Mapping HIV Vulnerability: The Role of PrEP Accessibility and Economic Inequality in Atlanta, Georgia

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Abstract

We quantify how transit-based access to pre-exposure prophylaxis (PrEP) aligns with socioeconomic disadvantage to shape HIV vulnerability in metropolitan Atlanta, Georgia, USA. Using ZIP code–level HIV prevalence and poverty data with multimodal travel times, we estimate transit-based accessibility via the enhanced two-step floating catchment area (E2SFCA) method, visualize joint patterns with bivariate choropleths, and synthesize the results into a 0–1 HIV Vulnerability Index (HVI). Accessibility peaks in the urban core and declines toward the southwest, where low PrEP access co-occurs with higher HIV burden and poverty. The HVI highlights contiguous high-vulnerability clusters south–southwest of the core and a smaller cluster to the east. Our findings support transit-aligned strategies—bringing PrEP to communities with mobile clinics, bridging first–last-mile gaps, and locating providers near frequent transit—to reduce travel burdens in priority neighborhoods and advance Ending the HIV Epidemic goals in the U.S.

CCS Concepts

• **Human-centered computing → Geographic visualization**; • **Information systems → Geographic information systems**; • **Applied computing → Health informatics**.

Keywords

HIV, spatial accessibility, pre-exposure prophylaxis, disparity, mapping, HIV vulnerability index, bivariate map

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1 Introduction

HIV is a global public health concern. As of 2022, an estimated 1.2 million people in the United States were living with HIV. An estimated 31,800 people in the United States became newly infected with HIV in 2022, which represents a 12% decrease since 2018 when the number of new infections was 36,200 [10]. To help speed efforts to end the HIV epidemic in the United States, the federal government released an updated National HIV/AIDS Strategy and the Ending the HIV Epidemic (EHE) initiative. The EHE initiative aims to reduce new infections by 75% by 2025 and by 90% by 2030, and to advance equity for HIV prevention and care [3]. Despite these national efforts, HIV continues to disproportionately affect the U.S. South. In 2021, the South was the location of 52% of new infections, despite accounting for only 38% of the U.S. population [1, 16]. This geographic and structural inequity demonstrates that the barriers to prevention and care that exist in the South need **to** be addressed if the goals of the EHE are to be realized nationally.

Pre-exposure prophylaxis (PrEP), a preventive medication that can reduce the risk of HIV infection by up to 99% if taken consistently [2, 3, 9], is a cornerstone of HIV prevention. Because of its efficacy, expanding PrEP uptake among populations at elevated risk is a national and local-level priority for HIV prevention. However, well-established disparities in PrEP access, due to geographic, socioeconomic, and structural factors, persist and limit its reach and impact [11, 12, 18]. Ensuring that PrEP providers are equitably spatially accessible to populations at elevated risk of HIV infection is an important for closing these prevention gaps. This is particularly true in Southern metros, which experience some of the highest rates of HIV prevalence.

The Atlanta metropolitan area serves as an illustrative example. Atlanta is one of the 57 EHE priority jurisdictions, where there is a disproportionate HIV burden and a range of intersecting racial, socioeconomic, and geographic disparities in health outcomes [5]. Therefore, examining spatial accessibility to PrEP in this jurisdiction is essential to support local intervention efforts, as well as to draw lessons for similar prevention challenges elsewhere in the South. Spatial accessibility to HIV care services has previously been investigated in the Atlanta area; for instance, Dasgupta et al. [5, 6] measured accessibility by private and public transportation and identified vulnerable areas with low clinic access and high HIV case counts, particularly in high-poverty communities. However, those studies used HIV case data only through 2011.

In this study, we build on this prior work by updating the HIV prevalence data through 2021 and by introducing an HIV Vulnerability Index that combines spatial accessibility to PrEP providers, HIV prevalence, and poverty levels. Unlike previous studies, we used bivariate mapping techniques, as well as a composite HIV vulnerability index, to more comprehensively characterize the geographic distribution of HIV burden, PrEP accessibility, and social disadvantage across the Atlanta's metropolitan area.

2 Methods

2.1 Study Area and Data

The study area is the Greater Atlanta Area, for which data on HIV prevalence rates and the percentage of people living in poverty were obtained at the ZIP code level from AIDSVu (aidsvu.org). The locations of PrEP service providers were also extracted from the same source through web crawling and subsequently geocoded for mapping.

