

A Multi-Temporal Geospatial Analysis of Urban Infrastructure Expansion and its Environmental Impact in Osogbo, Nigeria (1987–2023)

By

¹Joy O. Nwaezeigwe, ²Ademola B. Bakare, ³Oluwatimileyin G. Oluborode, and ⁴Sarafa A. Amuda

^{1,2}Department of Geography

³Department of Urban and Regional Planning
Obafemi Awolowo University Ile-Ife.

⁴Federal School of Surveying Oyo, Oyo State.

¹Corresponding Author Email: revauyeh@oauife.edu.ng

Abstract

This study provides a longitudinal analysis of urban infrastructure expansion and its concomitant environmental impacts in Osogbo, Nigeria, over a 36-year period (1987–2023). Utilizing a time-series of Landsat and Sentinel-2 optical imagery processed within the Google Earth Engine (GEE) [2025] platform, the spatial-temporal dynamics of urban footprints were quantified, specifically roads and buildings. A supervised classification algorithm (Random Forest) was employed to map land cover changes at five historical intervals. The results revealed a profound urban transformation, with the total urban infrastructure footprint expanding from 11.36 km² (20.43%) in 1987 to 26.52 km² (47.70%) in 2023, representing a 133.45% increase. This growth was predominantly driven by a 256.47% expansion in road networks. The environmental cost of this rapid urbanisation was significant, with vegetation cover declining sharply from 67.81% to 29.08% of the total area. The period between 2007 and 2017 marked the most intense phase of urbanisation and vegetation loss. The study also recorded a substantial increase in bare ground, indicating ongoing land conversion for future development. These findings underscore the critical trade-offs between urban development and ecological preservation. It was concluded that Osogbo's pattern of urban sprawl necessitates an urgent shift towards sustainable urban planning strategies that prioritise compact development, green infrastructure, and the conservation of remaining natural ecosystems to ensure long-term urban resilience.

Keywords: Urban Infrastructure Footprint, Land Use Change, Remote Sensing, GIS, Urban Sprawl, Sustainability, Osogbo

1. Introduction

Urban infrastructure serves as the backbone of cities, providing essential support for socio-economic and environmental functions. In developing nations like Nigeria, rapid and often unplanned urbanisation exerts immense pressure on these systems including transportation networks (roads, railways, bridges), and buildings (Residential, Industrial, or Commercial), leading to significant infrastructure deficits and environmental degradation (Cohen, 2006; United Nations, 2019). Cities expand spatially, consuming agricultural land and natural ecosystems, which results in habitat destruction, loss of biodiversity, and increased greenhouse gas emissions (Seto et al., 2011). Understanding the spatial footprint of this expansion is therefore crucial for assessing infrastructure efficiency, identifying service gaps, and evaluating environmental impacts (Kennedy et al., 2017). The growing number of people and expanding urban areas generate critical pressure on urban infrastructure which is detrimental to urban quality of life and can negatively impact economic output if left unchecked (Ade & Afolabi, 2013). Urban planners together with policymakers need to maintain and improve infrastructure systems in a manner that

corresponds with both metropolitan spatial expansion and population changes. According to Bettencourt et al. (2016), effective infrastructure planning is essential not only for maintaining urban productivity but also for promoting sustainability and resilience in the face of climate change and environmental degradation. Urban infrastructure operates as an essential marker revealing how well an urban area delivers vital services and maintains economic development as well as distributes resources fairly to residents.

Osogbo, the capital of Osun State in southwestern Nigeria, exemplifies these challenges. Its designation as a state capital in 1991 triggered rapid population growth and urban expansion, which has not been matched by commensurate infrastructure development (Adesina & Owoeye, 2014). This has resulted in traffic congestion, unreliable utility services, and the proliferation of informal settlements with limited access to basic amenities. A comprehensive, spatially explicit understanding of how the city's infrastructure footprint has evolved is a critical prerequisite for effective and sustainable urban planning. Like most Nigerian cities, Osogbo has experienced rapid increase in population and area, due to migration and natural population growth (Owoeye, 2019). The rapid urban expansion of Osogbo, the capital of Osun State, has not been matched by adequate infrastructural development. This mismatch has led to traffic congestion due to poorly developed and inadequately maintained road networks (Adedotun, Ogundahunsi, & Oyeniyi, 2016), limited access to potable water, as only a small portion of the population is connected to the public water supply system (Ibitoye & Okende, 2016), and frequent electricity outages that disrupt residential and commercial activities (Vanguard, 2023; IBEDC, 2023).. The urban growth without sufficient infrastructure development begs for a detail study of the city's infrastructure footprint to enable urban planning for the future. Recent advancements in Remote Sensing and Geographic Information Systems (GIS) offer powerful tools for such analyses.

The integration of multi-temporal satellite imagery and robust classification algorithms like Random Forest enables precise mapping and monitoring of urban growth over large areas and extended periods (Herold et al., 2003). This study leverages these technologies to conduct a longitudinal geospatial analysis of Osogbo. The aim of this study is to extract and analyse the urban infrastructure footprints in Osogbo between 1987 and 2023 to understand the extent and temporal dynamics of urban expansion. The specific objectives are to: determine the urban infrastructure footprints (roads and buildings) in Osogbo for the years 1987, 1997, 2007, 2017, and 2023; examine the temporal changes and rates of urban infrastructure expansion over the 36-year period; and analyse the concomitant environmental impacts, specifically the loss of vegetation and increase in bare land.

