Blue-Green Space Under Urban Stress: Investigating Population–Environment Interactions in Akure Using Geographically Weighted Regression Analysis

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Abstract: - Nigeria's rapid urbanization is changing the quantity, quality, and spatial distribution of urban blue-green spaces (UBGS), which comprises water bodies and vegetated areas. These changes have implications for ecosystem services, urban resilience, and human well-being. This study presents a rigorous, spatially explicit framework to investigate how population pressure produces heterogeneous patterns of urban blue-green spaces availability in Akure. The assumption of spatial stationarity and homogeneity rarely holds in urban socio-ecological systems, where processes operate differently across neighbourhoods, necessitating locally adaptive modelling approaches such as Geographically Weighted Regression (GWR). GWR explicitly models spatial non-stationarity and is appropriate for examining how drivers such as population density relate locally to Urban blue-green space (UBGS) metrics. The GWR method was used to study the impacts of population density interactions on UBGS across the nine political wards in the study area. The Normalized Difference Vegetation Index (NDVI) spectral index was used to analyze vegetation distribution using Landsat OLI 2024 imagery. Using a combination of remote sensing and GIS analysis, field surveys, and demographic and planning data, the study analysed the spatial dynamics of urban blue-green space distribution in relation to population density. Using standard GWR with adaptive bi-square kernel and AICc bandwidth selection, applied across nine administrative wards, the model explains 26.9% of the spatial variance in UBGS distribution ($R^2 = 0.269$). Local population coefficients range from approximately 61 to 110 across wards, confirming spatially heterogeneous ecological stress. The GWR results confirm that the relationship between population density pressure and urban blue-green space in Akure is spatially heterogeneous, with pronounced hotspots of ecological stress in the inner-city transition zones and rapidly urbanising wards, emphasizing the need for neighbourhood-based solutions tailored towards the peculiarity of ecological stress, which varies spatially across a city, and the mainstreaming of blue-green infrastructure into urban expansion corridors. These findings align with the SDG 11 (Sustainable Cities) and SDG 15 (Life on Land) policy frameworks, and suggest that Akure's UBGS trajectory reflects broader patterns of rapid ecological depletion in informally urbanizing Sub-Saharan African cities.

Key-Words: - Urban blue-green space, Geographically Weighted Regression, NDVI, Spatial non-stationarity, and ecological stress.

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1 Introduction

Rapid urbanization is projected to add 2.5 billion city dwellers between 2015 and 2050, with over 90% of expansion occurring in developing country cities [1]. International health and planning agencies estimate that urban populations with less than 9 m² of public green space per capita experience significantly higher risks of heat-related morbidity and cardiovascular stress, particularly in low-income and high-density neighbourhoods [2], [3]. Urban blue-green space (UBGS) comprises green spaces (parks, street trees, riparian vegetation) and blue spaces (water bodies, lakes, rivers, wetlands, and reservoirs). These natural resources provide cooling, flood mitigation, recreation, biodiversity habitat, and other ecosystem services that are critical for sustainable urban development and public health [4].

In Nigeria, population growth, land-use change, and unplanned urban expansion have placed UBGS under severe strain. Ondo State's capital, Akure, is a typical example, as urban expansion and development continue to encroach on its natural water bodies, wetlands, urban forests, and open spaces. Globally, 75% of 344 cities across 62 countries have experienced net reductions in urban green space, with a cumulative loss of 158 million m² offset only by 95 million m² of new or improved green cover, an average deficit of about 63 million m² per year [5]. This study investigates the interactions between population density and urban blue-green space in Akure to examine patterns of change and drivers of depletion.

This study is theoretically anchored in three complementary frameworks. First, Urban Metabolism Theory [6], [7]conceptualizes cities as systems that consume and degrade ecological resources at accelerating rates as population intensifies, attributing UBGS depletion as a metabolic consequence of urban growth. Second, Landscape Ecology Theory's patch-corridor-matrix model [8] explains how BGS fragmentation under density pressure disrupts ecological connectivity and degrades biodiversity corridors. Third, Environmental Justice Theory [9] provides the normative lens for interpreting unequal BGS loss across socioeconomic gradients, a dimension that GWR's local coefficient surfaces are uniquely equipped to reveal spatially. Together, these frameworks situate the empirical GWR analysis within a broader socio-ecological tradition that recognizes urban environmental outcomes as products of spatial, demographic, and governance processes operating simultaneously at multiple scales and implications for urban environmental sustainability and human wellbeing.

