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Spatial variation in HIV/AIDS prevalence and treatment coverage in Niger state using GIS-based spatial analysis

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Abstract

This study investigates the spatial variation in HIV/AIDS prevalence and treatment coverage across Niger State Local Government Areas (LGAs) of a selected region using a Geographic Information System (GIS)-based spatial analysis approach. The aim was to uncover geographic disparities in infection rates, testing outcomes, and antiretroviral therapy (ART) enrolment, thereby providing a spatially-informed framework for targeted intervention. Epidemiological data, disaggregated by gender, age, and testing status, were integrated with spatial boundary datasets in ArcGIS 10.2.1 to produce thematic maps reflecting HIV-positive and HIV-negative distributions, as well as ART uptake. The findings revealed a clear spatial heterogeneity in HIV/AIDS prevalence, with LGAs such as Kontagora, Paiko, Suleja, and Chanchaga consistently registering very high infection rates among both male and female populations. These high-burden LGAs formed a contiguous corridor of elevated HIV transmission concentrated in central and southeastern parts of the state. ART enrolment was similarly concentrated in these urban and peri-urban LGAs, indicating a positive correlation between disease burden and treatment access. In contrast, peripheral LGAs such as Borgu, Rijau, and Agwara exhibited low to moderate ART coverage and lower-case detection, highlighting structural gaps in healthcare access. Gender-based analysis revealed higher female prevalence in urban centers and lower male testing participation in rural LGAs, suggesting the influence of gender norms, stigma, and socio-economic barriers on service utilization. The distribution of HIV-negative results further confirmed disparities in testing coverage, with LGAs like Mokwa emerging as outliers with very high HIV-negative counts despite only moderate HIV-positive prevalence. The study concludes that HIV/AIDS in Niger State exhibits a strong spatial pattern influenced by urbanization, healthcare infrastructure, and socio-cultural dynamics. GIS-based analysis proved instrumental in identifying epidemiological hotspots, under-served areas, and testing gaps, offering a critical tool for spatial targeting of public health interventions. These findings advocate for a reorientation of HIV/AIDS control strategies to include spatial prioritization, equity-driven treatment distribution, and gender-responsive testing programs to advance toward universal health coverage and epidemic control.

Keywords: HIV/AIDS Prevalence; Geographic Information System (GIS); Spatial Analysis; Antiretroviral Therapy (ART); Epidemiological Mapping

1. Introduction

The HIV/AIDS continues to constitute a major public health challenge globally, particularly in sub-Saharan Africa where over two-thirds of the global HIV-positive population resides (UNAIDS, 2022). Despite significant advancements in treatment and prevention, the disease remains a leading cause of morbidity and mortality, especially among young adults and economically active populations (World Health Organization [WHO], 2021). Nigeria ranks among the top countries most burdened by the epidemic, with an estimated 1.9 million people living with HIV and a national adult prevalence rate of approximately 1.3% (National Agency for the Control of AIDS [NACA], 2020). However, the distribution of the disease across the country is far from uniform, exhibiting marked spatial and demographic disparities

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influenced by regional healthcare infrastructure, social behaviour, and policy implementation (Awofala & Ogundele, 2018; Ibrahim et al., 2020).

The application of Geographic Information Systems (GIS) in public health has revolutionized the capacity for real-time disease surveillance, spatial risk mapping, and resource allocation (Tanser & Le Sueur, 2002; Cromley & McLafferty, 2012). GIS allows for the integration of epidemiological data with geospatial layers to visualize and analyze the distribution of disease and health service accessibility over time and space (Fraser et al., 2005). In the context of HIV/AIDS, spatial analysis has proven effective in identifying epidemiological hotspots, assessing ART coverage, and targeting prevention efforts to vulnerable populations (Larmarange et al., 2011; Adedayo & Bakare, 2018).

Previous studies have shown that urbanization, mobility, socio-economic disparity, and gender norms are critical factors shaping the spatial dynamics of HIV transmission and treatment access (Gould, 1993; Oppong & Harold, 2004). Urban LGAs with dense populations and active commercial centers often exhibit higher prevalence due to increased sexual networking, transactional sex, and inadequate preventive education (Mberu et al., 2012; Adebayo et al., 2020). Conversely, rural regions frequently suffer from low testing rates, delayed diagnoses, and weak linkage to ART services, reflecting health system inequities (Adedimeji et al., 2011; Edewor, 2014).