Urban infrastructure includes the necessary systems which allows the sustainability of urban life including transportation networks (roads, bridges), utility services (water supply, electricity supply, waste disposal), and public infrastructure (healthcare, education, and recreational) services. Urban planners and policymakers require detailed information on the spatial distribution and condition of infrastructure to make informed decisions about future development. Additionally, the environmental impact of such a deficit is also tremendous. Uncontrolled and unplanned urban expansion left unchecked in expanding haphazardly into agricultural lands and natural ecosystems is causing environmental degradation including deforestation, loss of biodiversity, and increased greenhouse gas emissions (Cohen, 2006). One of the challenges that must be addressed is how to understand the development and expansion of infrastructure and, specifically, the intersection between the natural environment and the patterns of urban growth. These challenges can be addressed with a spatially explicit understanding of how this infrastructure has developed and expanded over time. Hence this research, which applies urban infrastructure footprint mapping and analysis to Osogbo using remote sensing and GIS technologies between 1987 and 2023.

2. Materials and Methods

Osogbo as seen in figure 1 is located in Southwestern Nigeria, approximately between latitude $7^{\circ}46'N$ and $8^{\circ}16'N$, and longitude $4^{\circ}34'E$ and $4^{\circ}56'E$. As the administrative and commercial capital of Osun State, it has experienced significant population growth, with current estimates exceeding 700,000 people. The city features a tropical wet and dry climate and is characterized by undulating lowlands interspersed with hills, primarily drained by the Osun River. This combination of rapid growth and diverse topography makes it an ideal case study for analysing urban infrastructure dynamics.

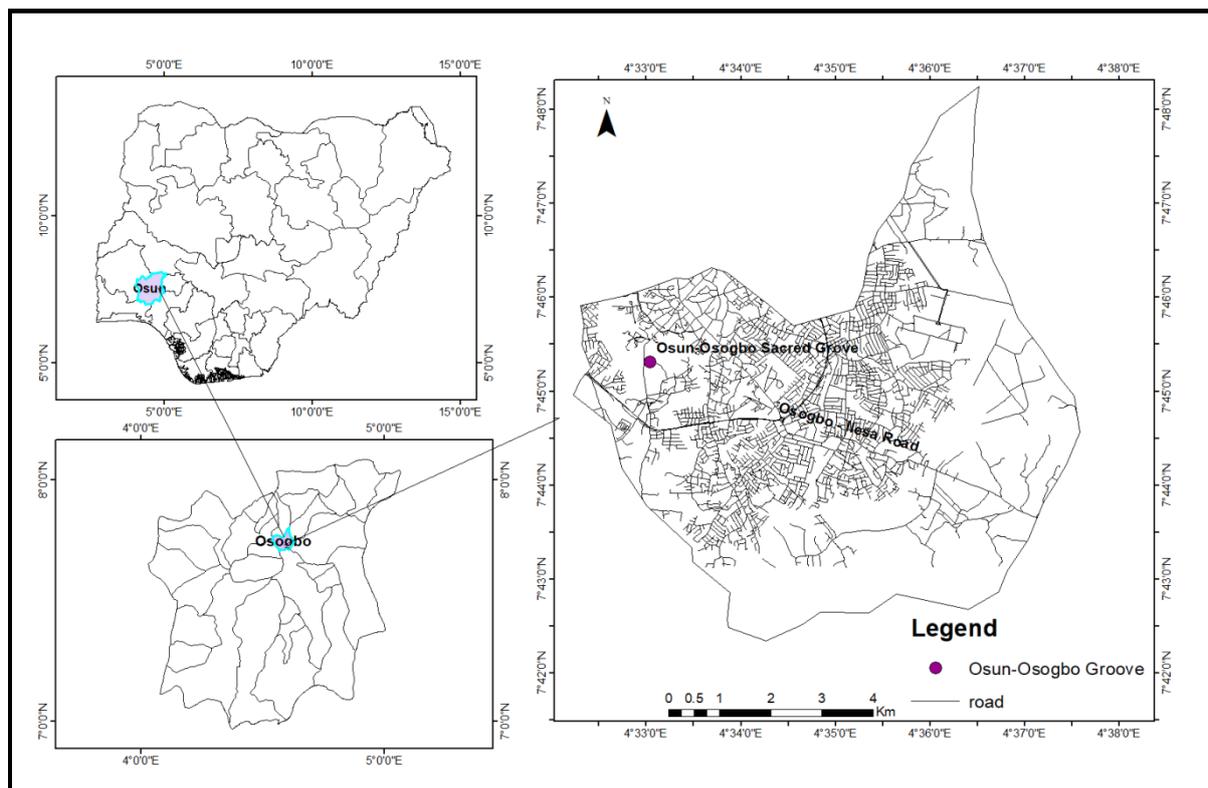


Figure 1: Map of Osun showing Osogbo, the Study Area

This study adopted a geospatial research design. Secondary data consisted of optical satellite imagery from Landsat 5 TM (1987, 1997), Landsat 7 ETM+ (2007), and Sentinel-2 MSI (2017, 2023), all sourced from the United States Geological Survey (USGS) and Copernicus Open Access Hub. Primary data included ground control points (GCPs) collected using a hand-held Garmin GPSMAP 66s device ($\pm 3\text{-}5\text{m}$ accuracy) for validation. All image processing and analysis were conducted within the Google Earth Engine (GEE) [2025] platform. Pre-processing for optical imagery involved using Landsat Collection 2 Level 2 surface reflectance data, which incorporates atmospheric correction. Cloud masking was applied using the QA_PIXEL band to exclude pixels with cloud cover exceeding 40%. Geometric correction was ensured using the pre-processed T1 product (RMSE $< 12\text{m}$), and all images were resampled to a consistent 30-meter spatial resolution and clipped to the study area boundary.

