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Spatio-Temporal Analysis of HIV Cases in Calabar Municipal, Cross River State, Nigeria (2020–2025)

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Abstract
Human Immunodeficiency Virus remains a major public health challenge in Nigeria, particularly in urban centres where population density, mobility, and socio-economic interactions increase vulnerability to transmission. Calabar Municipal, the administrative and commercial hub of Cross River State, exhibits demographic and spatial characteristics that influence HIV distribution and service demand. This study applies Geographic Information System techniques to map and analyze the spatial and temporal patterns of HIV cases in Calabar Municipal between 2020 and 2025. HIV surveillance indicators were examined using descriptive statistics, temporal trend analysis, spatial distribution by ward areas, age–sex disaggregation, and treatment outcome indicators. Results indicate a gradual increase in estimated people living with HIV over the study period, alongside improved antiretroviral therapy enrolment and viral load suppression, and a decline in AIDS-related mortality. Spatial analysis reveals clustering of HIV cases in densely populated and commercially active ward areas. The study demonstrates the usefulness of GIS-based HIV mapping for identifying high-burden zones, monitoring treatment outcomes, and supporting targeted intervention and resource allocation in urban public health planning.

Keywords: HIV Mapping, Geographic Information System, Spatio-Temporal Analysis, ART Coverage, Urban Health, Calabar Municipal

1. Introduction

Human Immunodeficiency Virus infection remains a major public health concern globally, despite notable advances in biomedical prevention, diagnosis, and treatment. Sub-Saharan Africa continues to bear a disproportionate share of the global HIV burden, accounting for the majority of people living with HIV and AIDS-related deaths worldwide. Although intensified international and national responses have led to measurable declines in HIV incidence and mortality in several countries, transmission persists in many urban settings where demographic pressure, mobility, and socio-economic inequalities intersect (Joint United Nations Programme on HIV/AIDS, 2023) [12].

Nigeria represents one of the countries with the largest absolute number of people living with HIV globally. While national prevalence has declined over the past two decades, the size of the population and uneven access to prevention and treatment services sustain a substantial disease burden (Federal Ministry of Health, 2019; UNAIDS, 2022) [8, 11]. HIV transmission in Nigeria exhibits marked spatial heterogeneity, with variations observed across states, urban and rural areas, and within cities themselves. These spatial differences are shaped by factors such as population density, economic activity, social behaviour, gender dynamics, and access to health services (Adebajo, Eluwa, & Allman, 2012; Adeyemi, 2020) [1, 2].

Urban centres play a particularly significant role in HIV dynamics. Cities concentrate populations, foster intense social interaction, and attract migrants seeking employment, education, and social opportunities. Such conditions can increase exposure to HIV risk factors, including multiple sexual partnerships, transactional sex, and substance use (Tanser, Bärnighausen, Cooke, & Newell, 2009) [15].

At the same time, urban areas often host better health infrastructure, leading to higher rates of HIV testing, diagnosis, and treatment coverage. This dual role creates complex spatial patterns in which high disease burden may coexist with relatively strong service provision (Cuadros, Abu-Raddad, Awad, & Abu-Raddad, 2017) [5].

Evidence from spatial epidemiology demonstrates that HIV cases are not evenly distributed within urban environments but tend to cluster in specific neighbourhoods associated with socio-economic deprivation, commercial activity, transport corridors, and high population mobility (Murray et al., 2014; Cuadros, Li, Mukandavire, Musuka, & Abu-Raddad, 2018) [13, 6]. These clusters often reflect underlying structural and behavioural drivers of transmission and are critical targets for focused intervention. Understanding such intra-urban variation is therefore essential for effective HIV prevention and treatment planning.

Conventional HIV surveillance systems in Nigeria rely primarily on aggregated facility-based reporting through national health information platforms. While these systems provide essential information on trends and program performance, aggregation at broad administrative scales limits the ability to identify localized hotspots and neighbourhood-level disparities (Nutor et al., 2020) [14]. This limitation constrains evidence-based resource allocation, particularly in urban local government areas where population characteristics vary considerably over short distances.