GWR was adopted to examine the impact of population density pressure on urban blue-green space across the study area's political wards. Observed situations of the conversion of urban blue-green space to built land, pollution of waterways, and fragmentation of green networks are widely reported, largely driven by informal development, weak development control, and inadequate integration of ecological considerations into urban planning [10]. The study further demonstrates that population pressure has not only reduced the quantity of urban blue-green space but has also diminished its accessibility and ecological functionality.

The spatial distribution of these pressures is uneven, with some political wards losing UBGS faster than others, motivating this study's use of a local, spatially varying modelling approach to identify variations in blue-green depletion and hotspot zones throughout the study area. Depleted green space is a negative indicator and is adverse to the environment [11]. Threats against the existing blue-green space and its sustainability continue to grow as Akure becomes more urbanized. In the face of this resource depletion, environmental degradation, changing climate, and changes in biodiversity prevalence, the need to act on urban nature is increasingly urgent [12]. The marginal cost of under-investing in blue-green infrastructure may rise by a significant percentage of annual municipal budgets over the coming decades, especially in climate-vulnerable African conurbations [13].

2 Related studies

To account for local non-stationarity in relationships that traditional global regression models are unable to capture, researchers examining the spatial dynamics between population distributions and environmental amenities have progressively used spatially explicit regression techniques, especially Geographically Weighted Regression (GWR) [14]. Instead of imposing a uniform impact assumption, GWR permits coefficients to vary across geographic locations, allowing researchers to identify localized population-environment interactions that reflect fundamental socio-spatial processes [14].

GWR has been used in several studies to investigate the distribution of urban blue-green spaces in relation to sociodemographic factors.

Several studies have adopted the use of GWR to explore how urban blue-green spaces are distributed relative to socio-demographic variables. Zhou et al. (2025) used a multiscale geographically weighted regression (MGWR) framework to evaluate local green space exposure in a densely populated Asian city Zhou, Y., et al. (2025) [15]. They found that the intensity and direction of connections between built environment features and green space access varied significantly across spatial contexts, highlighting the relevance of localized modeling in accurately portraying urban environmental fairness. The study found substantial regional variation in the relationship between population pressure and access to urban green resources, which is consistent with more general GWR applications in urban studies [15].

Similarly, studies in the United States have used GWR to investigate socioeconomic gaps in green space accessibility. In a study in Detroit, Michigan, researchers discovered that areas with higher socioeconomic vulnerability had much lower levels of green space access than less vulnerable communities, with GWR demonstrating varying local coefficients that were hidden by global models [16]. These findings not only corroborate current environmental justice issues but also highlight GWR's analytical efficacy in identifying imbalances at the sub-city scale [16].

Extending these approaches beyond typical green space measurements demonstrates the versatility of spatial regression. For example, researchers studying the impact of urban blue-green infrastructure on land surface temperature in Nanjing used machine learning and GWR methods to quantify how blue-green indices alter environmental exposure that is relevant to population health outcomes [17]. Although the primary outcome was temperature rather than population density, the study's incorporation of GWR yielded important insights into geographically varied environmental-population interactions within complex metropolitan matrices [17].

In China, empirical research using GWR to analyze the determinants of urban greenness indicated that variables such as road network density, building density, and demographic characteristics exhibited regionally varying effects on green space distribution patterns [18]. These findings are consistent with broader findings on the spatial non-stationarity of population-environment linkages, implying that urban form and demographic composition interact with ecological amenities in diverse ways, best captured by localized modeling frameworks.

Furthermore, research that focuses specifically on green space equity and demographic trends has emphasized the importance of GWR in exposing how access to both green and blue-green areas correlate with population factors such as income, age structure, and minority status. Kim and Nicholls [19] demonstrated how GWR can identify districts where demographic vulnerability is associated with limited access to parks and seaside facilities, offering a more detailed picture of urban environmental inequality than classic regression techniques.

Overall, these studies show that GWR and its derivatives improve our understanding of the spatially varied relationships between population dynamics and environmental infrastructure. This literature supports the postulation that population pressure on urban blue-green spaces is not uniform across geographic contexts. However, local socioeconomic realities, physical form, governance procedures, and infrastructural legacies all have an impact. These findings are consistent with the methodological justification for using GWR in the current investigation, which seeks to understand local differences in the link between population density/pressure and urban blue-green spaces provision.

3 Methods and materials

3.1 Study Area

The study area is Akure, located in south-western Nigeria. The study area comprises nine political wards as shown in Figure 1.