Image Classification and Feature Extraction: A supervised classification approach using the Random Forest (RF) algorithm was implemented. Training samples were created for five land cover classes: Roads, Buildings, Vegetation, Water Bodies, and Bare Ground. The model utilized spectral bands (Red, NIR, SWIR) and derived indices the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI) to enhance class separability.

Change Detection Analysis: A post-classification comparison technique was employed to analyse land cover changes between the five time periods. This involved overlaying the classified maps from different years to produce a change matrix, quantifying the transitions between urban and non-urban land covers.

Accuracy Assessment: The classification accuracy for each year was assessed using independent validation points. Error matrices were generated to compute overall accuracy, which consistently exceeded 98.5% for all optical imagery classifications, ensuring the reliability of the change analysis.

3. Results and Discussion

Urban Infrastructure Footprint Expansion (1987-2023)

The analysis revealed a dramatic and consistent expansion of Osogbo's urban infrastructure footprint over the 36-year study period (Table 1).

Table 1. Urban Infrastructure Footprint Change in Osogbo (1987-2023)

Year	Roads (km ²)	Road %	% Road Change	Buildings (km ²)	Building %	% Building Change	Total Urban (km ²)	Total Urban %	Vegetation %	Bare Ground %
1987	3.63	6.52	—	6.73	12.11	—	10.36	18.63	67.81	1.48
1997	6.27	11.22	72.1%	7.72	13.99	15.5%	14.00	25.17	67.96	1.54
2007	9.69	17.42	55.2%	8.70	15.65	11.9%	18.39	33.07	50.86	3.14
2017	11.53	20.84	19.6%	13.38	24.08	53.8%	25.91	44.82	31.11	19.14
2023	12.94	23.41	12.4%	13.58	24.57	2.0%	26.52	47.70	29.08	20.15

In 1987, the urban footprint was modest, covering 10.36 km². By 2023, it had more than doubled to 26.52 km². Road networks exhibited the most dramatic growth, expanding by 256.47%, from 3.63 km² to 12.94 km². Building coverage also increased substantially by 75.68%, from 6.73 km² to 13.58 km². The most intense period of urbanization occurred between 2007 and 2017, where the urban footprint grew by 40.8%, coinciding with a period of significant economic and demographic change.

Loss of Vegetation and Increase in Bare Ground.

The expansion of the urban footprint came at a significant environmental cost (Tables 2 and 3). Vegetation, which dominated the landscape in 1987 (67.81%), underwent a severe decline, reducing to just 29.08% by 2023 a net loss of 57.40%. This indicates a direct conversion of natural and agricultural lands to built-up surfaces. Concurrently, the area of bare ground increased dramatically from 1.48% to 20.15%, reflecting land cleared for future construction and the transitional phases of urban sprawl. This trend highlights the ongoing pressure on the city's natural land cover.

Table 2: Natural land Cover of study area classification

Year	Vegetation			Water bodies			Bare Ground		
	Area (ha)	% of Total	% Change	Area (ha)	% of Total	% Change	Area (ha)	% of Total	% Change
1987	3,771.74	70.13	-	542.67	9.76	-	82.14	1.48	-
1997	3,796.72	68.52	+0.66	266.22	4.77	-50.94	86.34	1.54	+5.11
2007	2,816.08	50.79	-25.83	720.02	13.00	+170.46	173.71	3.14	+101.19
2017	1,721.90	32.87	-38.85	175.27	3.17	-75.66	1,059.60	19.14	+509.98
2023	1,607.02	29.36	-6.67	154.45	2.79	-11.88	1,135.16	20.15	+7.13

Table 3: Land Use Change Over Time

Year	Urban Infrastructure (%)	Vegetation (%)	Bare Ground (%)
1987	18.63	67.81	1.48
1997	25.17	67.96	1.54
2007	33.07	50.86	3.14
2017	44.82	31.11	19.14
2023	47.70	29.08	20.15

Urban infrastructure footprint of Osogbo 1987

The classification of Osogbo's land cover for 1987 revealed a detailed distribution of urban infrastructure and other land cover types. The urban infrastructure footprint primarily includes roads and buildings, which represent key indicators of urbanisation. The total area covered by urban infrastructure otherwise known as infrastructure footprints of Osogbo in 1987 is 10.35km². Figure 2 shows the classification result of the Landsat image obtained for the period. As for the year 1987, the urban infrastructure footprint in Osogbo was relatively limited, with roads covering 362.69 hectares or 3.63km² (6.52%) and buildings occupying 673.02 hectares (12.11%). Together, these two infrastructures accounted for 1,035.71 hectares or 10.35km² (18.63%) of the total land area, as referenced in Table 1. The remaining 4,396.56 hectares (81.37%) fell under other land cover types, including vegetation, water bodies, and bare ground were grouped under "Other" in Figure 2 as the emphasis was on urban infrastructure. The spatial distribution of roads and buildings suggests a developing urban framework, likely concentrated around key transport corridors and central activity areas. The relatively small extent of road networks compared to later years indicates that urban expansion was still in its early stages. The footprint of buildings, while slightly higher than that of roads, remained modest, suggesting that built-up areas were not yet widespread. The result reflects a landscape where urban infrastructure was present but had not yet overtaken the natural environment in terms of spatial coverage. Therefore, from the results, it can be deduced that in 1987, Osogbo was in the early stages of urbanisation. The city's infrastructure was basic, with transportation networks and building developments in their infancy. Natural features, particularly vegetation and Water bodies, were the defining elements of the landscape. The limited urban footprint signaled a city with substantial room for future growth, but also the need for careful planning to balance development with environmental sustainability.