Gender also plays a crucial role in shaping the spatial burden of HIV/AIDS. Women, particularly adolescents and young adults, are biologically and socially more vulnerable to infection due to a combination of early marriage, limited access to healthcare, and socio-cultural power imbalances (FMOH, 2021; Adebajo et al., 2003). Meanwhile, men often engage in high-risk behaviours but are less likely to seek timely testing and treatment, contributing to hidden prevalence and delayed intervention (Mbonu et al., 2010; Shannon et al., 1991).

Despite the wealth of national statistics, there remains a critical gap in spatially detailed, disaggregated analysis of HIV/AIDS at sub-national levels in Nigeria. A localized understanding of prevalence and ART distribution is vital for designing effective, equity-driven interventions. This study, therefore, utilizes GIS-based spatial analysis to investigate the spatial variation in HIV/AIDS prevalence and treatment coverage across Local Government Areas (LGAs), providing empirical evidence to support spatial targeting in HIV control programs.

The specific objectives of this study are: (i) to map the spatial distribution of HIV-positive individuals by gender, (ii) to assess ART enrolment coverage across LGAs, and (iii) to identify geographic and demographic disparities in testing outcomes. Through these objectives, the study aims to strengthen the evidence base for spatially responsive HIV programming and contribute to the realization of global goals such as the UNAIDS 95-95-95 targets and Sustainable Development Goal 3.

2. Materials and Methods

2.1. Study Area

The study was conducted in Niger State, located in the North-Central geopolitical zone of Nigeria. Geographically, the state lies between latitudes 8°00'N and 11°30'N and longitudes 3°30'E and 7°20'E. It is bordered by Kebbi State to the northwest, Zamfara and Kaduna States to the north and northeast respectively, the Federal Capital Territory (FCT) to the southeast, and Kwara and Kogi States to the south. Niger State has a total landmass of approximately 76,363 km², making it the largest state in Nigeria by land area.

Administratively, Niger State is subdivided into 25 Local Government Areas (LGAs), with Minna serving as the state capital. The state's population is largely rural, although urban centers such as Minna, Bida, Suleja, and Kontagora host relatively high population densities. Niger State is characterized by diverse socio-economic activities including agriculture, trading, mining, and artisanal occupations. The state's demographic composition, population mobility, and variable healthcare infrastructure provide a suitable environment for analyzing spatial variation in HIV/AIDS prevalence and treatment coverage.

2.2. Data Collection

The study utilized secondary data sourced from the National Agency for the Control of AIDS (NACA). The data comprised HIV/AIDS surveillance records disaggregated by LGA and gender. Specifically, the dataset included the following indicators:

- CASE 1: Total number of individuals cumulatively enrolled into HIV care since the inception of the program

- CASE 2: Number of individuals currently receiving ART
- CASE 3: Number of persons enrolled for HIV care who initiated cotrimoxazole prophylaxis
- CASE 4: Number of operational ART treatment facilities
- CASE 5–7: Prevention of Mother-To-Child Transmission (PMTCT) indicators
- CASE 8–14: Number of individuals tested HIV-negative, disaggregated by age and gender
- CASE 15–21: Number of individuals tested HIV-positive, disaggregated by age and gender

These data were compiled in Microsoft Excel and geo-referenced to their respective LGAs. Supplementary base maps and administrative shapefiles of Niger State were obtained from the Office of the Surveyor-General of the Federation.

2.3. Data Processing and GIS Integration

The processing of HIV/AIDS-related data and subsequent spatial analysis were carried out using ArcGIS 10.2.1. Each indicator was assigned to its corresponding LGA and visualized using choropleth symbology. The following steps were followed:

- Data Preparation: Epidemiological indicators were categorized into thematic layers. Each LGA was assigned values corresponding to each HIV/AIDS metric.
- Data Classification: Spatial representation of prevalence, ART enrolment, and negative test results was conducted using natural breaks (Jenks) classification. The data were grouped into four categories: very high, high, moderate, and low.
- Spatial Queries: Attribute queries were executed using Structured Query Language (SQL) to isolate LGAs with values above or below predefined thresholds (e.g., ≥ 500 HIV-positive cases). These queries enabled focused analysis of high-risk zones.
- Mapping: Thematic maps were produced for each indicator, including general HIV prevalence, ART uptake, male and female-specific prevalence, and gender-based negative testing patterns. These maps visually illustrated spatial disparities and facilitated comparative analysis.

2.4. Analytical Framework

A descriptive spatial analysis approach was adopted. Each thematic map was interpreted in relation to demographic and socio-economic characteristics of the respective LGAs. Particular attention was paid to:

- Urban-rural disparities in prevalence and treatment
- Gender-based testing and treatment dynamics
- Correlation between disease burden and treatment access

The interpretation of results was informed by spatial health literature, epidemiological trends, and field insights from prior studies conducted in similar contexts. All maps were reviewed with reference to LGA-level population data to ensure contextual accuracy and interpretation integrity.