Geographic Information System technology provides a robust framework for addressing these challenges by enabling the integration of epidemiological data with spatial units such as wards, neighbourhoods, and facility catchment areas. GIS-based HIV mapping facilitates visualization of disease distribution, identification of spatial clusters, and assessment of service coverage and outcomes across space (Cromley & McLafferty, 2012; Tanser & LeSueur, 2019) [4, 16]. Such spatial insight enhances the capacity of health planners to design geographically targeted interventions and monitor their effectiveness over time.

Several studies have demonstrated the utility of GIS in HIV research, including mapping HIV prevalence, identifying high-risk populations, assessing accessibility to treatment services, and examining spatial inequalities in viral suppression and mortality (Goswami et al., 2018; Jia et al., 2014) [9, 10]. In sub-Saharan Africa, spatial analysis has been applied to guide community-based testing strategies, optimize ART service delivery, and support progress toward epidemic control (Bershteyn et al., 2018; Dwyer-Lindgren et al., 2019) [3, 7]. Despite these advances, GIS-based HIV mapping at the municipal or local government scale remains limited in Nigeria, particularly outside the largest metropolitan areas.

Calabar Municipal, the administrative and commercial centre of Cross River State, presents a relevant context for spatial analysis of HIV cases. The municipality hosts major markets, transport hubs, educational institutions, hospitality facilities, and tourism activities, all of which contribute to population movement and social interaction. These characteristics influence both HIV transmission risk and demand for prevention and treatment services. Yet, HIV data for Calabar Municipal are typically reported in aggregated form, offering limited insight into spatial variation across wards and neighbourhoods.

Spatio-temporal analysis of HIV cases at the municipal level is necessary for identifying priority areas, understanding demographic vulnerability, and monitoring progress in treatment outcomes such as ART retention and viral load suppression. Integrating multi-year HIV surveillance data within a GIS framework supports a more nuanced understanding of urban HIV dynamics and strengthens evidence-based public health planning (UNAIDS, 2023; Tanser & LeSueur, 2019) [12, 16].

This study therefore applies Geographic Information System–based methods to map and analyze HIV cases in Calabar Municipal between 2020 and 2025. The study examines temporal trends, spatial distribution across ward areas, demographic patterns of new diagnoses, and treatment outcome indicators. By embedding HIV surveillance data within a spatial analytical framework, the research contributes to urban HIV epidemiology in Nigeria and provides decision-support evidence for targeted intervention, service optimization, and sustainable HIV control in Calabar Municipal.

2. Materials and Methods

2.1. Study Area and Data Sources

Calabar Municipal Local Government Area is located in the southern coastal zone of Cross River State, Nigeria, and functions as the administrative, commercial, and tourism centre of the state. The municipality is characterized by high population density, mixed land use, and intense human mobility driven by markets, transport corridors, educational institutions, hospitality services, and government offices. These urban characteristics influence both HIV transmission dynamics and access to prevention and treatment services. Administratively, the Local Government Area is subdivided into wards that serve as the primary spatial units for health planning and data aggregation.

HIV data used in this study covered the period from 2020 to 2025 and comprised routine surveillance indicators commonly employed in HIV programme monitoring. The dataset included annual new HIV diagnoses, estimated numbers of people living with HIV, antiretroviral therapy enrolment, retention on ART at twelve months, viral load suppression status, and AIDS-related deaths. Demographic attributes such as age group and sex were included to support assessment of population-level vulnerability and transmission patterns. The age categories adopted were 0–14 years, 15–24 years, 25–34 years, 35–49 years, and 50 years and above, reflecting standard reporting frameworks for HIV epidemiological analysis.

Spatial data consisted of the administrative boundary of Calabar Municipal and ward-level spatial units used as proxies for neighbourhoods or service catchment areas. These spatial layers provided the geographic framework for aggregating and comparing HIV indicators across the municipality. All spatial datasets were prepared in a uniform coordinate reference system to ensure positional consistency during analysis and visualization.