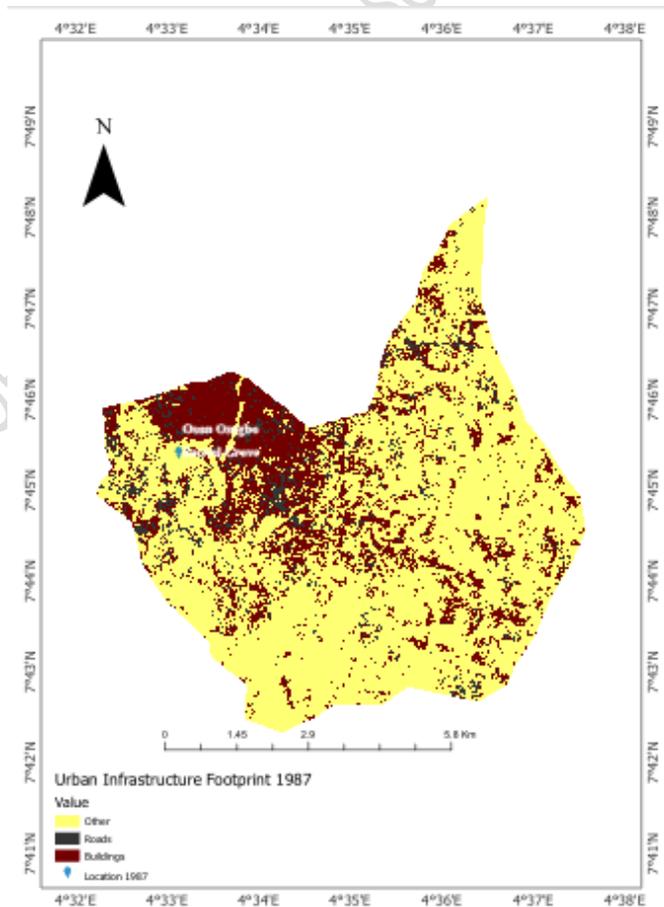


Figure 2: Urban Infrastructure Footprint 1987

Urban infrastructure footprint of Osogbo 1997

In the classification of Landsat image of 1997, the distribution of urban infrastructure in Osogbo provided a snapshot of a city in the early stages of urbanisation, characterized by a mix of natural landscapes and built environments. By 1997, Osogbo’s urban infrastructure footprint had expanded significantly compared to 1987, as indicated in Table 1. Roads covered 626.80 hectares (6.27km²) which makes up 11.22%, while buildings occupied 772.43 hectares (13.99%), bringing the total urban infrastructure footprint to 1,399.23 hectares or 13.99km² (25.17%). As depicted in Figure 3, this represents a noticeable increase in developed land, particularly in road networks, which saw a 72.86% growth in area over the ten-year period. The expansion of roads suggests increased connectivity and access, potentially supporting urban growth by facilitating movement within and beyond the city. The footprint of buildings remained relatively stable in percentage terms, with a moderate increase from 12.11% in 1987 to 13.99% in 1997, despite a minor reduction in absolute area. This stability suggests that while road networks expanded, built-up areas did not experience the same rapid growth during this period.

