geospatial dashboard could present generalised land-cover trends and planning priorities, while sensitive parcel information remains protected. Transparent monitoring can support community awareness and inter-agency coordination. It can also help distinguish officially planned growth areas from locations where conversion is occurring without adequate infrastructure.

Finally, future research should integrate population, road expansion, permit records, flood observations and surface-temperature data. Such integration would permit stronger explanation of drivers and impacts. The current series is an important baseline, but it should be treated as the beginning of a monitoring system rather than a complete causal account.

A metropolitan monitoring protocol should define decision thresholds before new maps are produced. For example, planning authorities could flag vegetation loss within protected buffers, built-up expansion within drainage corridors and land-cover change near critical infrastructure. Thresholds should be linked to field verification rather than automatic enforcement because classification is uncertain. A documented review pathway would convert maps from illustrative products into screening tools while preserving procedural fairness.

Green-space protection should be spatially targeted. The aggregate decline in dense vegetation supports concern, but interventions should focus on connected remnants, riparian strips and areas that provide demonstrable drainage, cooling or biodiversity functions. Parcel-level planning can then differentiate between land that requires strict protection, land suitable for managed use and already disturbed land where compact development may reduce pressure elsewhere. Such differentiation is more defensible than a uniform prohibition based on metropolitan percentages.

Wetland governance should integrate planning, environment and disaster-management agencies. Field inventories should identify wetland type, hydrological connectivity, occupation and service function. Permit review should require a mapped relationship between proposed development and verified wetland boundaries, while drainage plans should assess cumulative downstream effects. The observed class trend justifies monitoring but not an assumption that all mapped wetland has identical value or legal status.

Public reporting should include uncertainty alongside change. Future maps could show confidence or class probability, validation results and areas where imagery was inadequate. Publishing only a crisp categorical map can encourage users to treat every boundary as exact. Transparent uncertainty supports better decisions by indicating where site inspection is essential and where broad strategic interpretation is appropriate.

Conclusion

The reproducible tabulated series shows a clear decline in dense vegetation and an increase in built-up area across Calabar Metropolis between 1992 and 2022. Dense vegetation fell by 425 hectares, built-up land increased by 150 hectares, wetland increased by 281.25 hectares, sparse vegetation changed little in net terms, waterbody remained constant and bareland appeared after 2002.

These findings support planning concern, but not every environmental claim in the source thesis can be demonstrated by the available data. The study did not directly measure heat, flooding, biodiversity, water quality or livelihood loss. Correlations across four dates are descriptive, and the missing accuracy assessment limits quantified confidence. The conflicting abstract percentages were therefore excluded in favour of the complete tables.

The strongest conclusion is that Calabar requires repeatable, accuracy-documented and higher-resolution monitoring linked to land-use planning and drainage governance. Protecting remaining vegetation, verifying wetland condition and scrutinising conversion fronts are proportionate responses to the observed pattern. Stronger causal conclusions should await spatial transition analysis and independent environmental measurements.

The analysis further demonstrates the importance of internal consistency checks in secondary geospatial research. The source abstract and complete area tables did not support the same percentages. Rather than average or selectively combine them, the article used the series that maintained a constant mapped extent and disclosed the discrepancy. This procedure preserves the original evidence while avoiding false certainty. Similar archival studies should publish machine-readable class tables, metadata and validation outputs so that later researchers can distinguish substantive landscape change from transcription or classification error.

For policy, the appropriate response is an adaptive monitoring cycle: map, validate, screen priority locations, verify them in the field, decide through existing legal procedures and then update the database. Such a cycle connects geospatial evidence to accountable planning without treating classification as a substitute for site assessment. It also permits future research to test whether observed land-cover changes are associated with flooding, heat or livelihood outcomes using independently measured variables.

Declarations

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Ethics statement

The research was completed as a supervised academic study using adult respondents and/or non-identifiable spatial or administrative records.

Conflict of interest

The author declares no known financial or personal conflict of interest relating to this manuscript.

Data availability

Data were sourced from the field

Author contribution

All the authors did Conceptualisation, methodology, investigation, data curation, analysis, visualisation, original drafting and revision.

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