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Geospatial Analysis of HIV/AIDS Prevalence in Delta State, Nigeria Using GIS Technology

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Abstract:
This study applied Geographic Information System (GIS) technology to examine the spatial characteristics and distribution of HIV/AIDS prevalence across the twenty-five Local Government Areas (LGAs) in Delta State, Nigeria. Data were obtained from the National Agency for the Control of AIDS (NACA) and the 2006 census provided by the National Population Commission. Through spatial queries and map-based analyses using ArcGIS 10.2.1, patterns of infection and demographic associations were identified. The results revealed that HIV prevalence is disproportionately higher in urbanized areas such as Warri South, Warri North, and Sapele, likely due to socioeconomic factors associated with industrial activities. The GIS-based analysis enabled the visualization of disease hotspots and supported projections of future prevalence based on current trends. These findings underscore the relevance of geospatial techniques in public health monitoring, planning, and targeted intervention strategies.
Keywords: *HIV/AIDS Prevalence, Geographic Information System (GIS), Spatial Epidemiology, Delta State, Public Health Mapping*

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I. Introduction

The Human Immunodeficiency Virus (HIV), the causative agent of acquired immunodeficiency syndrome (AIDS), remains one of the most pervasive and impactful epidemics globally. Since its discovery in the early 1980s, HIV/AIDS has resulted in immense health, economic, and social burdens, particularly in sub-Saharan Africa (UNAIDS, 2023). The virus primarily attacks the immune system, rendering the host susceptible to opportunistic infections and certain malignancies, often culminating in death if untreated (Gallo, 2006). Although medical advances such as antiretroviral therapy (ART) have significantly improved life expectancy for infected individuals, the disease continues to pose a formidable public health challenge in low- and middle-income countries (WHO, 2022).

Nigeria is among the countries with the highest number of people living with HIV/AIDS. As of the latest national reports, approximately 1.9 million Nigerians are infected, with a prevalence rate of 1.3% among adults aged 15–49 years (NACA, 2021). The epidemiology of the virus in Nigeria is heterogeneous, with variation in prevalence among states, urban and rural areas, genders, and age groups (FMOH, 2021). Delta State, located in the oil-rich Niger Delta region, is one of the states with notable HIV prevalence, attributed to a complex interplay of socio-economic, cultural, and infrastructural factors (Iweze et al., 2019; Edewor, 2014).

Several studies have demonstrated that geographic patterns and human mobility significantly affect the spatial spread of HIV (Oppong & Harold, 2004; Gould, 1993). High population density, urbanization, and proximity to transport corridors are commonly associated with elevated HIV prevalence rates (Hogan et al., 2015; Larmarange et al., 2011). Urban centers such as Warri and Sapele in Delta State experience frequent human movement related to industrial and commercial activities, thereby contributing to increased transmission risk (Okonkwo & Oladipo, 2016). Additionally, stigmatization, gender inequality, and limited access to healthcare services exacerbate vulnerabilities, particularly among young women and key populations (Adebayo et al., 2020; Mberu et al., 2012).

To address these spatial and demographic disparities, Geographic Information Systems (GIS) provide a robust analytical framework for mapping, monitoring, and analyzing the distribution and determinants of HIV/AIDS (Tanser & Le Sueur, 2002). GIS facilitates the integration of epidemiological data with spatial variables, enabling visualization of hotspots, identification of vulnerable populations, and efficient resource allocation (Fraser et al., 2005; Adedayo & Bakare, 2018). Such spatially explicit health data offer essential insights for policy formulation, planning interventions, and measuring progress toward global targets such as the UNAIDS 95-95-95 strategy (UNAIDS, 2022).

The spatial diffusion of HIV/AIDS has been classified into distinct global patterns, notably AIDS North, AIDS South, and AIDS North/South, reflecting variations in transmission dynamics, affected populations, and regional responses (Wood, 1988). In the African context, heterosexual transmission remains the dominant mode, often interlinked with poverty, limited education, and cultural practices (Awoyemi & Olorunfemi, 2010; Awofala & Ogundele, 2018). In Nigeria, geographic disparities persist, necessitating localized studies that integrate spatial and epidemiological dimensions to better inform decision-making.