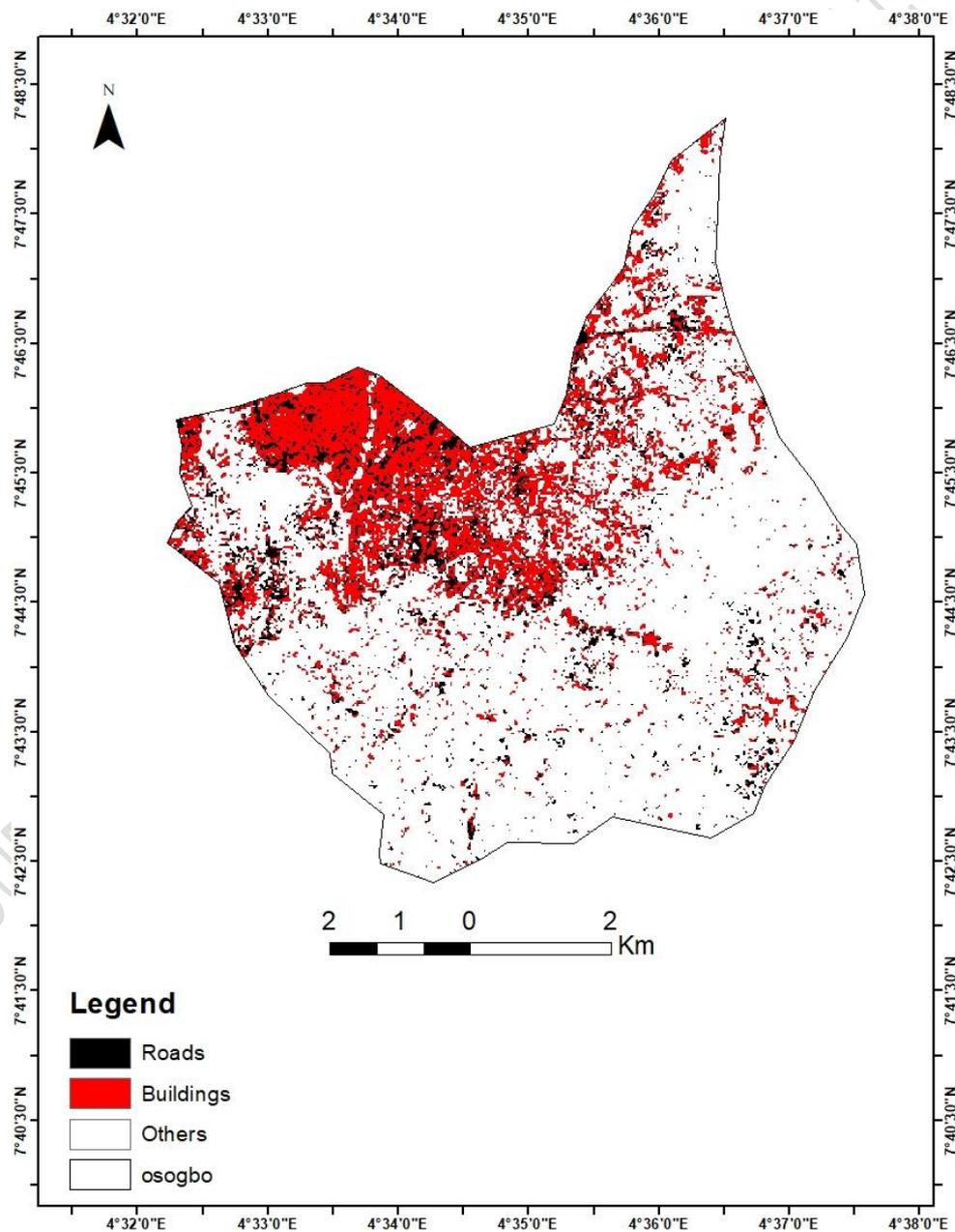


Figure 3: Urban Infrastructure footprint of Osogbo 1997

From the results of the classification, it can be observed that natural land cover grouped as "Other" land cover classes declined to 4,149.27 hectares (74.83%), reflecting a shift toward urban development. The

reduction in these categories suggests that some areas previously covered by vegetation or other natural features were converted to roads and buildings. However, despite this transition, the majority of Osogbo's landscape in 1997 remained outside the built-up zone, indicating that urban expansion was occurring gradually rather than rapidly overtaking the natural environment. The urban infrastructure footprint of 25.17% indicates a moderate yet contained level of urban development, with significant room for expansion. Vegetation's dominance suggests that urbanization was still in its early stages in 1997, allowing for future growth while maintaining ecological balance. The well-developed road network relative to building infrastructure reflects an emphasis on connectivity, which may have facilitated both economic activities and community integration. Also, the minimal bare ground percentage points to efficient land management practices, minimizing waste and promoting sustainable use of resources. The 1997 urban infrastructure footprint of Osogbo highlights a city at a transitional phase of urbanisation, with a strong emphasis on preserving its natural landscape. The balanced distribution between built-up areas and vegetation suggests a city that was yet to face the pressures of rapid urban sprawl.

Urban Infrastructure Analysis for 2007

From the urban infrastructure classification indices for Osogbo in 2007, we can observe a phenomenal increase in urban footprint in the study area. Osogbo experienced substantial urban transformation between 1997 and 2007, as evidenced by the result of the analysis. This period was marked by significant shifts in land use patterns, particularly in vegetation, built environments, and infrastructure development. The analysis of urban infrastructure footprints in Osogbo for 2007 reveals significant changes when compared to 1997, showcasing the impact of a decade of development. The urban infrastructure footprints, including roads and buildings, expanded considerably, highlighting a trend of infrastructure led urban growth. By 2007, Osogbo's urban landscape had undergone significant changes, with a sharp increase in the extent of roads and buildings. As presented in Table 1, roads expanded to 968.60 hectares or 9.69 km² which is about 17.42% of the total land mass, while buildings covered 870.02 hectares or 8.70 km² (15.65%), resulting in a combined urban infrastructure footprint of 1,838.62 hectares or 18.39 km² (33.07%). Figure 4 highlights this transformation, showing a substantial increase in built-up areas compared to previous years.

The road network experienced the most pronounced growth, increasing by 55.2% from 1997. This expansion suggests greater urban connectivity, potentially driven by infrastructure development projects and increased mobility demands. The growth in road coverage also implies an expanding urban boundary, facilitating access to newly developed areas. Similarly, the area occupied by buildings increased by 11.9% from 1997, reflecting a more intensified pattern of urbanisation. The increase in built-up space suggests growing residential, commercial, and institutional developments, which may have contributed to a shift in land use dynamics. As observed, other land cover classes declined to 3,709.80 hectares (66.80%), marking a continued conversion of natural landscapes into urban infrastructure. Compared to previous years, this period represents a critical phase in Osogbo's urban transformation, where infrastructure growth became more pronounced, reshaping the city's spatial structure.

The findings illustrate a clear shift from natural landscapes to urbanized areas over the decade, with roads leading the transformation. The emphasis on infrastructure development is evident in the rapid expansion of road networks, which likely facilitated subsequent building construction. Osun State was created in August 1991 from the old Oyo State, and Osogbo was designated as its capital city. This political milestone marked a turning point in the city's development, as being a state capital attracted administrative functions, investments, and an influx of people. The increased government presence and the need to establish new state infrastructure spurred urbanisation, leading to significant growth in housing, transportation networks, and other urban features (Ojo, 2012). This status as a capital city continues to be a driving force behind the city's rapid urban expansion and its evolving infrastructure

footprint. While this growth reflects progress, the significant loss of vegetation highlights a need for balanced urban planning that considers environmental sustainability.