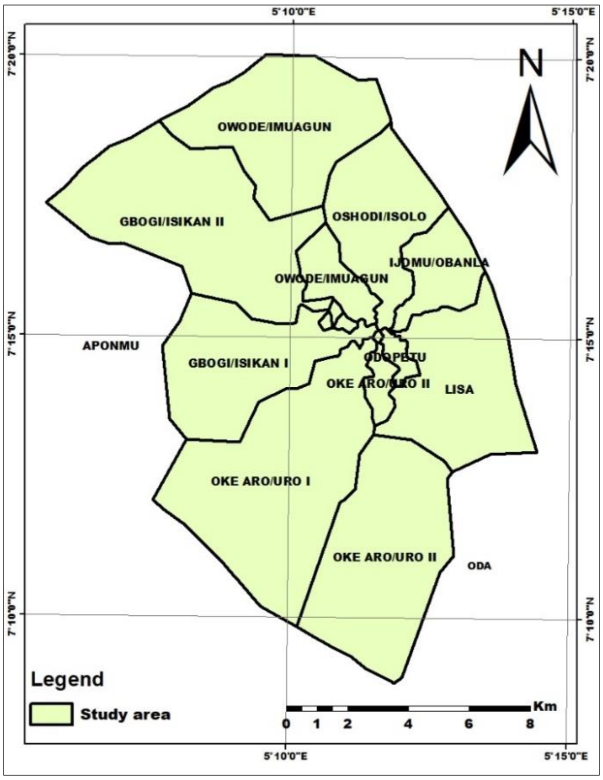

Fig. 1: Map of a kure

Source: BC Consultancy, 2026

While the primary administrative wards (n=9) serve as the units of analysis, the GWR utilized an adaptive bandwidth based on the Corrected Akaike Information Criterion (AICc). This method optimizes the local sample size for each regression point, mitigating the risks of overfitting commonly associated with small spatial datasets.

3.2 Data Sources and Variable Definition.

To ensure reproducibility and statistical transparency, the variables used in the GWR model are characterized in Table 1. The dependent variable, UBGS, is derived from Landsat 8 imagery using NDVI to capture both aquatic and vegetative health. The independent variable, population, was standardized as density to account for the varying geographic sizes of the administrative wards.

Table 1. Data Characterization and Technical Specifications

Data Category	Variable	Type	Measurement Unit / Proxy	Source	Year	Resolution / Scale
Dependent (Y)	Urban Blue-Green Space (UBGS)	Raster	NDVI (Normalized Difference Vegetation Index)	Landsat 8 OLI (USGS Earth Explorer)	2024	30 Meters
Independent (X)	Population Pressure	Vector	Population Density (Persons/km²)	National Population Commission (NPC) / WorldPop	2024	Ward Level
Cartographic	Administrative Boundaries	Vector	Ward Polygons	Office of the Surveyor General, Ondo State	2020	1:50,000
Statistical	Spatial Weights	Matrix	Adaptive Bi-square Kernel	GWR Model Output	2024	-

Source: Author's computation, 2026

UBGS represents the Dependent Variable. NDVI metrics were used to estimate available urban blue-green space in the study area. This is because it provides a continuous numerical value (0 to 1), which is more sensitive to GWR analysis than simple Green and Not Green discrete classification. Population Density was used instead of Total Population to represent the independent variable, in order to ensure that larger wards do not skew the results simply because of their geographic size.

Preceding GWR estimation, exploratory spatial data analysis and global regression diagnostics revealed the presence of spatial autocorrelation and heterogeneity, supporting the use of a local regression technique. This study used Geographically Weighted Regression to investigate the geographically varied association between population density pressure and urban blue-green spaces dynamics in Akure. Unlike traditional global regression models such as Ordinary Least Squares (OLS), which presume spatial stationarity in interactions across space, GWR explicitly accommodates spatial non-stationarity by allowing model parameters to change locally across geographical units.

GWR is most suited for urban environmental research because socio-ecological processes vary across space due to variances in development intensity, planning control, socioeconomic characteristics, and physical conditions. In Akure, the interaction between population density and urban blue-green space change is likely to vary across the urban core, transitional zones, and peri-urban periphery. The GWR outputs, including local parameter estimates, coefficients of determination (Local R²), and standardized residuals, were mapped to visualize the spatial structure of population density-urban blue-green space interactions in Akure.