2.2. Data Processing and Analytical Procedures

Data processing involved organizing and standardizing HIV surveillance records to ensure temporal continuity and internal consistency across the six-year study period. Annual aggregation of HIV indicators was conducted to examine temporal trends in disease burden, treatment coverage, and outcomes. Cumulative aggregation was applied to support spatial comparison of HIV burden across wards, while age–

sex disaggregation enabled detailed demographic analysis of new HIV diagnoses.

Descriptive statistical analysis was employed to summarize HIV indicators by year, ward, age group, and sex. Temporal analysis focused on identifying changes in HIV burden and treatment outcomes over time, including trends in ART enrolment, retention, viral load suppression, and AIDS-related mortality. Spatial analysis emphasized the comparison of HIV indicators across ward areas to identify zones with relatively higher concentrations of cases and service demand.

To enhance interpretation of public health impact, a severity-oriented analytical perspective was adopted. Indicators associated with adverse outcomes, such as AIDS-related deaths and lack of viral suppression, were examined alongside indicators reflecting treatment success. This approach allowed assessment of HIV burden beyond simple case counts and supported identification of areas experiencing greater service pressure or poorer outcomes.

All analyses were conducted within a GIS-supported environment to facilitate spatial interpretation and visualization of results. The methodological framework prioritizes clarity and relevance for urban HIV programme planning and is adaptable for integration with additional variables such as health facility locations, population density, and mobility indicators in future studies.

3. Results

3.1. Annual HIV Service Indicators in Calabar Municipal (2020–2025)

The annual HIV service indicators reveal clear trends in HIV burden and treatment outcomes in Calabar Municipal over the six-year period. Table 1 summarizes key indicators, while Figure 1 illustrates selected temporal trends.

Table 1: Annual HIV Service Indicators in Calabar Municipal (2020–2025)

Year	New HIV Diagnoses	Estimated PLHIV	ART Enrolled	ART Retained at 12 Months	Viral Load Suppression	AIDS-Related Deaths
2020	1,020	14,800	12,050	10,720	9,060	260
2021	980	15,050	12,620	11,340	9,880	245
2022	1,050	15,420	13,410	12,160	10,820	238
2023	1,120	15,780	14,230	13,010	11,880	228
2024	1,180	16,150	15,060	13,910	12,980	220
2025	1,250	16,520	15,920	14,860	14,050	212