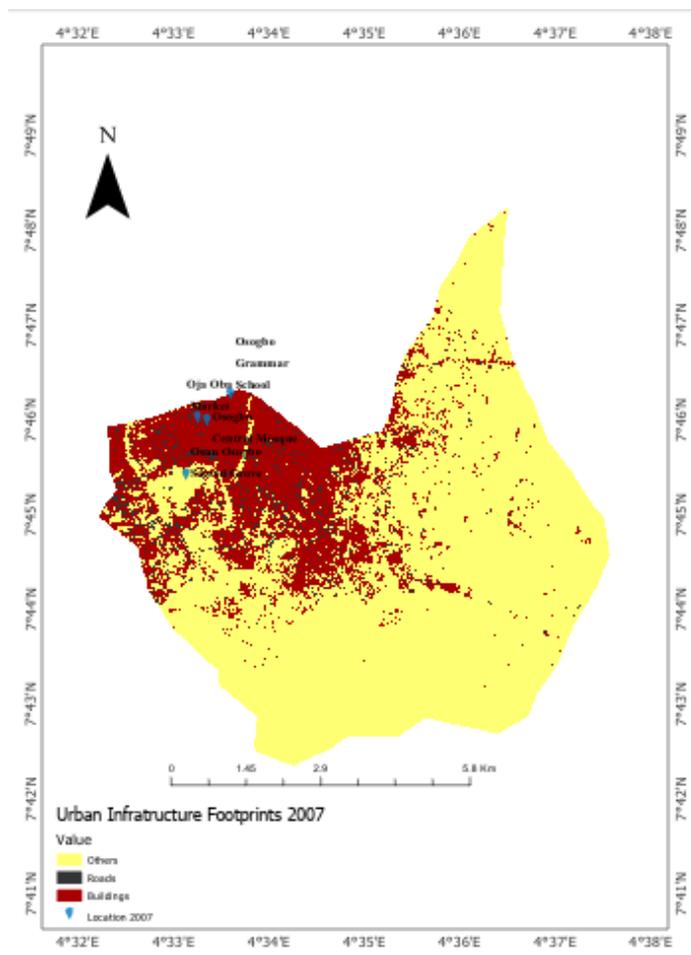


Figure 4: Urban Infrastructure footprints of Osogbo 2007

Urban Infrastructure Footprint Analysis for 2017

The 2017 data provide an in-depth view of Osogbo’s urban development, revealing significant transformations in land use and infrastructure over the past two decades. When analysed alongside data from 2007 and 1997, the trends indicate a steady progression of urbanisation, marked by infrastructure expansion, environmental changes, and shifting development. Osogbo had experienced one of its most significant periods of urban expansion, with a sharp increase in both road networks and built-up areas by 2017. As shown in Table 1, roads covered 1,153.30 hectares or 11.53 km² (20.84%), while buildings occupied 1,338.44 hectares (24.08%), bringing the total urban footprint to 2,491.74 hectares or 24.92 km² (44.82%). Figure 5 illustrates this rapid transformation, highlighting the extent of built-up expansion compared to previous years. The 20% increase in road coverage from 2007 indicates further improvements in urban connectivity, likely supporting higher levels of mobility and access to newly developed areas. The expansion of roads may also reflect urban sprawl, as infrastructure extended beyond the city’s core into previously undeveloped regions. The growing density of road networks suggests a shift toward a more structured urban layout, accommodating both residential and commercial development.

Building coverage saw an even more substantial growth, increasing by 53.8% from 2007 (Table 1). This sharp rise in built-up land suggests intensified urbanisation, likely driven by population growth and increasing housing and commercial demands. The built-up area now occupied over a quarter of the total land area, marking a significant shift in Osogbo’s urban profile. This rapid urban transformation underscores the need for sustainable urban planning to balance infrastructure growth with environmental

preservation. The 2007–2017 period, in particular, saw the most intense urbanisation, posing critical challenges and opportunities for managing Osogbo's future development trajectory. The continuous reduction in vegetation and water bodies raises concerns about environmental sustainability, highlighting the need for urban planning strategies that integrate green spaces and water resource management. Meanwhile, the large areas of bare ground in 2017 point to ongoing or planned developments, suggesting that Osogbo was preparing for further urban intensification as the period from 1997 to 2007 was marked by a focus on building development, while 2007 to 2017 saw an emphasis on transportation infrastructure. This shift reflects evolving priorities in urban planning, likely driven by the need to enhance connectivity and support economic activities.