The GWR model is expressed as:

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{n} \beta_k\,(u_i, v_i)x_{ik} + \varepsilon_i$$

where □□ represents the dependent variable (urban blue-green space change) at location □; □□□ represents the independent variable (population density); □□□□ are the spatial coordinates of location □; □□ (□□, □□) are location-specific parameters; and □□ is the error term. The model was calibrated using an adaptive kernel bandwidth chosen by minimising the corrected Akaike Information Criterion (AICc), resulting in an ideal mix of model fit and complexity. The spatial weighting system gives more weight to observations that are closer to each regression point, following Tobler's First Law of Geography, which states that local sites are more closely associated than distant ones.

GIS-Arc Map 10.7.1 software was used to carry out NDVI analysis on Landsat 8 OLI/TIRS, 2024, as shown in Figure 2. Raster calculator was used for NDVI analysis using the red and near infrared bands of the Landsat 8 Imagery, as shown in the flow chart below.

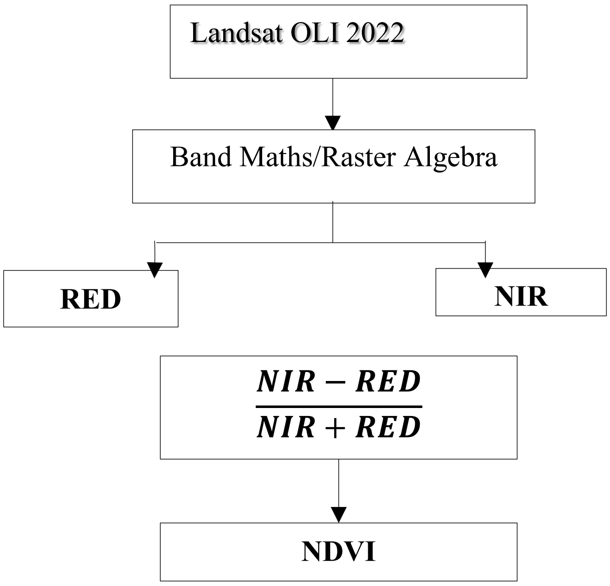

Fig. 2: NDVI flowchart

4. Results and Discussions

4.1 Urban-green space distribution shown with the Normalized Difference Vegetation Index (NDVI) map

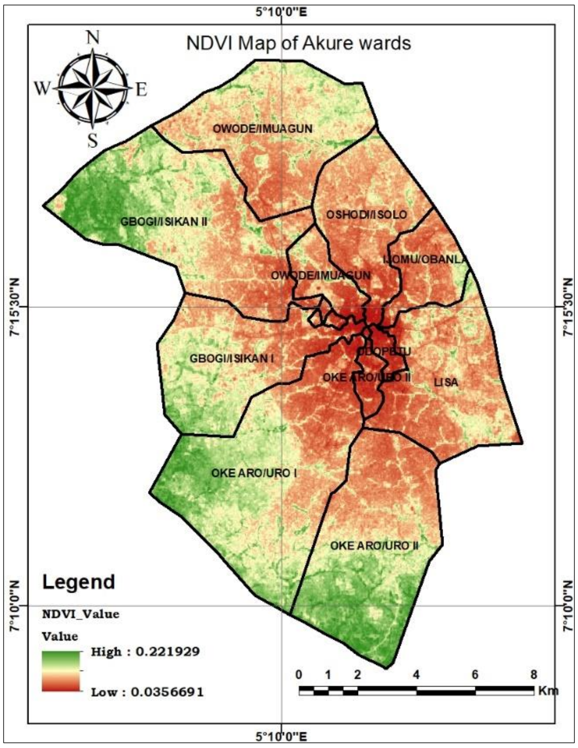

Fig. 3: Akure NDVI ward map showing UBGS distribution
Source: BC consultancy Geo-spatial, 2026

The NDVI map shown in Figure 3 shows the study area and the distribution of green across the study area. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock and sand. Low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate tropical rainforests (values approaching 1). Landsat 8 OLI/TIRS was used for NDVI analysis and further analysed using the raster calculator tool in ArcGIS to get the absolute values for built-up areas and urban blue-green space. These values were used as feeders for the GWR analysis. In this study, NDVI provided the expression of vegetation condition, while GWR been the core focus of the study, is used to explain the spatially varying relationships between population and UBGS.

4.2 Discussion of Geographically Weighted Regression (GWR) Results

4.2.1 Model Performance and Overall Explanation

Geographically weighted regression (GWR) in ArcGIS was used to account for spatial dependencies and analyze the relationship between urban population and urban blue-green space availability across the nine political wards in the study area. This method assessed the extent to which changes in urban resident population influence changes in urban blue-green space availability.