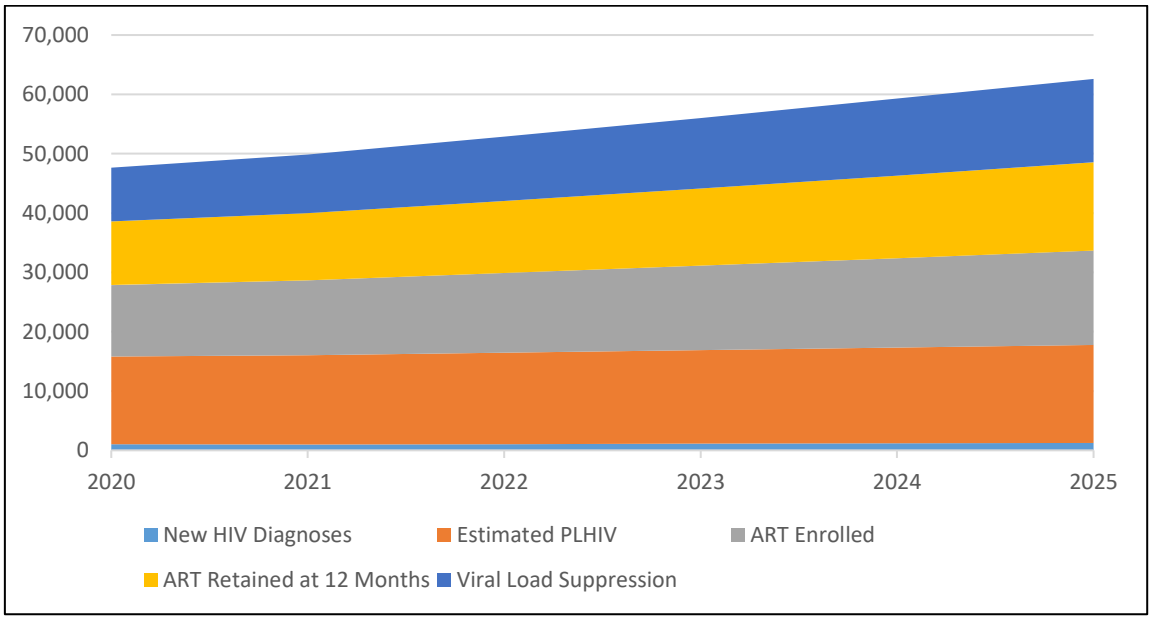

Fig 1: Temporal Trends in Key HIV Service Indicators (2020–2025)

The results indicate a gradual increase in the estimated number of people living with HIV over the study period, rising from 14,800 in 2020 to 16,520 in 2025. ART enrolment and retention at twelve months show steady improvement, accompanied by a substantial increase in viral load suppression. In contrast, AIDS-related deaths decline consistently, suggesting positive impacts of improved treatment coverage and adherence.

3.2. Cumulative HIV Cases by Ward Area in Calabar Municipal (2020–2025)

Spatial analysis demonstrates variation in HIV burden across ward areas within Calabar Municipal. Table 2 presents cumulative new HIV diagnoses, ART enrolment, and AIDS-related deaths by ward area for the study period, while Figure 2 illustrates their spatial distribution.

Table 2: Cumulative HIV Indicators by Ward Area in Calabar Municipal (2020–2025)

Ward Area	New Diagnoses	ART Enrolled	AIDS-Related Deaths
Marian	1,320	4,420	148
Watt Market Axis	1,240	4,260	141
Calabar South Extension Axis	1,180	4,010	132
Big Qua	1,050	3,610	121
Ikot Ansa	1,010	3,480	110
Ekpo Abasi	980	3,420	118
Ikot Ishie	860	2,980	101
Edim Otop	790	2,740	92
Total	8,430	28,920	963