3. Results

The analysis presents the spatial variation in HIV/AIDS prevalence and treatment coverage across the study area by utilizing a series of georeferenced thematic maps derived from disaggregated epidemiological data. These maps illustrate the geographic distribution of key HIV/AIDS indicators, including gender-specific prevalence, testing outcomes, and enrolment in antiretroviral therapy (ART). Each Local Government Area (LGA) is classified into one of four epidemiological intensity categories—very high, high, moderate, and low—based on reported case counts. This classification enables a clearer understanding of the spatial epidemiology of HIV/AIDS and supports the identification of priority areas for targeted intervention, resource allocation, and policy implementation.

3.1. Pattern of HIV/AIDS Prevalence among Female Populations

The spatial pattern of HIV/AIDS among female individuals reveals a pronounced degree of geographic heterogeneity across the LGAs. The map (see Figure 1) shows that LGAs such as Kontagora, Paiko, Tafa, and parts of Chanchaga exhibit very high case intensities, denoted in red. These LGAs represent zones of concentrated female infections and should be prioritized as transmission hotspots.

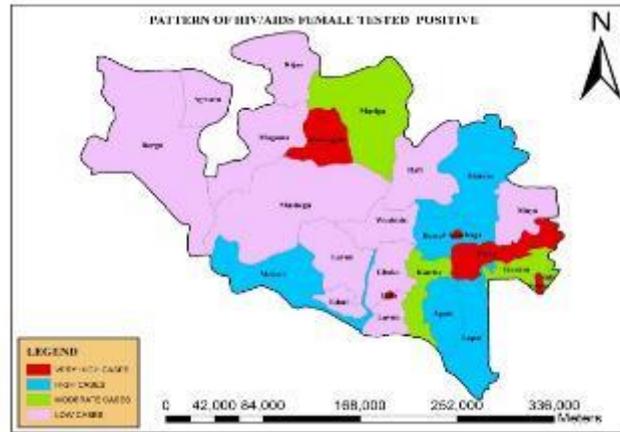


Figure 1 Pattern of HIV/AIDS Female tested positive

The elevated prevalence in these areas may be attributed to a convergence of socio-economic and structural vulnerabilities, including urbanization, high population density, and the prevalence of transactional sex. Urban centers like Paiko and Chanchaga often experience elevated exposure to HIV transmission risks due to a higher presence of transient populations, informal labor markets, and limited access to consistent reproductive health education and services. The observed prevalence patterns in these LGAs reflect well-established epidemiological findings that link urban and peri-urban areas with higher HIV burdens, particularly among women and adolescent girls, due to structural inequalities and increased biological susceptibility.

In contrast, LGAs such as Mariga, Gurara, and Suleja fall within the high case category (depicted in green), indicating substantial but not extreme female HIV prevalence. These areas likely experience moderate to high levels of risk behaviour and possibly benefit from more robust testing and reporting mechanisms compared to lower-ranked zones.

Meanwhile, a significant number of LGAs located in the western and northwestern regions of the state—including Borgu, Rijau, Agwara, and Magama—are categorized under moderate and low case intensities. These LGAs, displayed in blue and pink respectively, suggest either genuinely lower prevalence or potentially limited access to testing services, leading to underreporting. The observed disparity between urban and rural LGAs indicates the persistence of a spatial inequality in HIV risk and health system responsiveness, which must be addressed through targeted outreach, mobile testing units, and awareness campaigns.

3.2. Pattern of HIV/AIDS Prevalence among Males

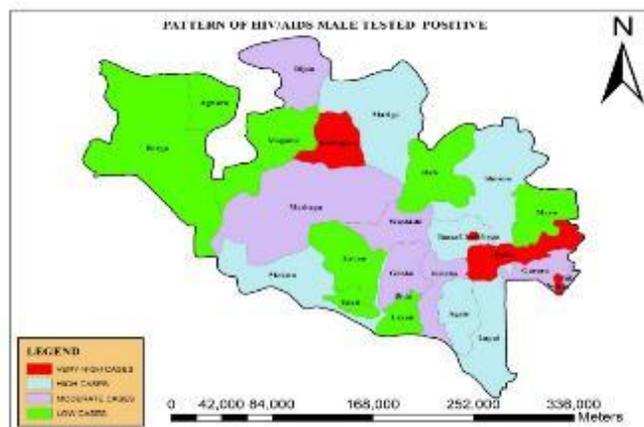


Figure 2 Pattern of HIV/AIDS Male Tested Positive

The spatial distribution of HIV/AIDS prevalence among male individuals, as illustrated in Figure 2, exhibits a distinct yet complementary configuration relative to the female-based distribution. Kontagora, Paiko, and Suleja prominently emerge as Local Government Areas (LGAs) with very high case intensities, represented in red. These LGAs are

characterized by a substantial concentration of confirmed HIV-positive male cases, marking them as critical epidemiological hotspots requiring urgent and sustained intervention.