Table 1. Geographically weighted regression (GWR)

GWR_phd_supp

OID	VARNAME	VARIABLE	DEFINITION
0	Bandwidth	17642.896819	
1	ResidualSquares	2.544861e+14	
2	EffectiveNumber	2.53315	
3	Sigma	6273148.99854	
4	AICc	316.825441	
5	R2	0.269628	
6	R2Adjusted	0.096473	
7	Dependent Field	0	G_Space
8	Explanatory Field	1	R_Populatn

Source: ArcGIS statistics computation, 2025

Residuals in GWR represent the differences between observed and predicted values of the dependent variable. A positive residual indicates that the observed value is higher than the predicted value, while a negative residual indicates the opposite. In geographically weighted regression (GWR), standard residuals are used to assess the goodness-of-fit and the adequacy of the model; they are adjusted to account for the spatial variability inherent in GWR. In the case of this study, as shown in Tables 1 and 2 and Figure 1, the pattern of standard residuals shows that the model effectively explained the variables. The result shows that the adjusted R^2 of our model is 0.0096, with the $R^2 = 0.269$. The R-square value of 0.269 indicates that the residents' population accounted for 26.9% of the depletion of green space in Akure metropolis, indicating that the weighted regression explains 26.9% of the variance in the data.

Table 2. Geographically Weighted Regression- Standard residuals of residents' population **and the depletion of urban blue-green spaces at the ward scale**

GWR standard deviation

FID	Shape *	Wards	Observed	Cond	LocalR2	Predicted	Intercept	C1_R_Popul	StdResid
0	Polygon	Gbogi_Isinkan1	6814800	5.290417	0.130384	8492262.03672	1005419.30059	81.844885	-0.301983
1	Polygon	Gbogi_Isinkan2	14198400	5.210263	0.083931	4611736.99939	2132817.38568	63.464404	1.880981
2	Polygon	Ijomu_Obanala	529200	5.209402	0.139055	3104511.75654	344447.011024	83.044432	-0.512753
3	Polygon	Odopetu	1643400	5.275545	0.17522	5607767.58215	-352371.625544	95.970295	-0.68411
4	Polygon	Odopetu	4500	5.26675	0.157355	3441677.61702	98063.81397	90.260604	-0.658942
5	Polygon	Okearo_Uro1	16890300	5.371048	0.174036	10487692.4699	88921.128776	97.297535	1.328128
6	Polygon	Okearo_Uro2	13247100	5.407119	0.214459	7114759.7224	-855767.880792	110.163197	1.069452
7	Polygon	Oshodi_Isolo	690300	5.18692	0.113536	6950052.07183	990702.476667	73.95202	-1.091817
8	Polygon	Owode_Imuagun	5737500	5.164283	0.082253	8534276.37195	1905394.43307	61.878145	-0.587685

Source: ArcGIS statistics computation, 2024.

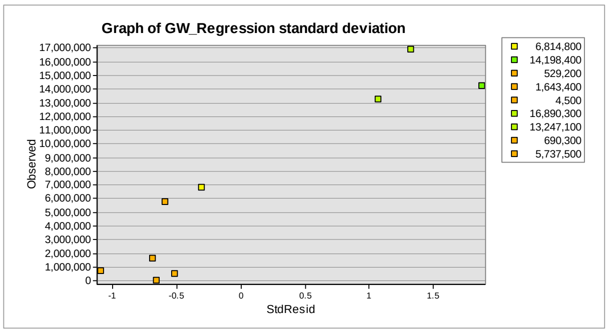

Fig. 4: Geographically weighted regression graph showing a scatter plot of standardized residuals
Source: ArcGIS statistics computation, 2026.

4.2.1.2 Interpretation of the Geographically Weighted Regression (GWR) Standard Deviation Plot

Figure 4 depicts the scatter plot of standardized residuals (StdResid) on the horizontal axis and observed values on the vertical axis, as obtained from the Geographically Weighted Regression (GWR) model. The model is designed to investigate how population density and pressure affect the distribution of urban blue-green space in the research area. The plot is an analytical tool for determining the spatial variability, model fit, and heteroscedasticity of the GWR data.