2.2 Measuring Spatial Accessibility

Spatial accessibility has been quantified in many studies using two-step floating catchment area (2SFCA) method and enhanced two-step floating catchment area (E2SFCA) method, which incorporate the supply of health care providers and population demand with a predefined travel time or distance threshold [15]. They have also been applied to HIV related services such as spatial access to PrEP providers in large metropolitan areas like Chicago and New York City [12, 14]. In this study, we use E2SFCA method to measure spatial access to PrEP providers in the Atlanta metropolitan area.

The enhanced two-step floating catchment area (E2SFCA) method consists of two steps:

(1) **Provider-to-population ratio.** For each PrEP provider, define a travel-time catchment (e.g., within a maximum threshold T minutes). Compute the ratio of provider capacity to the local demand population (ages 16+) inside the catchment, applying a distance-decay weight to down-weight residents farther from the provider.
(2) **Accessibility aggregation.** For each demand location (ZIP code population centroid), sum the distance-decay–weighted provider ratios for all providers reachable within T. This yields an overall accessibility score that increases with greater nearby capacity and shorter travel times.

Travel times between each demand location and PrEP provider were estimated using public transit (bus and metro). Existing work has found that HIV prevalence is particularly high among persons living in poverty/unemployment, a population less likely to own a car and, as a result, needs to rely on public transit–making transportation a key social determinant of care [6, 7]. To account for this, travel times between each demand location and PrEP provider site were estimated using the R5 routing engine (implemented in Python) that allows for the computation of multimodal travel-time by public transit. This estimation approach allows for a more comprehensive measure of PrEP access that accounts for not just provider and population supply/demand, but the spatial and transportation barriers individuals face when accessing care.

2.3 Visual Analytics: Bivariate Mapping

We employed bivariate choropleth mapping as a visual analytics tool which allowed us to visually explore and compare two values at the same time by using a color scheme that represents the combination of two variables, PrEP Accessibility Scores and either HIV prevalence or a measure of socioeconomic status like poverty. We used this type of map to identify areas of overlapping low PrEP accessibility and high HIV prevalence/poverty to identify communities that are disproportionately affected by HIV.

2.4 Inequity Index: Composite Vulnerability Measure

To further quantify inequalities in HIV infection and care, we developed a **HIV Vulnerability Index (HVI)**—a composite indicator that summarizes multiple risk dimensions into a single score for each spatial unit (e.g., county, ZIP code, or census tract). The HVI provides an integrated measure of community vulnerability by capturing social, structural, and epidemiological factors that contribute to HIV risk.

Prior research has shown that individuals with poor accessibility to PrEP providers are more likely to develop HIV-related symptoms or contract the virus [17]. Economic disadvantage further compounds this risk, as poverty limits both preventive and treatment opportunities [13]. Building on this evidence, we constructed the HVI using three primary dimensions: (1) **social disadvantage** measured by poverty rate, (2) **structural barriers** represented by spatial accessibility to PrEP providers, and (3) **epidemiological burden** captured through HIV prevalence rates.

All input variables were normalized to a common scale (0–1) to enable meaningful combination. The index was constructed such that higher poverty, lower accessibility, and higher HIV prevalence each contribute to greater vulnerability. Accessibility values were inverted to reflect that limited or more difficult access to services increases vulnerability. These components were then combined with adjustable weights to allow flexibility in emphasizing particular factors:

$$\mathrm{HVI} = w_p \cdot poverty \; + \; w_a \cdot (1 - access) \; + \; w_i \cdot incidence,$$

where w_p, w_a, and w_i are the weights for poverty, accessibility, and incidence, respectively (default = 0.33 each). By design, a higher HVI corresponds to greater vulnerability.

Interpretation of the HVI is straightforward. Values near 0 indicate relatively low vulnerability, reflecting areas with low poverty, strong accessibility to PrEP, and low HIV prevalence. In contrast, values approaching 1 indicate high vulnerability, where high poverty, poor accessibility, and high HIV burden converge. As a relative measure, the HVI facilitates systematic comparisons of HIV vulnerability across geographic units, allowing identification of clusters of communities at disproportionate risk.