This study contributes to this growing body of literature by applying GIS-based spatial analysis to assess the prevalence and distribution of HIV/AIDS in Delta State. By incorporating population data, testing statistics, and treatment metrics, the research aims to develop a geospatial framework that supports the identification of high-risk areas and guides targeted intervention strategies. The approach adopted in this study builds on earlier works that emphasize the critical importance of "where" in understanding the "what" and "why" of epidemics (Shannon et al., 1991; Tanser et al., 2000).

II. Materials and Methods

2.1 Study Area

Delta State is located in the southern geopolitical zone of Nigeria, within the oil-rich Niger Delta region. It spans an estimated area of 17,698 square kilometers and shares boundaries with Edo State to the north and west, Anambra, Imo, and Rivers States to the east, and Bayelsa State to the south. The state lies approximately between latitudes 5°00′N and 6°30′N and longitudes 5°00′E and 6°45′E. As of the 2006 national census, the population was recorded at 4,112,445 people, distributed across twenty-five Local Government Areas (LGAs), including Warri South, Sapele, Ughelli North, and Oshimili South. The state is characterized by low-lying terrain, extensive river networks, and swampy coastal zones, which are integral to the Niger Delta ecosystem.

The socio-cultural landscape of Delta State is shaped by the presence of multiple ethnic groups, notably the Urhobo, Itsekiri, Ijaw, Isoko, and Igbo. These groups exhibit shared cultural traits such as traditional festivals, music, crafts, and religious practices. The urban centers, especially those engaged in oil and gas activities, such as Warri and Sapele, have experienced rapid growth and are associated with increased population density and higher social vulnerability, factors that are critical in understanding HIV/AIDS transmission dynamics within the state.

2.2 Data Sources

This study utilized both primary and secondary data sources. The HIV/AIDS prevalence data were sourced from sentinel surveillance reports conducted by the National Agency for the Control of AIDS (NACA) in partnership with the Federal Ministry of Health (FMOH). These reports contain disaggregated data on multiple indicators including total persons enrolled in HIV care, individuals currently on antiretroviral treatment (ART), number of HIV-positive pregnant women, and test results classified by sex and age cohorts.

Population data were obtained from the 2006 census conducted by the National Population Commission (NPC), which provided demographic figures for each LGA. These datasets were essential for normalizing HIV prevalence values and assessing disease burden relative to population size. Geospatial boundary data for Delta State and its LGAs were obtained in analog format from the Delta State Ministry of Lands and Surveys, which were subsequently digitized for geospatial analysis.

2.3 Hardware and Software Requirements

The geospatial and statistical analyses in this study were carried out using a combination of digital tools and computational hardware. A Hewlett-Packard (HP) Centrino Duo laptop with a processing speed of 2.2 GHz, 3 GB RAM, and 320 GB hard disk drive was used for all software installations and spatial data processing. The system supported full multimedia capabilities, essential for visualizing maps, graphs, and attribute tables.

For spatial data acquisition, a Garmin 76Xcs handheld Global Positioning System (GPS) device was used to collect coordinate reference points for geo-referencing physical features and validating map locations. An A0 flatbed scanner was employed to scan the analog administrative maps of Delta State to prepare them for on-screen digitization. A DeskJet 1280 printer was used for printing high-resolution map outputs and visual aids. These tools ensured that both the spatial and tabular datasets could be processed, analyzed, and presented with precision.

The primary software used for spatial analysis and map production was ArcGIS version 10.2.1, developed by Environmental Systems Research Institute (ESRI). The software was instrumental in digitizing boundaries, generating choropleth maps, and executing attribute-based queries. Attribute tables were managed and pre-processed using Microsoft Excel 2016, which facilitated the entry, cleaning, and formatting of HIV-related indicators. Microsoft Word 2016 was used for documentation and report writing. Multimedia applications were utilized to enhance visual presentations and integrate image-based data where necessary. The synergy between these software packages provided a comprehensive environment for geospatial epidemiological analysis.

2.5. Data Preparation and Processing

The first stage of data processing involved the conversion of analog administrative maps into digital format through scanning and geo-referencing. Using the Garmin GPS, reference coordinates were acquired and applied in ArcGIS to align the scanned images with the correct geographical projection system. The map of Delta State was digitized to delineate LGA boundaries, water bodies, and major settlement areas. Attribute tables were constructed in Microsoft Excel with columns representing LGA names, population sizes, and 21 distinct HIV indicators designated as CASE1 through CASE21.