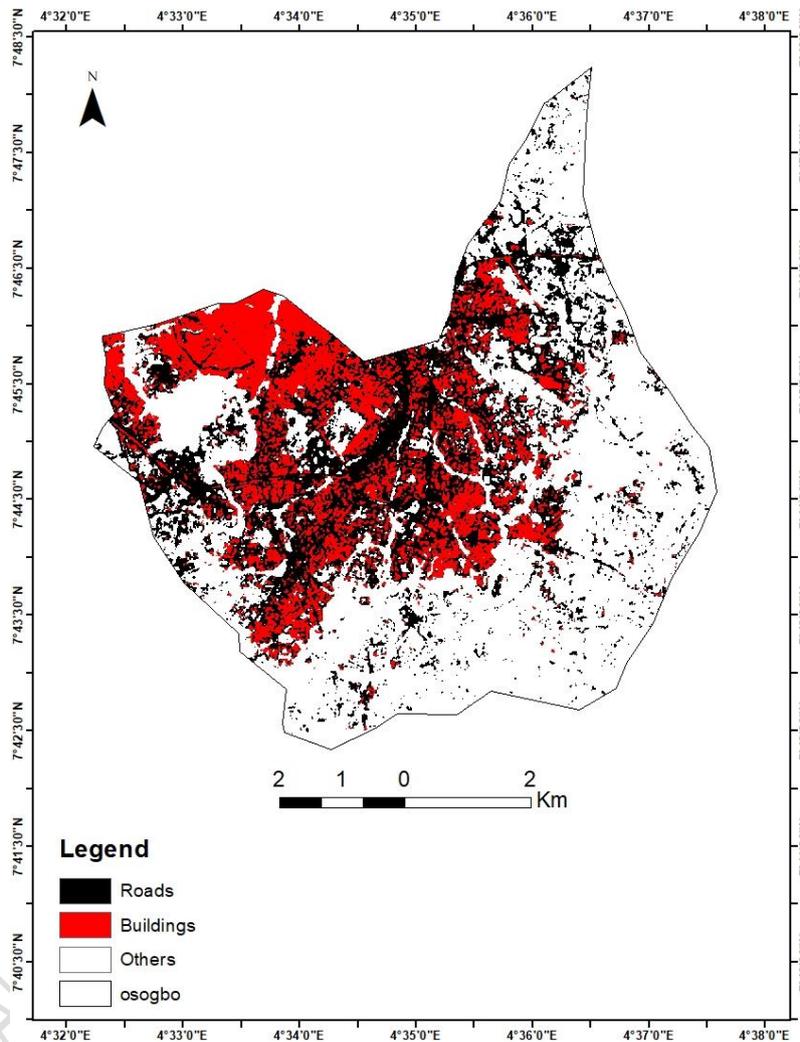


Figure 5: Urban Infrastructure footprints of Osogbo 2017

Urban Infrastructure Footprints analysis of Osogbo 2023

The analysis of urban infrastructure footprints in Osogbo for 2023 reveals nuanced changes in land use and development trends when compared to 2017. This expansion, though subtle, underscores a continuous trend of urbanisation in the city. However, the individual components of the built-up area tell a more detailed story. 2023 data showed Osogbo’s urban infrastructure had expanded significantly, continuing the trend observed in previous decades. As presented in Table 1, roads covered 1,294.03 hectares or 12.94 km² (23.41%), while buildings occupied 1,357.85 hectares (24.57%), bringing the total urban footprint to 2,651.88 hectares or 26.52 km² (47.70%). Figure 6 highlights this transformation, illustrating the increasing dominance of built-up areas within the city.

The road network expanded by 12.4% from 2017 to 2023, reflecting continued improvements in connectivity and accessibility. This increase suggests further urban sprawl and densification, as new road

networks facilitated development beyond the city centre. The expansion of roads may also indicate a response to increased traffic demand, supporting both economic activities and residential growth. Building coverage increased from 2017, maintaining a high proportion of total land use. With nearly a quarter of Osogbo’s total land area now occupied by buildings, the built environment has become a defining feature of the city’s landscape. The expansion of commercial, residential, and industrial structures reflects growing urban density and land-use conversion, reinforcing the trend of urban intensification. The natural land cover classes declined to 2,896.62 hectares (52.02%), indicating a continued reduction in non-urban land. While this still represents a balance between built-up and non-built-up areas, the long-term trajectory suggests that Osogbo’s urban footprint is likely to continue expanding. The results highlights the significant transformation that has occurred over the past 36 years, underscoring the extent to which infrastructure development has reshaped the city’s spatial structure. These trends suggest a strategic reallocation of land use in Osogbo, with an emphasis on improving transportation infrastructure as evidenced by the substantial road network expansion. The overall urban footprint grew, indicating an evolving infrastructure pattern. The reduction in natural features, such as vegetation and water bodies, coupled with the increase in bare ground, suggests ongoing urbanisation and land-use transformation. This analysis highlights the need for sustainable urban planning to balance development with the preservation of natural resources, ensuring long-term environmental and social wellbeing.