The recurrence of high prevalence levels in both male and female populations within Kontagora and Paiko suggests a shared set of epidemiological determinants. These likely include urbanization, high population mobility, and commercial or industrial activities that increase exposure to high-risk sexual networks. The simultaneous presence of male and female HIV clusters in the same LGAs indicates that the transmission dynamics in these areas are not gender-exclusive and may be driven by broader structural and behavioural factors such as low condom use, gender-based violence, and inadequate access to comprehensive sexual health education. These findings support the urgent need for gender-integrated prevention and treatment strategies within these high-burden LGAs.

In contrast to the patterns observed in female prevalence, the map reveals that a greater number of LGAs located in the western and northwestern parts of the state—including Borgu, Agwara, Rijau, and Magama—fall within the low and moderate prevalence categories (shown in green and light blue, respectively). These lower values may reflect genuinely reduced male infection rates or, alternatively, may be indicative of underreporting due to limited access to testing services, social stigma, or cultural norms that deter males from seeking HIV testing and care. It is important to recognize that male populations, especially in rural areas, often exhibit lower health-seeking behaviour, which may obscure the true prevalence and delay early diagnosis.

Additionally, several LGAs, including Lavun and Mokwa, occupy moderate prevalence categories, suggesting the existence of smaller-scale infection clusters. These areas may act as transitional zones where the HIV burden is neither negligible nor as severe as in the urban centers, thereby requiring more nuanced public health responses that combine preventive education with routine surveillance.

3.3. General Pattern of HIV/AIDS Individuals Tested Positive

The thematic map presented in Figure 3, portrays the composite spatial distribution of HIV-positive cases across both male and female populations in the study area. This combined analysis provides a holistic epidemiological perspective on the geographic burden of HIV/AIDS in the state, reflecting aggregate infection levels per Local Government Area (LGA) without disaggregating by gender. The spatial synthesis highlights significant disparities in prevalence, clearly delineating zones of high transmission intensity and zones of lower reported incidence.

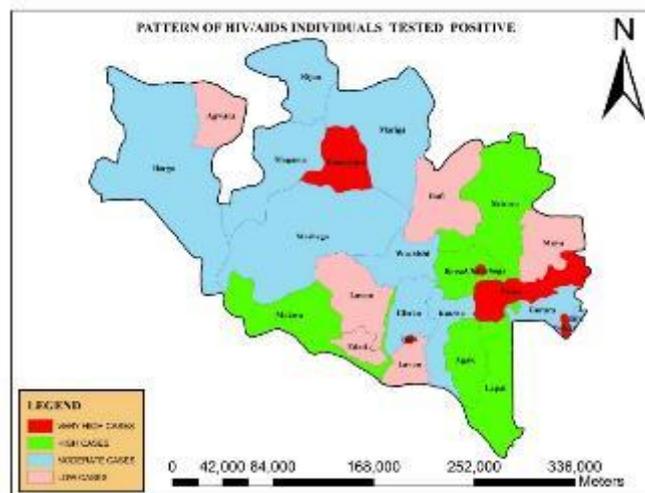


Figure 3 Pattern of HIV/AIDS Individual Tested Positive

The LGAs of Kontagora, Paiko, Chanchaga, and Tafa are consistently categorized under the very high prevalence class, represented in red on the map. These areas exhibit the most substantial concentrations of HIV-positive individuals in the state and form a spatially contiguous axis of elevated HIV burden that stretches from the central region through the southeastern LGAs. Their designation as high-burden zones align with socio-epidemiological characteristics common to such localities, including urbanization, economic migration, higher population densities, and increased exposure to high-risk sexual behaviour. These LGAs also serve as administrative, commercial, and transport hubs, which inherently amplify interpersonal contact and social mixing, thereby facilitating the conditions for more rapid viral transmission.

Chanchaga, which houses the state capital, and Tafa, a rapidly urbanizing region, are particularly noteworthy for their dual status as centers of economic opportunity and epicentres of disease burden. The concentration of infection in these zones underscores the need for spatially prioritized public health responses and continuous surveillance, particularly among mobile populations, informal workers, and underserved urban settlements.