The collected datasets were systematically compiled and organized using Microsoft Excel to facilitate subsequent geospatial analysis. Each entry in the spreadsheet corresponded to a specific Local Government Area (LGA) within Delta State, with columns designed to accommodate both demographic and epidemiological variables. The spreadsheet structure began with the identification of all twenty-five LGAs, followed by the inclusion of their respective population figures as recorded in the 2006 National Population Census. These demographic values provided the basis for computing prevalence rates and understanding population-adjusted disease burdens.

The HIV/AIDS-related indicators were encoded into twenty-one distinct categorical variables, labeled CASE1 through CASE21. These variables encapsulated a broad spectrum of surveillance metrics essential for a comprehensive assessment of the epidemic. CASE1 represented the cumulative number of individuals enrolled into HIV care since the inception of the national program, serving as a baseline indicator of long-term case accumulation. CASE2 accounted for the total number of individuals across all age groups currently receiving antiretroviral therapy (ART), thereby reflecting ongoing treatment engagement. CASE3 identified those newly enrolled individuals who commenced cotrimoxazole (CTX) prophylaxis within the reference month, indicating immediate intervention following diagnosis.

CASE4 recorded the total number of ART facilities operating within each LGA, providing an infrastructural dimension to the dataset. CASE5 captured the number of pregnant women with a previously confirmed HIV-positive status, whereas CASE6 detailed the number of HIV-positive pregnant women assessed for ART eligibility based on clinical staging criteria. CASE7 provided insight into vertical transmission prevention efforts by enumerating the number of HIV-exposed infants who received the first dose of nevirapine (NVP) prophylaxis.

Testing outcomes were disaggregated by age and sex across CASE8 to CASE20. CASE8, CASE9, and CASE10 referred to the number of HIV-negative females within the 0–19, 20–49, and 50+ age groups, respectively. Correspondingly, CASE11, CASE12, and CASE13 represented HIV-negative males within the same age brackets. CASE14 aggregated the total number of individuals who tested HIV-negative, irrespective of sex or age. On the other hand, CASE15 through CASE17 denoted HIV-positive females across the three defined age categories, while CASE18 through CASE20 recorded HIV-positive males. Finally, CASE21 represented the total number of individuals who tested HIV-positive, providing an overall summary indicator for each LGA.

Following the tabulation and verification of these variables, the structured dataset was imported into ArcGIS 10.2.1 for spatial processing and analysis. The GIS environment facilitated attribute-based queries, thematic mapping, and hotspot identification. This integration enabled the visualization of spatial heterogeneity in HIV prevalence and the detection of epidemiological trends across Delta State. The use of ArcGIS also supported the generation of choropleth maps, spatial overlays, and graphical outputs, thereby enhancing the interpretability of the surveillance data within a geographic framework.

2.6. Analytical Methods

Several attribute-based queries were conducted to interrogate the dataset and extract meaningful patterns. For instance, queries were constructed to identify LGAs with 500 or more individuals testing HIV positive (CASE21), and to isolate areas with high numbers of HIV-negative individuals among females and males aged 0–19 years (CASE8 and CASE11). These queries allowed for the detection of disease clusters and gender-specific disparities. Spatial distribution maps were created for each query result, and choropleth symbology was applied to visually differentiate LGAs based on their infection levels.

The normalized prevalence was computed by dividing HIV-positive counts by the total population of each LGA, thereby adjusting for population effects. Graphs and tables were also generated to complement the maps, enabling a comparative analysis across the entire state. The methodology facilitated spatial interpretation and helped derive relationships between population characteristics and HIV prevalence rates.

III.Results

3.1 Identification of Local Government Areas with High HIV Positivity Counts (CASE21 ≥ 500)

The first spatial query executed within the ArcGIS 10.2.1 environment was designed to isolate and identify Local Government Areas (LGAs) in Delta State where the number of individuals who tested HIV positive was equal to or greater than 500. This analysis was based on the CASE21 variable, which represents the total number of individuals confirmed to be HIV positive across each LGA. The threshold of 500 was selected to delineate high-burden areas and facilitate targeted spatial comparisons among the LGAs.