The horizontal axis reflects the standardized residuals, while the vertical axis depicts the observed population-related values linked with urban blue-green spaces outcomes. The spread of points across both positive and negative standardized residuals highlights the non-stationary nature of the relationship between population pressure and blue-green infrastructure, thereby justifying the application of GWR rather than a global regression model.

Areas with large positive standardized residuals (StdResid > 1.0) indicate locations where the model underestimates the observed values, signifying that population density has a stronger-than-expected pressure on urban blue-green spaces in these zones. These points are likely associated with high-density urban cores or rapidly urbanizing corridors, where land-use competition, infrastructural expansion, and transport development significantly constrain urban blue-green spaces availability.

Negative standardized residuals (StdResid < -0.5) reveal that the model overestimates the observed influence, signifying lower population pressure or better-preserved urban blue-green spaces than expected. Such areas are peri-urban zones, urban edges, or districts with effective land use planning policies that protect green buffers, wetlands, or urban forests despite population growth.

The wide range of measured values from low to extremely high magnitudes shows significant geographical variation in population-environment interactions. This variation highlights one of GWR's key strengths, which is its ability to capture localized parameter estimates and residual patterns that traditional Ordinary Least Squares (OLS) regression ignores.

Importantly, the absence of a clear systematic pattern or funnel-shaped distribution in the residuals suggests that the GWR model appropriately explains spatial heterogeneity. Overall, Figure 4 and Table 2 show factual evidence that population density and pressure affect urban blue-green spaces in uneven ways, supporting the notion that place-based planning interventions are required. In terms of policy, the findings recommend that high-residual zones be prioritized for blue-green infrastructure protection, climate adaptation measures, and sustainable transportation corridor planning, particularly in rapidly urbanizing areas.

4.2.2 Evidence of Spatially Varying Relationships (Local R^2)

Spatial Non-Stationarity and Local Model Fit

The local R^2 values range approximately from 0.08 to 0.21 across the wards in the study area, as shown in Table 2, demonstrating substantial spatial heterogeneity in the strength of the population-urban blue-green spaces relationship. This means that in some wards, population explains over 20% of the change in urban blue-green spaces, while in others it explains less than 10%. Notably, wards such as Okearo_Uro2 (Local $R^2 \approx 0.214$) and Okearo_Uro1 ($\approx$ 0.174) show a stronger population-environment connection, suggesting intense urban pressure on ecological assets.

Wards such as Owode_Imuagun ($\approx$ 0.082) and Gbogi_Isinkan2 ($\approx$ 0.084) show weaker relationships, where population density is lower, and are the wards covering the peripheral areas of the city, implying that other factors (planning control, land speculation, institutional decisions, or physical constraints) may be more influential there. This spatial heterogeneity confirms that urban stress on urban blue-green spaces in Akure is geographically uneven and context-dependent.

4.2.3 Interpretation of Population Coefficient (C1_R_Popul)

The population coefficient varies spatially across wards. Values range roughly from ~61 to ~110. This wide variation shows that in some wards (e.g., Okearo_Uro2 $\approx$ 110, OkeAro_Uro1 $\approx$ 97, Odopetu $\approx$ 95), population growth exerts a much stronger pressure on urban blue-green spaces. In others (e.g., Owode_Imuagun $\approx$ 62, Gbogi_Isinkan2 $\approx$ 63), the impact is weaker. This indicates that a unit increase in population does not produce the same ecological impact everywhere in Akure. Higher coefficients are concentrated in rapidly urbanising and peri-urban transition zones such as Okearo_Uro2, Okearo_Uro1, and Odopetu, suggesting that population increase in these areas translates into much stronger ecological pressure through land conversion, encroachment on wetlands, and loss of vegetated surfaces. Lower coefficients in more stable or less development-pressured wards indicate that a unit increase in population does not exert the same level of environmental impact across the city.

Hence, high-impact zones are likely to be rapidly urbanizing, experiencing informal development, located in peri-urban or urban-transition belts, and weakly regulated in terms of development control. This confirms the existence of spatially uneven urban stress on blue-green infrastructure.

4.2.4 Residual Patterns and Model Reliability

The standardised residuals are mostly within ±2, indicating no serious model instability, no extreme outliers dominating the results, and a reasonably well-behaved spatial model. The standardised residuals are mostly within the acceptable range of ±2, indicating the absence of severe outliers and suggesting that the model is statistically stable. This strengthens the credibility of the inference that population pressure is a real and spatially structured driver of the change in urban blue-green spaces in Akure. The spatial pattern of residuals further suggests that while population is a significant driver, other unmodelled factors such as land governance, speculative development, and infrastructure placement also contribute to the change in urban blue-green spaces.