Conversely, the LGAs of Rafi, Muya, and Agwara are classified under the low prevalence category, represented in blue. These areas are predominantly rural and exhibit lower population densities, fewer urban infrastructures, and limited commercial activity. The reduced prevalence in these LGAs may be attributable to both genuine epidemiological conditions and structural factors such as limited access to healthcare services, underreporting, or low testing uptake. It is possible that HIV prevalence in these zones is underestimated due to weak surveillance systems or cultural resistance to voluntary testing.

The spatial pattern illustrated in this map reinforces the established hypothesis that HIV/AIDS prevalence is strongly associated with urbanization and socio-economic dynamics. Urban LGAs tend to report higher incidence rates not solely due to increased risk behaviour but also due to the presence of testing and treatment facilities, which enhance detection. This urban-rural differential highlights the dual imperative of sustaining interventions in high-burden urban centers while also scaling up testing and outreach efforts in rural LGAs to ensure comprehensive surveillance.

This composite spatial distribution serves as an essential tool for health system planning, resource targeting, and evidence-based policymaking. By revealing a corridor of HIV intensity that spans central to southeastern LGAs, this analysis provides a framework for the spatial prioritization of HIV prevention and treatment programs. Such programs may include community-based testing campaigns, mobile outreach clinics, and targeted behavioural change interventions tailored to the socio-cultural dynamics of each LGA.

3.4. Distribution of Individuals Enrolled for ART

Figure 4 presents the spatial distribution of individuals enrolled in Antiretroviral Therapy (ART) across the Local Government Areas (LGAs) within the study area. This map reflects treatment coverage and indirectly measures healthcare access, HIV case detection efficiency, and the responsiveness of the health system to diagnosed individuals. ART enrolment data provides a critical metric for assessing how effectively diagnosed persons are being linked to sustained treatment, which is essential for viral suppression and the reduction of onward transmission.

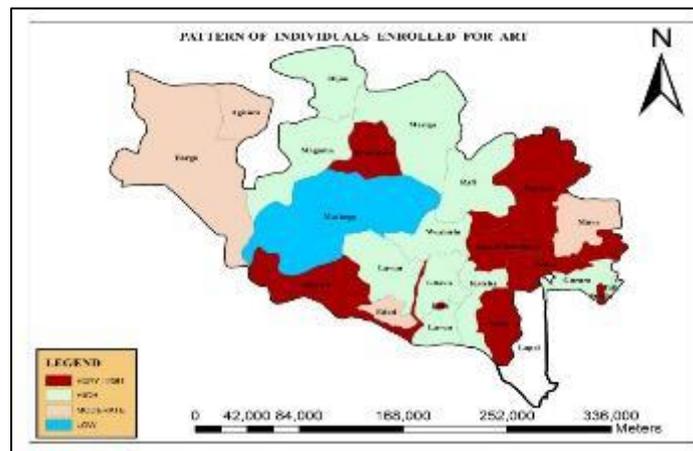


Figure 4 Pattern of Individuals Enrolled for ART (Anti Retro-viral Treatment)

The results indicate that LGAs such as Kontagora, Shiroro, Bosso, Chanchaga, and Agaie exhibit very high ART enrolment levels, represented in red. These LGAs also correspond with previously identified high-prevalence zones, suggesting that treatment access and programmatic follow-up are more robust in regions where HIV burden is already recognized as significant. The alignment between high prevalence and high ART coverage in these LGAs is indicative of a relatively functional public health response, where health services have been deployed effectively to meet the needs of infected individuals. This level of service delivery likely benefits from the presence of established healthcare infrastructure, government-supported treatment centers, and possibly the activities of non-governmental organizations (NGOs) and development partners involved in HIV/AIDS programming.

Chanchaga, which includes the state capital, and Bosso, a densely populated adjacent LGA, are particularly noteworthy for their strong ART enrolment figures. These areas likely benefit from urban-based healthcare systems, greater availability of trained personnel, and improved public awareness, all of which contribute to better diagnosis-to-treatment linkage.

In contrast, LGAs located in the western and northern peripheries of the state, including Borgu, Agwara, and Rijau, demonstrate low to moderate ART enrolment, represented in blue and green. These LGAs either have fewer confirmed HIV-positive individuals or face significant challenges in linking diagnosed persons to ART services. Factors contributing to these lower enrolment figures may include geographic isolation, poor road infrastructure, under-resourced health facilities, cultural resistance to biomedical interventions, or gaps in testing and follow-up systems. Additionally, in rural or nomadic communities, healthcare-seeking behaviour may be influenced by traditional beliefs and logistical barriers that hinder consistent access to ART.