Upon executing the attribute-based selection query ("CASE21" ≥ 500), a subset of LGAs was extracted, representing zones of significant disease concentration. The results indicated that Warri South, Warri North, and Sapele were the most heavily affected LGAs, each reporting 845, 520, and 780 confirmed HIV-positive individuals respectively. These values positioned the three LGAs well above the selected threshold, highlighting them as epidemiological hotspots within the state.

The elevated prevalence in these LGAs is plausibly linked to the socio-economic dynamics of their urban environments. Warri South, for instance, is a major urban and commercial hub with a high concentration of oil and gas industries. These industrial zones attract a large influx of mobile workers, contractors, and informal sector participants, which, in turn, may stimulate behaviors that increase HIV transmission risk, such as transactional and unprotected sex. The presence of a transient and economically active population in these areas has been associated in multiple studies with higher HIV prevalence due to limited access to sustained healthcare, inconsistent condom use, and exposure to multiple sexual networks (Adebajo et al., 2003; Orubuloye et al., 1994).

Sapele and Warri North, while less urbanized than Warri South, also host significant industrial activities and port operations. The resulting socio-economic interactions, including commercial sex activities, further compound the risk environment. The spatial pattern revealed by the query corroborates the hypothesis that urbanization and industrial presence correlate positively with heightened HIV prevalence.

The result was further visualized using a bar chart to depict the comparative magnitude of HIV-positive cases across the selected LGAs, enabling clearer interpretation for public health planning. The map output, presented as Figure 1, also illustrates the spatial distribution of the identified high-prevalence LGAs within the broader context of Delta State. These findings provide a spatially informed basis for deploying focused interventions, such as intensified awareness campaigns, expanded HIV testing services, and improved accessibility to antiretroviral therapy in the most affected LGAs.

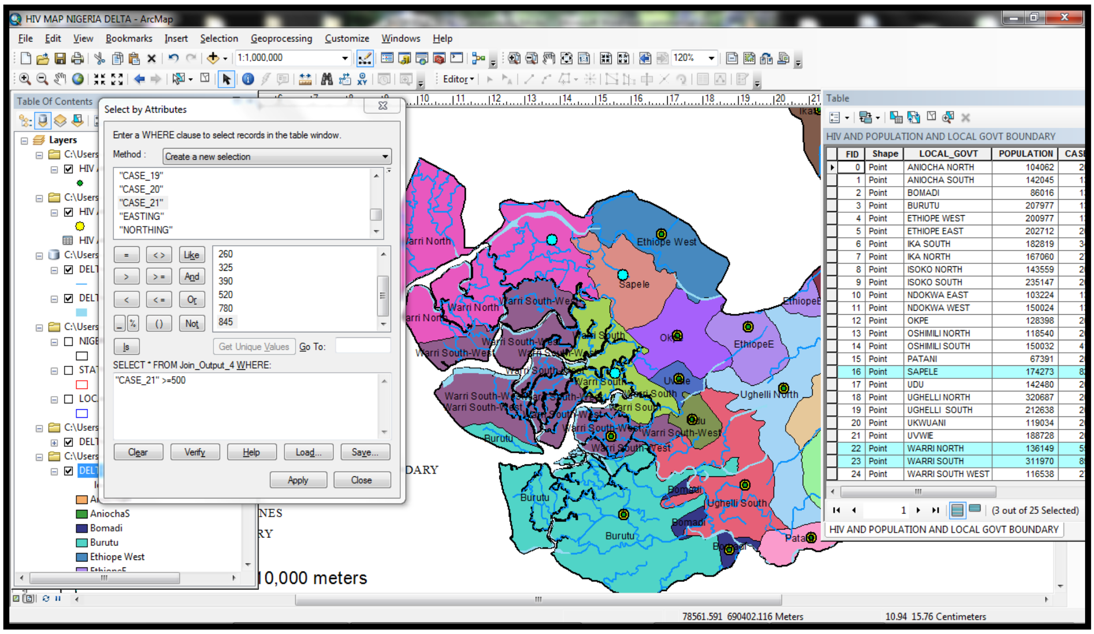

Figure 1: Showing the areas with highest Persons Tested HIV Positive that is Equal or Above 500 Persons.