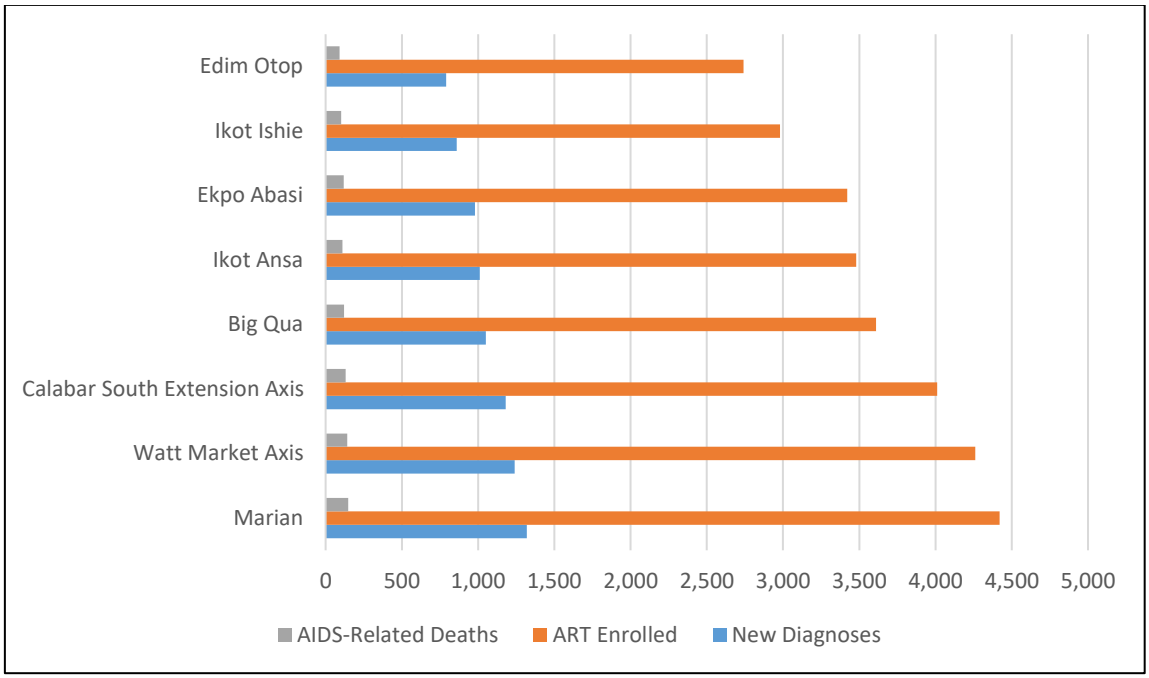

Fig 2: Spatial Distribution of Cumulative HIV Cases by Ward Area

Higher concentrations of HIV cases are observed in Marian, Watt Market axis, and Calabar South extension areas. These wards are characterized by high population density, commercial activity, and mobility, which contribute to increased exposure and service demand. Lower cumulative counts are recorded in less densely populated residential wards.

3.3. Distribution of New HIV Diagnoses by Age Group and Sex (2020–2025)

Demographic analysis reveals marked variation in new HIV diagnoses by age group and sex. Table 3 summarizes the cumulative distribution of new diagnoses, while Figure 3 presents their proportional representation.

Table 3: Distribution of New HIV Diagnoses by Age Group and Sex (2020–2025)

Age Group	Male	Female	Total	Percentage (%)
0–14	210	180	390	4.6
15–24	720	1,180	1,900	22.5
25–34	1,280	2,060	3,340	39.6
35–49	920	1,360	2,280	27.0
50+	280	240	520	6.2
Total	3,410	5,020	8,430	100.0

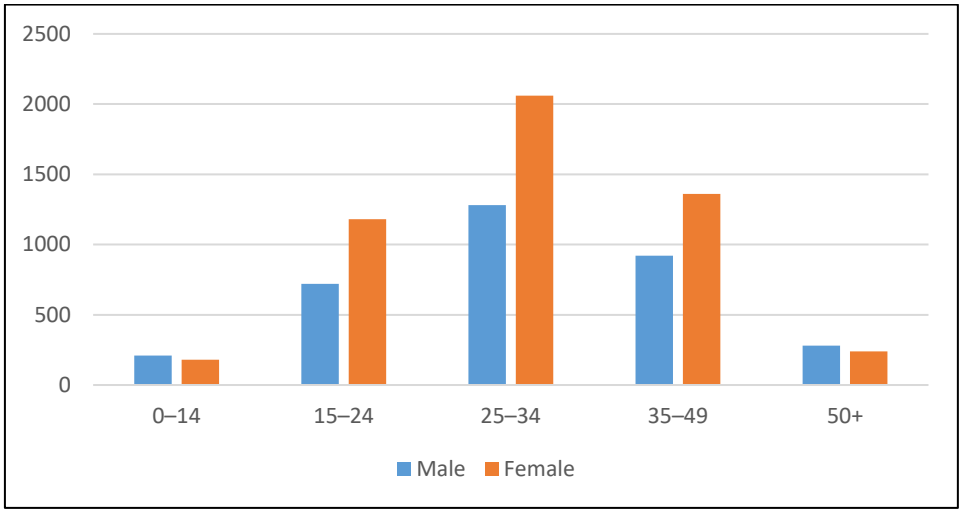

Fig 3: Proportion of New HIV Diagnoses by Age Group and Sex

The highest proportion of new HIV diagnoses occurs among individuals aged 25–34 years, followed by those aged 35–49 years. Females account for a larger share of new diagnoses across most age groups, particularly within the 15–34 year cohort, indicating gendered vulnerability within the urban population.

3.4. Mean Monthly Pattern of New HIV Diagnoses (Average for 2020–2025)

Temporal aggregation of monthly data reveals modest but consistent variation in new HIV diagnoses throughout the year. Table 4 presents the mean monthly number of new diagnoses, while Figure 4 illustrates the monthly pattern.