The spatial disparity between ART enrolment in urban and rural LGAs underscores an inequity in healthcare delivery and highlights the need for strategic intervention to close the treatment gap. Health authorities must consider deploying mobile treatment units, strengthening community-based healthcare delivery models, and incentivizing healthcare personnel to serve in remote areas. Additionally, awareness campaigns and decentralized ART distribution mechanisms can help reduce attrition and improve long-term treatment adherence in underserved regions.

3.5. Gender-Based Negative Test Patterns

The gender-disaggregated spatial distribution of HIV-negative test results provides valuable insight into the differential uptake of HIV testing services across the study area. Figure 4 and 5 illustrating HIV-negative male and HIV-negative female populations reveal both convergences and disparities that are indicative of underlying socio-cultural, infrastructural, and behavioural factors affecting health service access.

For the male demographic, the results show that the southern and southeastern LGAs—including Agaie, Lapai, and Paiko—record very high numbers of males who tested HIV negative, denoted in red on the map. This suggests that these LGAs have experienced relatively high male testing coverage, possibly due to the presence of urban centers, outreach programs, or more accessible health facilities. Central LGAs such as Mashegu, Lavun, and Mokwa fall within moderate to high case categories, indicating an appreciable, though not optimal, level of testing uptake among males. In contrast, western LGAs such as Borgu and Rijau exhibit low numbers of HIV-negative male test results, represented in blue, suggesting either limited male participation in voluntary testing or broader systemic issues such as lack of facility access, stigma, or cultural reluctance among men to seek medical screening.

Similarly, the female HIV-negative test results, as presented in Figure 5 reveal a spatial distribution that is partially consistent with the male pattern but also marked by distinct characteristics. LGAs such as Shiroro, Paiko, and Lapai again stand out as high and very high zones of HIV-negative female testing, which may be attributed to successful female-focused outreach, antenatal care programs, and education campaigns that emphasize routine HIV screening, particularly during pregnancy. These LGAs may also benefit from community health extension workers who often target women as primary points of health contact.

However, LGAs such as Mokwa, Edati, and parts of Tafa report low numbers of HIV-negative females, indicating potential testing gaps or weak surveillance. These regions may face cultural barriers that restrict female autonomy in accessing healthcare or may lack the community-level infrastructure necessary to support widespread testing initiatives.

The combined interpretation of these maps reveals a distinct but overlapping pattern of testing across gender lines. While some LGAs, notably Paiko and Lapai, demonstrate consistently high testing rates for both males and females, other areas show gender-specific discrepancies. For instance, Shiroro registers high HIV-negative female counts but only moderate male counts, suggesting that female-focused programs may be more successful or that men in those areas are less likely to participate in testing.

These variations highlight several critical concerns. First, access to HIV testing services is not geographically uniform across the state, and gender remains a key determinant of service utilization. Second, socio-cultural dynamics—including gender roles, stigma, and economic dependency—likely influence the willingness and ability of individuals to undergo testing. Third, health infrastructure, including the presence of trained personnel, testing centers, and mobile clinics, plays a decisive role in shaping testing patterns.