3.2 Identification of the LGA with the Highest Number of HIV Positive Individuals

The second spatial query conducted within the ArcGIS 10.2.1 environment was aimed at pinpointing the specific Local Government Area (LGA) with the highest absolute number of individuals who tested HIV positive in Delta State. This query also relied on the CASE21 variable, which captures the cumulative count of confirmed HIV-positive cases across all twenty-five LGAs in the state.

Upon execution of the selection query that ranked LGAs by descending order of CASE21 values, Warri South emerged as the LGA with the single highest number of HIV-positive individuals, reporting a total of 845 confirmed cases. This value not only exceeded the 500-case threshold used in the first query but also stood out significantly from all other LGAs, including Sapele (780 cases) and Warri North (520 cases), which were the next closest in prevalence, see figure 2.

The epidemiological prominence of Warri South in this context can be explained through its unique socio-economic characteristics. Warri South is a densely populated urban LGA and serves as a nucleus of industrial and commercial activity within Delta State. It hosts a concentration of oil refineries, seaport operations, and a large number of corporate and informal sector establishments. The presence of these facilities has led to substantial labor migration, resulting in a transient and economically mobile population.

Empirical studies have shown that such economic hubs often exhibit higher rates of HIV transmission due to a confluence of risk factors. These include increased engagement in transactional sex, multiple concurrent partnerships, limited access to sustained healthcare services, and social dislocation among migrant workers (Awofala & Ogundele, 2018; Orubuloye et al., 1994). The commercial sex industry, which often thrives in regions experiencing high male-dominated migration for industrial labor, also contributes to elevated HIV prevalence due to inconsistent condom usage and high partner turnover (UNAIDS, 2022; Larmarange et al., 2011).

Furthermore, urban anonymity, which provides a level of detachment from community-based stigma, may encourage risky sexual behavior. The spatial analysis reinforces the assertion that Warri South represents a critical point of concern in the geospatial distribution of HIV/AIDS within Delta State. By identifying it as the most heavily burdened LGA, the results of this query underscore the necessity for geographically targeted interventions such as intensified voluntary counseling and testing (VCT), behavioral change communication, and expansion of treatment facilities.

The result also serves as a guide for state-level health authorities to prioritize Warri South in resource allocation, public health messaging, and mobile outreach programs. These data-driven strategies can significantly contribute to flattening the curve of HIV transmission in high-risk urban centers. A corresponding map and bar chart visualization of this query provides a spatial and comparative representation of the epidemiological burden concentrated in Warri South, further validating its status as the epicenter of the HIV/AIDS challenge in Delta State.