Table 4: Mean Monthly Pattern of New HIV Diagnoses in Calabar Municipal (2020–2025)

Month	Mean New Diagnoses
January	78
February	70
March	74
April	68
May	72
June	75
July	80
August	77
September	73
October	76
November	79
December	86

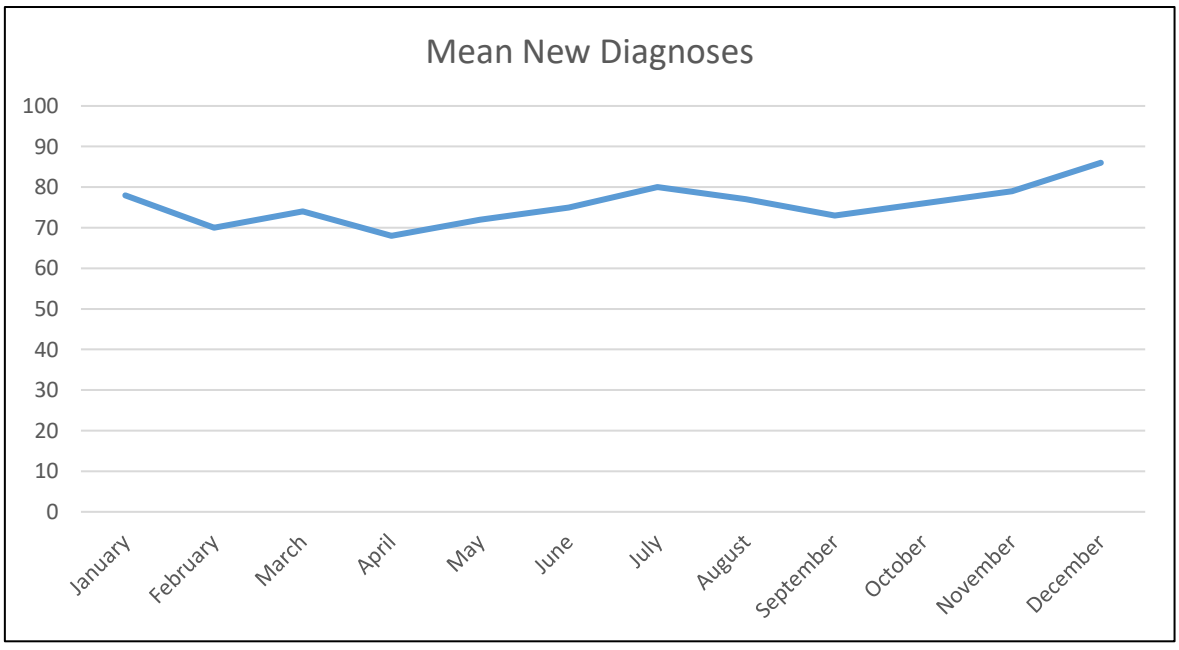

Fig 4: Mean Monthly Distribution of New HIV Diagnoses

The results show relatively stable monthly diagnosis rates, with a noticeable increase in December. This pattern may reflect intensified testing campaigns, increased health-seeking behaviour, and higher social interaction during festive periods.

3.5. Severity Weighting Scheme for HIV Burden and Service Pressure Index

To support integrated assessment of HIV burden and service pressure, a severity weighting scheme was adopted to reflect the relative public health impact of different HIV indicators. Table 5 and figure 5 presents the weighting structure applied.

Table 5: Severity Weighting Scheme for HIV Burden and Service Pressure Index

Indicator Component	Assigned Weight
AIDS-related death	5
Unsuppressed viral load	4
Not retained on ART at 12 months	3
New HIV diagnosis	2
On ART and virally suppressed	1