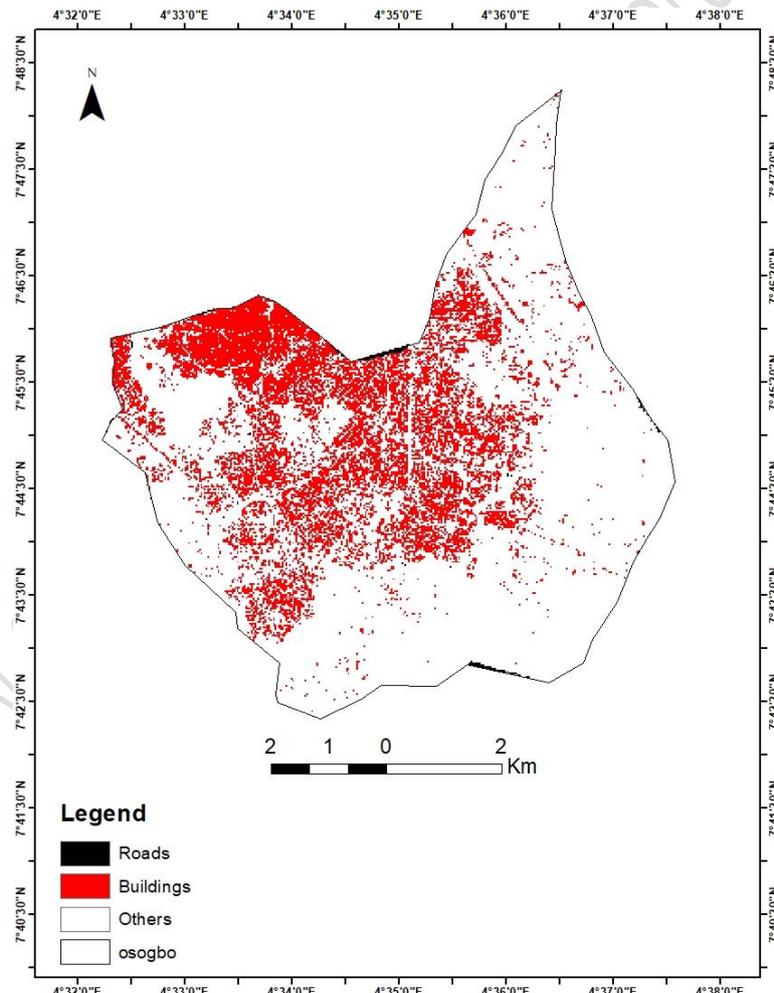


Figure 6: Urban Infrastructure Footprints of Osogbo 2023

The findings from this study paint a clear picture of rapid and extensive urban transformation in Osogbo. The 133.45% increase in the urban infrastructure footprint between 1987 and 2023 aligns with broader patterns of urbanisation across Sub-Saharan Africa, where urban growth often outpaces planning and infrastructure provision (Cohen, 2006). The staggering 256.47% expansion of the road network

underscores a strategic emphasis on improving connectivity, likely to facilitate economic activities and access to newly developed areas, including informal settlements on the urban periphery (Jiboye, 2011). The growth in building footprints reflects rising housing demand, commercial development, and the city's elevated status as a state capital. The most critical finding, however, is the severe environmental trade-off. The 57.4% loss of vegetation cover has profound implications for urban sustainability. Vegetation plays a crucial role in mitigating urban heat island effects, supporting biodiversity, managing stormwater runoff, and sequestering carbon (Seto et al., 2011). Its large-scale conversion to impervious surfaces like roads and buildings increases the city's vulnerability to climate change impacts, including flooding and extreme heat events. The substantial increase in bare ground further signals that the process of land conversion is ongoing, presenting both a challenge and an opportunity for integrating green infrastructure into future development plans. The period of most intense change (2007-2017) suggests that urbanisation in Osogbo may be following a trajectory of uncontrolled sprawl, similar to patterns observed in other medium-sized Nigerian cities (Owoeye, 2014). This pattern is inefficient, consumes excessive land, and strains municipal resources. To counter this, urban planners and policymakers must pivot towards sustainable urban forms. Strategies should include promoting compact, mixed-use development to reduce land consumption, enforcing the protection of green belts and ecologically sensitive areas, and mandating the integration of green spaces and sustainable urban drainage systems into new developments.

5. Conclusion

This study has successfully quantified the rapid expansion of Osogbo's urban infrastructure and its significant environmental costs over 36 years. The city has transformed from a landscape dominated by vegetation to one where built-up areas are now the defining feature. While this expansion reflects socio-economic progress, the associated loss of natural ecosystems poses serious risks to urban resilience and quality of life. The insights derived from this multi-temporal geospatial analysis provide an evidence base for urgent action. Future urban planning in Osogbo, and in similar rapidly growing cities, must prioritize sustainable development principles. This involves moving away from unstructured sprawl towards more compact, efficient, and environmentally integrated urban forms. The preservation and restoration of green infrastructure should be a central pillar of this strategy to ensure that urban growth does not compromise the ecological foundations upon which the city's long-term health and sustainability depend.

References

- Ade, M.A. and Afolabi, Y.D., (2013) Monitoring Urban Sprawl in the Federal Capital Territory of Nigeria Using Remote Sensing and GIS Techniques. *Ethiopian Journal of Environmental Studies and Management*, 4, 82-95. <https://doi.org/10.4314/ejesm.v6i1.10>
- Adedotun, S. B., Ogundahunsi, D. S., & Oyeniyi, A. S. (2016). *Assessment of road transport infrastructure in Osogbo, Osun State, Nigeria*. WIT Transactions on the Built Environment, 164, 61–72. <https://doi.org/10.2495/UT160061>. WIT Press
- Bettencourt, L. M., Yang, V. C., Lobo, J., Kempes, C. P., Rybski, D., & Hamilton, M. J. (2016). The interpretation of urban scaling analysis in time. *Journal of the Royal Society Interface*, 13(121), 20160005
- Cohen, B. (2006). Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in Society*, 28(1-2), 63-80.
- Herold, M., Goldstein, N. C., & Clarke, K. C. (2003). The spatiotemporal form of urban growth: Measurement, analysis and modelling. *Remote Sensing of Environment*, 86(3), 286-302.
- Ibitoye, M. O., & Okende, F. (2016). *A GIS-based assessment of potable water network distribution in Osogbo, Nigeria*. Ife Research Publications in Geography, 14, 17–29. (PDF). ResearchGate
- Jiboye, A. D. (2011). Sustainable urbanization: Issues and challenges for effective urban governance in Nigeria. *Journal of Sustainable Development*, 4(6), 211-224.
- Kennedy, C. A., Stewart, I., Facchini, A., Cersosimo, I., Mele, R., Chen, B., ... & Sahin, A. D. (2017). Energy and material flows of megacities. *Proceedings of the National Academy of Sciences*, 114(1), 44-49.

- Kennedy, C., Pincetl, S., & Bunje, P. (2017). The study of urban metabolism and its applications to urban planning and design. *Environmental Pollution*, 159(8-9), 1965-1973. <https://doi.org/10.1016/j.envpol.2010.10.022>
- Owoeye, J. O. (2014). *Urban development and land use planning of Akure region, Nigeria*. Lambert Academic Publishing.
- Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS ONE*, 6(8), e23777.
- United Nations. (2019). *World urbanization prospects: The 2018 revision*. Department of Economic and Social Affairs, Population Division.
- Vanguard. (2023, July 31). *TCN disconnects Osogbo from national grid over staff assault*. Vanguard News. <https://www.vanguardngr.com/2023/07/tcn-disconnects-osogbo-from-national-grid-over-staff-assault/>