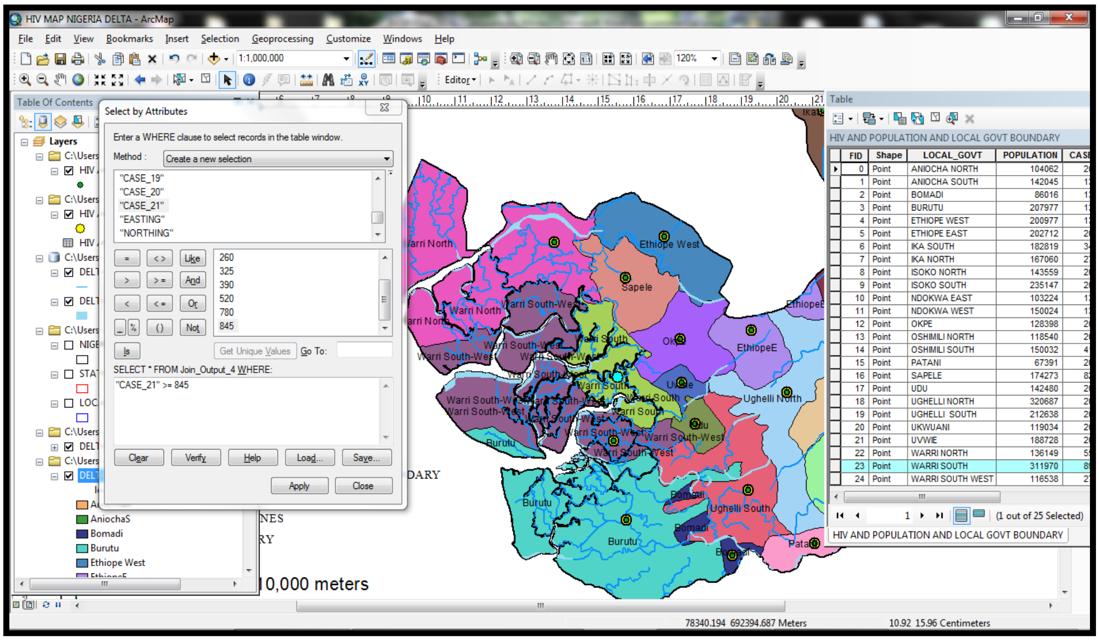

Figure 2: showing the Query for the Local Government Area with the Highest Number of HIV Positive Individuals.

3.3 Identification of LGAs with High Numbers of HIV-Negative Individuals Aged 0–19 by Sex (CASE8 and CASE11 ≥ 500)

The third spatial analysis focused on the distribution of HIV-negative individuals within the vulnerable youth demographic, specifically those aged 0 to 19 years. This assessment was disaggregated by sex using the CASE8 and CASE11 variables. CASE8 corresponds to the number of females aged 0–19 who tested HIV negative, while CASE11 records the number of HIV-negative males within the same age bracket. The purpose of this query was to detect LGAs where a relatively high number (≥ 500) of youths tested negative for HIV, thus serving as a proxy for areas with either better testing coverage or potentially lower transmission rates among adolescents.

The attribute-based queries (CASE8 ≥ 500 and CASE11 ≥ 500) were independently applied to the dataset. The results revealed a common set of LGAs where the youth population (both female and male) demonstrated relatively high HIV-negative counts. These LGAs included Ika North, Ika South, Sapele, Oshimili South, Warri North, Warri South, and Warri South West. In each of these locations, both the female and male 0–19 age group returned 500 or more HIV-negative results.

This trend may suggest the effectiveness of local HIV prevention campaigns, increased access to voluntary counseling and testing (VCT) services, and positive behavioral outcomes among adolescents. In regions like Oshimili South and Ika South, for instance, the presence of multiple secondary and tertiary educational institutions may contribute to greater awareness and utilization of testing services by adolescents. Additionally, these LGAs are relatively urbanized, which may imply better access to healthcare facilities and information dissemination platforms such as radio, community health campaigns, and school-based outreach programs (FMOH, 2021; Adebayo et al., 2020).

The relatively high numbers of HIV-negative youth in these areas also open up strategic opportunities for prevention interventions. These LGAs can serve as model zones for replicating successful youth-centered HIV prevention strategies, such as comprehensive sexuality education, youth-friendly testing centers, and peer educator networks. Conversely, the data also reflect the need for continued surveillance to ensure that the status of HIV-negative individuals is maintained through sustained outreach and follow-up.

It is important to note that these figures alone do not necessarily imply lower incidence or risk. A high count of negative results could also be indicative of proactive testing campaigns rather than lower transmission. Therefore, while the data are promising, they should be interpreted in conjunction with broader behavioral and epidemiological factors such as awareness levels, condom use, and retention in prevention programs (UNAIDS, 2022; Tanser & Le Sueur, 2002).

Figures 3 and 4 present the mapped spatial distribution of HIV-negative female and male individuals aged 0–19, respectively. These maps clearly highlight clusters of LGAs exceeding the 500-count threshold, and they underscore the potential for reinforcing youth-focused HIV interventions in those areas. This third query therefore adds an important demographic dimension to the spatial epidemiological profile of Delta State by shifting focus from prevalence to prevention potential among adolescents.