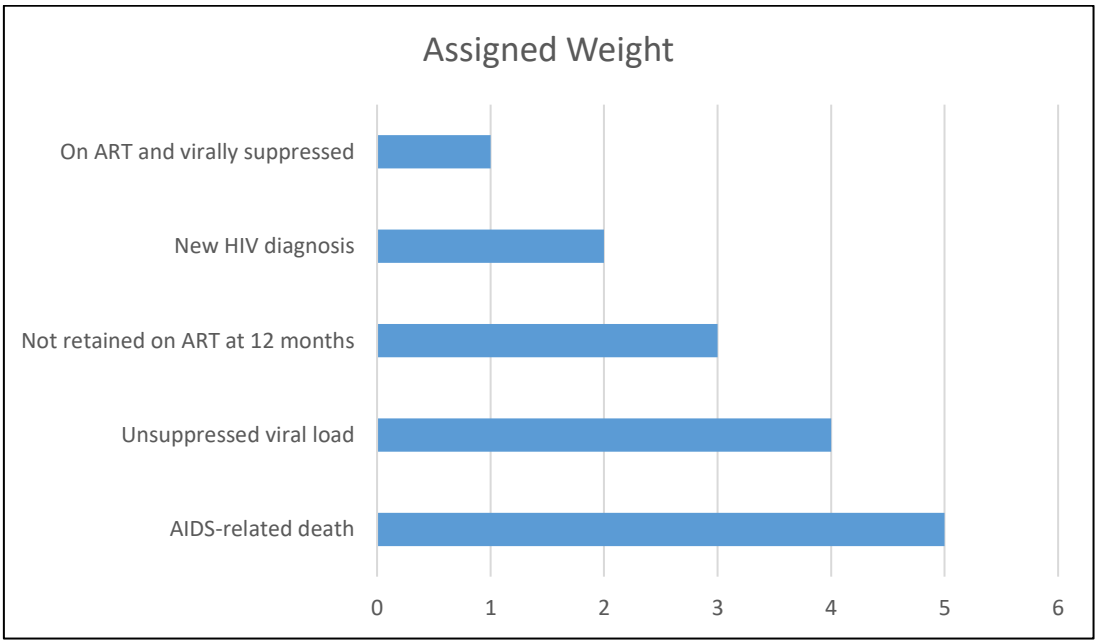

Fig 5: Conceptual Representation of HIV Severity Weighting

The weighting scheme assigns greater influence to indicators associated with adverse outcomes, ensuring that areas experiencing poorer treatment results or higher mortality are appropriately highlighted. This approach supports prioritization of wards requiring intensified programmatic attention. Overall, the results demonstrate that HIV burden and service outcomes in Calabar Municipal vary across time, space, and demographic groups. The integration of temporal trends, spatial distribution, and severity considerations provides a comprehensive

4. Discussion of Results

The results of this study reveal clear temporal, spatial, and demographic patterns in HIV burden and service delivery in Calabar Municipal between 2020 and 2025, reflecting the complex interaction between ongoing transmission, urban dynamics, and expanding access to treatment services. The gradual increase in the estimated number of people living with HIV over the study period is indicative of improved survival resulting from expanded antiretroviral therapy coverage rather than a sharp escalation in new infections. This interpretation is supported by the simultaneous rise in ART enrolment, retention, and viral load suppression alongside a consistent decline in AIDS-related deaths. These trends suggest measurable progress toward treatment effectiveness and improved long-term health outcomes among people living with HIV in the municipality.

The pattern of new HIV diagnoses shows relative stability with a modest upward trend toward the latter years of the study period. This stability implies that while prevention efforts may be moderating transmission, new infections continue to occur at a sustained level within the urban population. The observed increase in diagnoses in later years may also reflect improved case-finding strategies, expanded testing services, and greater community awareness rather than a true increase in incidence. The concurrent improvement in treatment indicators reinforces the likelihood that health system performance has strengthened over time.

Spatial analysis highlights pronounced heterogeneity in HIV burden across ward areas in Calabar Municipal. Higher cumulative numbers of new diagnoses and people enrolled on ART are concentrated in wards such as Marian, Watt Market axis, and Calabar South extension. These areas are characterized by high population density, intense commercial activity, transport hubs, and increased population mobility, all of which are known to elevate vulnerability to HIV transmission. The clustering of cases in these wards underscores the influence of urban structure and socio-economic activity on HIV distribution. In contrast, wards with lower population density and predominantly residential land use record comparatively fewer cases, reinforcing the role of localized contextual factors in shaping HIV risk.