The Effective Number of Parameters ($\approx$ 2.53) confirms that the process is not purely global, the relationship varies locally, and urban stress diffuses spatially across neighbouring wards. This supports the conceptual framing of the study, which states that urban blue-green spaces in Akure are under spatially contagious urban stress, driven by population concentration and outward urban expansion.

4.3 Implications for the Paper's Core Argument

The GWR results empirically demonstrate that Population-urban blue-green spaces interaction is spatially non-stationary, urban stress on ecological assets is not uniform across Akure, where some peri-urban and transition wards are hotspots of ecological pressure, and as such, city-wide "one-size-fits-all" planning policies will not be suitable to address urban blue-green spaces depletion in Akure. Strong Policy Interpretation on the results implies that Akure needs spatially targeted blue-green infrastructure protection, differentiated planning control strategies, priority ecological conservation zones in high-impact wards, and integration of blue-green infrastructure into urban expansion corridors. These findings connect directly with the Sustainable Development Goals. SDG 11 (Sustainable Cities and Communities, Target 11.7) advocates for access to safe, inclusive green and public spaces. SDG 15 (Life on Land) calls for the protection and restoration of terrestrial and freshwater ecosystems. The WHO's Urban Green Space Guideline furthermore recommends that all urban residents should have access to at least 1 hectare of public green space within 300 metres of their residence [20]. This is a benchmark against which Akure's ward-level UBGS provision should be assessed. Furthermore, the global 30x30 biodiversity commitment to protect 30% of land and water by 2030 reinforces the urgency of conserving Akure's remaining ecological assets. Sponge city design principles, urban biodiversity corridors, and mandatory green space quotas in development approvals represent some planning strategies to safeguard Akure’s blue-green infrastructure under growing urban stress, to boost urban resilience and sustainability.

4.4 Policy Implications for Akure Urban Planning.

The GWR results reveal that population density pressure produces spatially heterogeneous ecological stress on Akure’s urban blue-green space (UBGS), with pronounced hotspots in inner-city transition zones such as Odopetu and Oshodi/Isolo wards, as well as rapidly urbanising political wards. This pattern indicates the need for a shift from uniform city-wide planning to neighbourhood-tailored, spatially targeted policies that prioritise UBGS protection and restoration in the most vulnerable areas. Akure’s urban planning should adopt ward-specific UBGS thresholds, establishing the minimum m² of green and blue space per capita, and integrate these into zoning regulations, giving stricter control in high-pressure wards. Planning authorities should designate Ecological Stress Priority Zones (ESPZs) in vulnerable wards.

Planning authorities should also ensure that UBGS protection is embedded in urban expansion corridors. Every major road, transit, and peri-urban expansion axis should include green belts, linear parks, and stormwater-retaining blue-green infrastructure, implemented through a “green-first” corridor-planning principle.

Akure’s planning framework should explicitly align with SDG 11 (Sustainable Cities and Communities) and SDG 15 (Life on Land). To achieve SDG 11, the city can establish quantifiable objectives, such as ensuring a growing proportion of citizens reside within 500 meters of high-quality public green or blue spaces, and that all significant infrastructure projects integrate Urban Blue-Green Space (UBGS) elements. SDG 15 should prioritize the protection and restoration of urban ecosystems, the promotion of native species and green infrastructure, and the monitoring of land use changes to avert a net loss of green cover. By integrating these goals into the Akure Urban Master Plan, Ondo State development policy, and climate adaptation strategies, the city can mainstream UBGS as an essential tool for sustainable, resilient, and equitable urban growth.

5 Conclusion and Recommendations

Conclusively, the paper exerts emphasis on the peculiarity of spatial-based planning, hinging on the realities of spatial non-stationarity in the occurrence of several phenomena across places. This study has demonstrated, through a spatially explicit GWR framework, that the relationship between population density and urban blue-green space depletion in Akure is fundamentally non-stationary: it varies in strength, magnitude, and policy significance across the city’s nine administrative wards. The empirical finding that population coefficients range from approximately 61 to 110, with hotspots concentrated in Okearo_Uro2, Okearo_Uro1, and Odopetu, challenges the prevailing tendency in Nigerian urban planning to apply uniform city-wide environmental standards that fail to account for neighbourhood-scale ecological differentiation. The study’s methodological contribution lies in establishing GWR as an appropriate analytical tool for Sub-Saharan African urban environmental research, where rapid informal urbanization produces spatially uneven ecological footprints that global regression models systematically obscure. In terms of policy, the findings advocate for: (1) spatially targeted UBGS protection ordinances prioritizing high-coefficient wards; (2) differentiated development control regimes that intensify regulation in ecologically stressed transition zones; (3) integration of blue-green infrastructure corridors into Akure’s statutory land-use plan; and (4) alignment of local planning targets with SDG 11 and SDG 15 commitments.