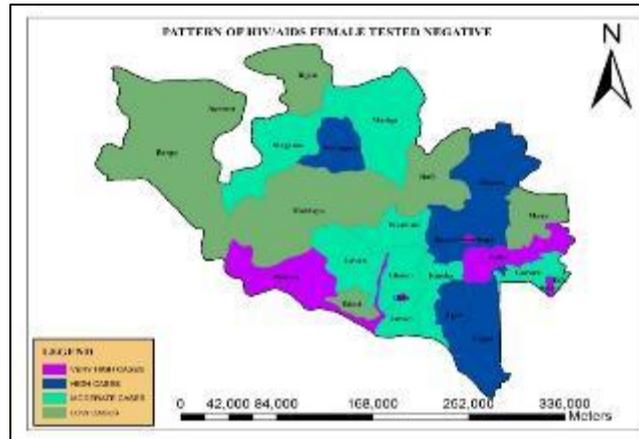


Figure 5 Pattern of HIV/AIDS Female Tested Negative

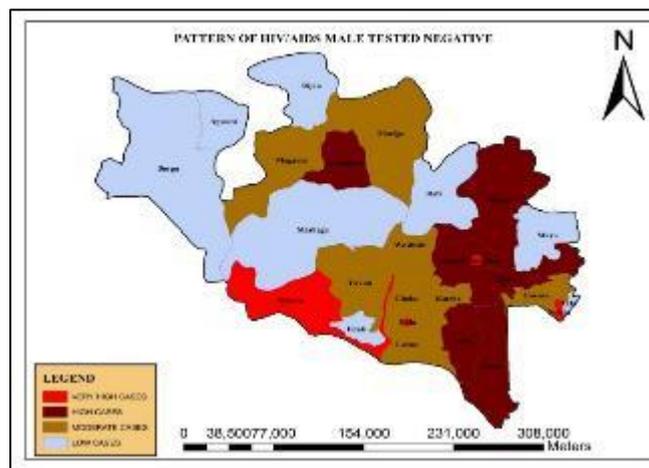


Figure 6 Pattern of HIV/AIDS Male Tested Negative

3.6. Pattern of HIV/AIDS Individuals Tested Negative

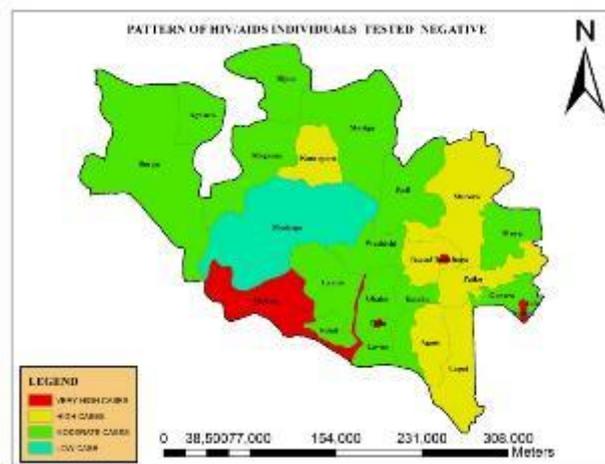


Figure 7 Pattern of HIV/AIDS Individuals Tested Negative

Figure 7 presents the spatial distribution of individuals who tested HIV negative across all Local Government Areas (LGAs), offering a complementary and inverse perspective to the maps detailing HIV-positive prevalence. This pattern serves as a proxy for evaluating both testing coverage and the potential success of local prevention strategies. The

interpretation of HIV-negative test results, especially when contextualized against known HIV prevalence, reveals nuanced insights into the accessibility, efficiency, and spatial targeting of testing services across the state.

LGAs such as Borgu, Agwara, and Shiroro are classified within the high or moderate HIV-negative test categories, represented in green and yellow respectively. These figures suggest relatively widespread participation in HIV testing within these areas or alternatively, a genuinely low burden of infection. Borgu and Agwara, located in the northwestern periphery of the state, had previously exhibited low HIV-positive counts, and their moderate-to-high negative test rates further substantiate the assumption that these LGAs may benefit from either lower transmission dynamics or effective awareness and prevention interventions. Similarly, Shiroro's classification implies that efforts in community mobilization, counselling, and possibly antenatal screening programs may be achieving favorable outcomes in test outreach and prevention.

In contrast, LGAs such as Kontagora and Bosso—which are known from earlier figures to have very high HIV-positive prevalence—record only moderate to low levels of HIV-negative individuals. This inverse relationship is indicative of high-test positivity rates, where a large proportion of those being tested are found to be positive. This could be due to several factors, including late-stage testing (where individuals seek testing only after symptoms emerge), selective testing focused on high-risk individuals, or a genuine intensification of the epidemic in these areas. The lower numbers of negative results in these high-prevalence zones may also reflect a lack of proactive community-based testing strategies aimed at reaching low-risk or asymptomatic individuals.

Of particular interest is the case of Mokwa, which emerges as an anomaly in the spatial pattern. Mokwa records very high numbers of HIV-negative individuals while maintaining moderate HIV-positive prevalence. This configuration may suggest a more balanced and widespread testing effort across population subgroups in Mokwa, enabling the identification of negative cases at scale. Alternatively, it could indicate a localized success in HIV prevention strategies, such as effective behavioural change communication, improved condom distribution, or high treatment adherence among positive individuals, which collectively contribute to a reduction in new infections.

4. Discussion of Findings

The spatial analysis of HIV/AIDS indicators across the Local Government Areas (LGAs) of the study area using Geographic Information System (GIS) has yielded critical insights into the geographic dimensions of disease prevalence, testing behaviour, and treatment accessibility. The thematic interpretations derived from gender-specific and general prevalence patterns, antiretroviral therapy (ART) enrolment, and HIV-negative testing outcomes underscore both the public health significance of the findings and their broader implications for policy and practice.

4.1. Spatial Epidemiology and Targeted Interventions

One of the most significant contributions of the study lies in its capacity to spatially delineate HIV/AIDS hotspots. LGAs such as Kontagora, Paiko, Chanchaga, and Suleja consistently appeared as high-burden areas across multiple indicators—HIV-positive cases, ART enrolment, and gender-disaggregated data. These findings provide empirical support for geographically targeted interventions; whereby limited resources can be strategically concentrated in areas with the highest transmission potential. Spatial epidemiology enables public health authorities to move from generalized interventions to precision public health, where responses are tailored to local needs and dynamics.