Demographic analysis reveals that young adults, particularly those aged 25–34 years, account for the largest proportion of new HIV diagnoses, followed by individuals aged 35–49 years. These age groups represent the most economically active and socially mobile segments of the population, which increases exposure to behavioural and structural risk factors. The consistently higher proportion of female diagnoses across most age categories highlights persistent gender-related vulnerability within the urban setting. Factors such as biological susceptibility, socio-economic inequality, and differential access to prevention resources likely contribute to this pattern and point to the need for gender-responsive HIV programming.

The mean monthly pattern of new HIV diagnoses demonstrates relatively modest awareness of seasonal fluctuation, with a noticeable increase in December. This peak may be associated with intensified testing campaigns, increased health-seeking behaviour, and heightened social interaction during festive periods. The absence of strong seasonal variability in other months suggests that HIV transmission and diagnosis in Calabar Municipal are driven more by structural and behavioural factors than by environmental seasonality, distinguishing HIV dynamics from those of climate-sensitive diseases.

The application of a severity weighting scheme provides an integrative perspective on HIV burden and service pressure by accounting for both adverse outcomes and treatment success. By assigning higher weights to AIDS-related deaths, unsuppressed viral load, and poor treatment retention, the framework emphasizes areas where health system challenges remain most pronounced. This approach demonstrates that reliance on new diagnosis counts alone may underestimate public health impact in wards experiencing poorer treatment outcomes. Incorporating severity into spatial assessment therefore enhances prioritization of interventions and supports more equitable allocation of limited resources.

Overall, the findings demonstrate that HIV burden and service outcomes in Calabar Municipal are spatially heterogeneous, demographically differentiated, and dynamically evolving over time. The results affirm the value of GIS-based HIV mapping for revealing intra-urban disparities that are not apparent in aggregated surveillance data. Integrating spatial analysis into routine HIV monitoring provides a stronger empirical basis for targeted prevention, optimized treatment delivery, and sustained progress toward epidemic control within the study area.

5. Conclusion

This study has demonstrated the effectiveness of Geographic Information System–based HIV case mapping in examining the spatial and temporal dynamics of HIV burden and service delivery in Calabar Municipal, Cross River State, between 2020 and 2025. By integrating HIV surveillance indicators with spatial units at the ward level, the research provided a detailed understanding of how HIV cases, treatment coverage, and outcomes vary within the municipality over time.

The findings indicate a gradual increase in the estimated population of people living with HIV, occurring alongside substantial improvements in antiretroviral therapy enrolment, retention, and viral load suppression. The concurrent decline in AIDS-related mortality suggests that treatment scale-up and improved adherence have yielded positive public health outcomes. However, the persistence of new HIV diagnoses throughout the study period indicates that transmission remains ongoing, particularly among young and economically active populations.

Spatial analysis revealed clear clustering of HIV cases in densely populated and commercially active ward areas, highlighting the influence of urban structure, mobility, and socio-economic activity on HIV vulnerability. Demographic analysis showed that females and young adults bear a disproportionate share of new diagnoses, underscoring the continued relevance of gender- and age-responsive prevention strategies. The relatively stable monthly pattern of diagnoses, with a peak during the festive period, reflects behavioural and service-related dynamics rather than strong seasonal influences.

The incorporation of a severity weighting scheme provided an integrated assessment of HIV burden and service pressure, demonstrating that areas with fewer diagnoses may still experience substantial public health impact due to poorer treatment outcomes or higher mortality. This approach reinforces the need to consider treatment quality and outcomes alongside case detection in HIV programme planning.

Overall, the study underscores the importance of spatially informed and demographically targeted HIV interventions within urban local government areas. Institutionalizing GIS-based HIV mapping within routine surveillance and planning processes would enhance evidence-based decision-making, improve equity in service delivery, and support sustained progress toward HIV epidemic control in Calabar Municipal and similar urban settings.

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