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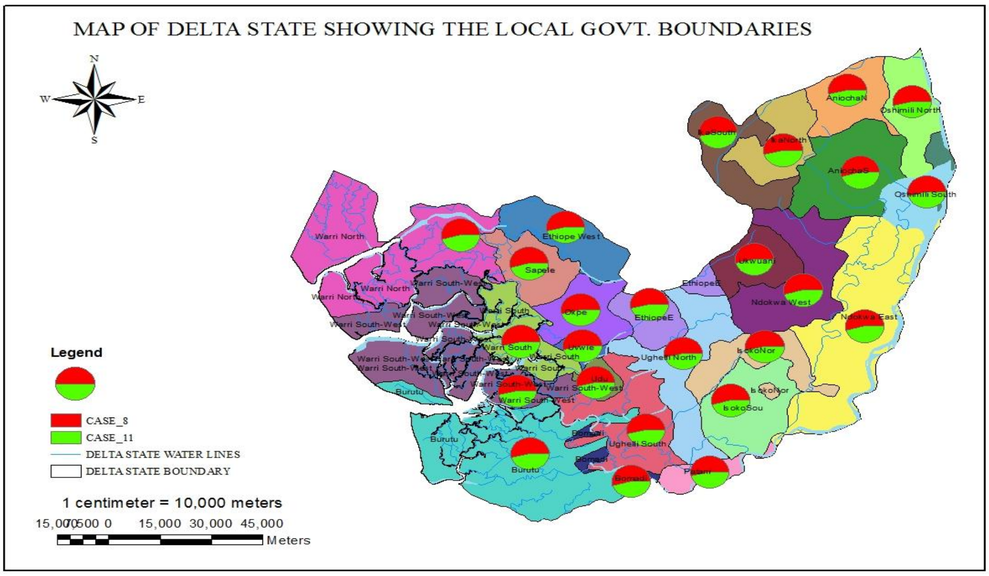

Figure 3: Showing (case 8) females Tested Negative Between (0-19) and (case 11) Males Tested Negative Between (0-19).

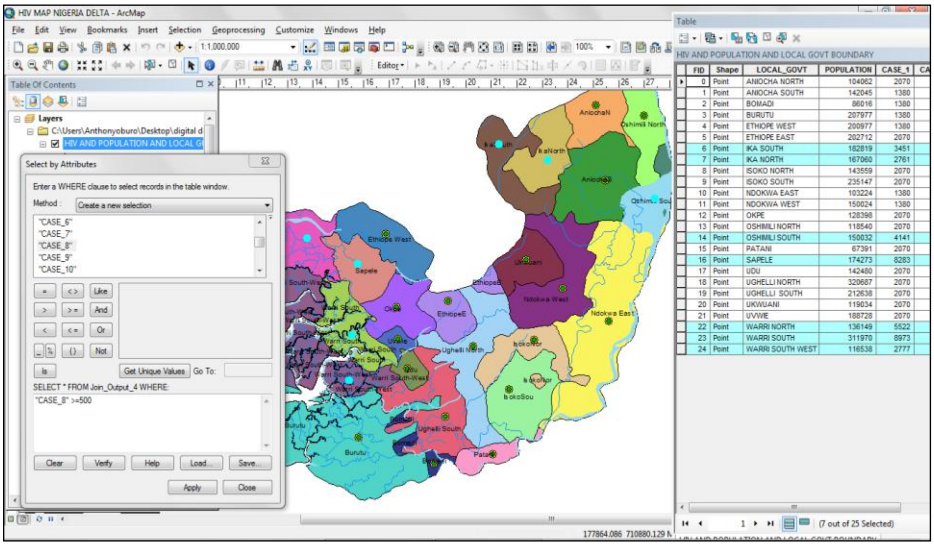

figure 4: showing (case 8) Females Tested Negative Between (0-19) Above or Equal to 500 Persons

The application of Geographic Information System (GIS) technology in this study has effectively facilitated the spatial monitoring of HIV/AIDS prevalence across Delta State. By integrating georeferenced epidemiological data with administrative boundaries, GIS enabled a comprehensive visual representation of how the epidemic has evolved within each of the twenty-five Local Government Areas (LGAs) over the period under review. The spatial models developed using ArcGIS 10.2.1 provided the analytical capacity to detect both geographical disparities and temporal patterns in HIV transmission that would otherwise remain obscured in aggregate national-level statistics.

Figures 1 through 4 illustrate a series of spatial queries designed to highlight key epidemiological features, including total HIV-positive counts, high-risk zones, and demographic subgroups. These spatial outputs underscore the functionality of GIS as a decision-support tool in public health. Specifically, the platform facilitated the identification of LGAs with disproportionately high caseloads, such as Warri South, Sapele, and Warri North, which emerged as disease epicentres based on the CASE21 variable representing total HIV-positive individuals. Such spatial delineation allows for targeted interventions, resource prioritization, and localized program implementation.