4.2. Gender-Responsive Programming

The disaggregated data revealed important gender-based disparities in both prevalence and testing patterns. High HIV prevalence among females in urban LGAs and uneven male participation in testing services reflect persistent structural and cultural barriers that influence access to healthcare. These results underscore the need for gender-responsive programming that considers the unique vulnerabilities of women and the behavioural and social factors that deter men from seeking HIV-related services. Integrating gender-sensitive outreach, peer education, and differentiated testing models will be essential for closing these gaps.

4.3. Inequity in Healthcare Access and ART Coverage

The distribution of ART enrolment revealed a strong correlation between treatment access and urban infrastructure. While ART coverage is high in LGAs with robust health facilities, several rural and remote LGAs—such as Borgu, Rijau, and Agwara—showed alarmingly low treatment enrolment. This disparity suggests not only limited physical access to treatment centers but also possible under-diagnosis due to weak surveillance systems. The implication is clear:

strengthening rural healthcare delivery through mobile clinics, community ART distribution, and integrated testing-treatment programs is essential to achieving equitable health outcomes.

4.4. Testing Gaps and Underreporting in Low-Prevalence Areas

The maps of HIV-negative test outcomes revealed inconsistencies in testing distribution. Several LGAs with low HIV prevalence also reported low negative test numbers, pointing to potential underreporting or poor testing uptake. This reinforces the need to interpret low prevalence cautiously, especially in areas where testing services are limited. It also emphasizes the necessity for state-wide scaling up of voluntary counselling and testing (VCT), particularly in communities where stigma or geographic isolation impedes service utilization.

4.5. Evidence for Policy Planning and Program Design

These findings serve as a valuable decision-support tool for health administrators and policymakers. By presenting a geospatially explicit picture of the HIV/AIDS landscape, the study equips stakeholders with actionable intelligence for planning resource allocation, selecting sentinel surveillance sites, and prioritizing behavioural change communication campaigns. The ability to project infection trends based on current spatial data also enhances preparedness and contributes to the design of sustainable long-term responses.

4.6. Contribution to Sustainable Development Goals (SDGs)

The insights generated from this study align with global health targets, particularly SDG 3, which aims to ensure healthy lives and promote well-being for all. The spatial disparities identified underscore the importance of equitable healthcare delivery as a core component of sustainable development. By identifying underserved regions and vulnerable populations, the study provides a roadmap for localizing national HIV strategies to ensure no community is left behind.

5. Conclusion

This study applied Geographic Information System (GIS) techniques to evaluate the spatial distribution of HIV/AIDS prevalence, testing outcomes, and antiretroviral therapy (ART) enrolment across Niger State Local Government Areas (LGAs) within the study area. By integrating disaggregated epidemiological data into spatial models, the research successfully revealed geographic disparities in the burden of the disease and in the delivery of critical health services.

The results demonstrated that HIV/AIDS prevalence is not uniformly distributed but is instead spatially concentrated in a corridor of urban and peri-urban LGAs such as Kontagora, Paiko, Suleja, and Chanchaga. These areas consistently reported very high numbers of HIV-positive individuals across both genders and also accounted for the majority of ART enrolments. The geographic clustering of cases in urban centers confirms the role of socio-economic factors, population density, and mobility in facilitating the transmission of HIV. In contrast, several rural LGAs—including Borgu, Rijau, and Agwara—exhibited lower prevalence rates, though these may reflect limited access to testing services and underreporting rather than genuinely low transmission.

Gender-disaggregated analysis revealed meaningful differences in HIV prevalence and testing patterns. While females showed higher prevalence rates in many LGAs, particularly in urban centers, the maps of HIV-negative results illustrated gaps in testing uptake among males in some regions. This highlights the influence of gender norms, stigma, and access barriers in shaping the HIV response and supports the need for gender-specific intervention strategies.

The study also found that ART access was highest in LGAs with strong healthcare infrastructure, leaving many peripheral and rural areas with limited treatment coverage. This inequity in service delivery poses a serious obstacle to achieving state-wide epidemic control and suggests an urgent need to decentralize ART services through mobile clinics, community-based distribution, and rural facility upgrades.

Overall, the use of GIS significantly enhanced the understanding of the spatial dynamics of HIV/AIDS in the study area. It provided a multidimensional perspective that combined epidemiological and geographic data, enabling stakeholders to identify high-burden areas, service gaps, and demographic disparities with precision. The findings from this research underscore the importance of incorporating spatial analysis into routine public health surveillance and planning.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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