Limitations and Future Research

The study was limited to the Landsat 8 OLI image, which has a spatial resolution of 30m; future research could use an image with a spatial resolution of 5m. Also, the study was not done on a temporal basis; future studies could extend this framework longitudinally using GTWR (Geographically Temporal Weighted Regression) to establish temporal dynamics of UBGS depletion.

References:

[1] UN Habitat. (2023). Financing sustainable urbanization: Counting the costs and closing the gap. United Nations Human Settlements Programme. https://unhabitat.org/financing-sustainable- urbanization-counting-the-costs-and- closing-the-gap

[2] World Health Organization. (2020). Urban green space interventions and health: A review of impacts and effectiveness. WHO Regional Office for Europe. https://www.who.int/europe/publicatio ns/m/item/urban-green-space-interventions-

and-health--a-review-of- impacts-and-effectiveness
[3] UN Habitat. (2025). Global urban trends and Sustainable Development Goal 11: Sustainable cities and communities.
[4] Swedish International Development Cooperation Agency (2016). Urban Development, Biodiversity and Ecosystems, SIDA, Stockholm.
[5] Husqvarna Group. (2024). Urban Green Space Report 2024. Husqvarna Group. https://www.husqvarnagroup.com/en/press/new-satellite-data-showing-urban-green-spaces-continue-decline-across-world-2279198
[6] Wolman, M. G. (1964). Problems posed by sediment derived from construction activities in Maryland (Report No. 125). Maryland Water Pollution Control Commission.
[7] Kennedy, R. E., Cohen, W. B., & Schroeder, T. A. (2007). Trajectory-based change detection for automated characterization of forest disturbance dynamics. Remote Sensing of Environment,110(3), 370–386. https://doi.org/10.1016/j.rse.2007.03.010
[8] Forman, R.T.T. (1995). Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press.
[9] Schlosberg, D. (2007). Defining environmental justice: Theories, movements, and nature. Oxford University Press.https://doi.org/10.1093/acprof:oso/9780199286294.001.0001
[10] Chiamaka Lovelyn Olisa, Michael Ajide Oyinloye, Ayo Emmanuel Olajuyigbe, Samuel Olumide Akande, Babatope Sunday Olisa, (2023). "Changing Patterns of Urban Green Spaces in Akure, Nigeria," WSEAS Transactions on International Journal of Environmental Engineering and Development, vol. 1, pp. 157-174, DOI:10.37394/232033.2023.1.18
[11] Saidur, Selim, Md Senaul, Ruishan, & Pankaj, & Pankaj, K. (2020). Spatio-temporal changes of green spaces and their impact on the urban environment of Mumbai, India. Springer Nature, Environment Development and Sustainability 23(12).
[12] WHO. (2022). “Urban nature, green spaces and health”. Webinar. Retrieved from https://ufmsecretariat.org/form-ufm-who-webinar-on-urban-nature-green-space-and-health/
[13] World Bank. (2024). Financing climate resilient and inclusive cities in Africa. World Bank.
[14] Fotheringham, A.S., Brunsdon, C., & Charlton, M. (2002). Geographically Weighted Regression: The Analysis of Spatially Varying Relationships. Wiley.
[15] Zhou, Y., et al. (2025). Multiscale GWR assessment of green space exposure in high-density cities Urban Climate.
[16] Jessica LaReaux &, David Watkins (2025). Geospatial analysis for promoting urban green space equity: Case study of Detroit, Michigan, USA
[17] Wang, H., et al. (2024). Blue-green infrastructure and urban temperature regimes: A GWR approach. Habitat International
[18] Li, J., & Chen, S. (2023). Driving factors of urban greenness: A GWR perspective. Land Use Policy
[19] Kim, S., & Nicholls, S. (2016). Green access equity: A GWR application. Journal of Leisure Research
[20] World Health Organization. (2016). Urban green spaces and health: A review of evidence. WHO Regional Office for Europe.https://www.who.int/europe/publications/i/item/WHO-EURO-2016-3352-43111-60341

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