The data used in this analysis originated from sentinel surveillance surveys conducted by the National Agency for the Control of AIDS (NACA) in conjunction with the Federal Ministry of Health (FMOH). The spatial integration of these datasets into GIS models permitted not only descriptive mapping but also the detection of micro-level trends across LGAs. The resulting geospatial outputs revealed clear urban-rural disparities in prevalence rates, with urban centers exhibiting higher case densities. This urban concentration aligns with established epidemiological theory, which posits that urbanization, economic migration, and commercial activity are significant drivers of HIV transmission due to increased population mixing, risky sexual behavior, and ease of virus propagation through dense social networks (Awofala & Ogundele, 2018; UNAIDS, 2022).

Importantly, the use of GIS introduced a dynamic spatial-temporal lens to HIV monitoring. While national surveillance systems often report cumulative statistics without spatial specificity, the GIS approach adopted in this study enabled disaggregation by both space and demographic category. This provided a nuanced understanding of how the epidemic is distributed, which age-sex groups are most affected, and which LGAs exhibit the highest vulnerability or resilience. Through map-based visualization, health authorities can now observe the heterogeneity of disease burden and respond with geographically tailored strategies.

Moreover, the spatial models generated from this study are not only retrospective but also predictive. By analyzing current trends in prevalence and overlaying them with demographic data, GIS allowed for short-term projections of potential future burden areas assuming current transmission dynamics persist. This capacity for anticipatory modeling is invaluable in designing proactive interventions, forecasting demand for antiretroviral therapy (ART), and allocating human and financial resources in a rational and evidence-based manner.

The projections and spatial patterns identified have broader implications for national and subnational HIV/AIDS policy formulation. They serve as empirical evidence to support the integration of spatial data analytics into existing surveillance frameworks. Additionally, these findings may inform global partners, such as UNAIDS and the World Health Organization (WHO), on the need for geospatial precision in HIV response planning, especially in resource-limited settings such as Delta State.

Overall, the results indicate that HIV/AIDS in Delta State is not uniformly distributed but rather exhibits pronounced clustering in urbanized LGAs. These insights call for a recalibration of intervention efforts to ensure that the most affected areas receive commensurate attention. The utility of GIS in achieving these outcomes is evident, and its continued integration into public health monitoring systems is strongly recommended.

IV.Conclusion

This study has demonstrated the significant potential of Geographic Information Systems (GIS) in the spatial monitoring and analysis of HIV/AIDS prevalence across Delta State, Nigeria. By integrating epidemiological surveillance data with geospatial mapping techniques, the study identified distinct spatial variations in disease distribution, revealing that the burden of HIV/AIDS is disproportionately concentrated in urban and industrialized LGAs such as Warri South, Sapele, and Warri North. These areas exhibited high numbers of HIV-positive individuals, a pattern that correlates with socio-economic dynamics, including increased mobility, transactional sex, and population density associated with oil and gas activities.

The use of disaggregated indicators, such as CASE21 for total HIV-positive cases and CASE8 and CASE11 for HIV-negative youth by sex, enabled detailed assessments of both disease burden and prevention landscapes across the 0–19 age demographic. These findings highlight spatially embedded risks and opportunities for public health interventions. The ability of GIS to visualize and quantify these spatial relationships offers a more localized and data-driven foundation for strategic planning, surveillance, and policy implementation.

Through spatial queries and thematic mapping, the study confirmed that GIS can not only describe current disease patterns but also support short-term projections based on prevailing trends. The resulting insights enable health authorities to optimize the allocation of limited resources, prioritize high-risk LGAs for intervention, and tailor HIV prevention and treatment strategies to specific demographic and geographic contexts.

Furthermore, the study underlines the value of building institutional capacity in geospatial technologies to strengthen epidemiological surveillance systems. As HIV/AIDS remains a pressing public health concern in Nigeria, integrating GIS into routine monitoring frameworks can enhance the responsiveness and effectiveness of national and state-level health programs.

The results presented serve as a baseline for future geospatial health studies in the region and call for continuous data collection, validation, and the development of spatially explicit models to inform a more targeted and efficient response to the HIV/AIDS epidemic.

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