3 Results

3.1 Spatial Accessibility by Public Transportation Mode

Figure 1 maps transit-based accessibility to PrEP providers using the enhanced two-step floating catchment area (E2SFCA) method, with provider locations overlaid. Darker blues indicate higher accessibility; lighter tones indicate lower accessibility; gray denotes

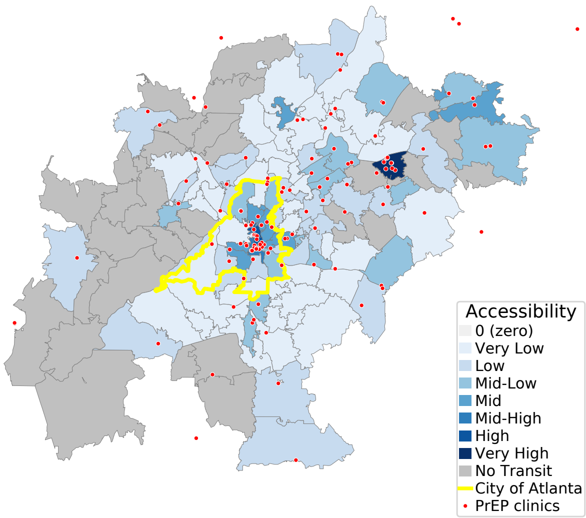

Figure 1: Accessibility to PrEP providers by public transit

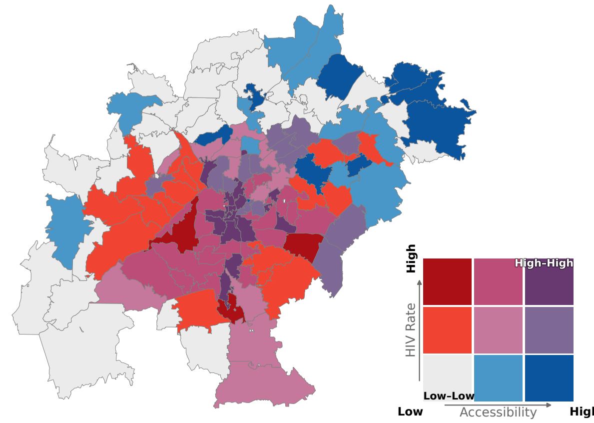

Figure 2: Bivariate Map: Accessibility × HIV Prevalence

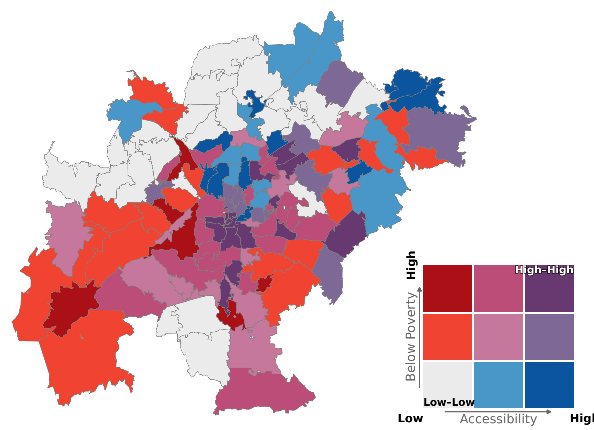

Figure 3: Bivariate Map: Accessibility × Below Poverty

areas lacking fixed-route bus or rail service. Accessibility peaks in Atlanta's core—where MARTA rail lines converge and bus routes are densest and most frequent—and declines with distance as route density thins, headways lengthen, and transfers and first–last-mile costs accumulate. This drop is especially pronounced in the southwestern suburbs, where large contiguous "no-transit" zones coincide with sparse provider locations, producing long and complex transit journeys to limited care options. By contrast, portions of the northeastern suburban corridor maintain moderate to high accessibility because arterial bus routes connect efficiently to the rail spine and PrEP providers cluster near medical and employment centers; notably, ZIP 30046 (Lawrenceville) forms a high-access cluster. Together, these patterns reflect a spatial mismatch co-produced by transit supply (coverage, frequency, connectivity) and healthcare supply (provider siting), reinforced by lower-density land use and historical underinvestment in the southwest.

3.2 Bivariate Mapping of Transit Access, HIV Burden, and Poverty

To examine how spatial accessibility intersects with epidemiological and socioeconomic need, we produced bivariate choropleth maps. Each variable was discretized into three quantile-based classes (low, medium, high), yielding a 3×3 grid of nine color blends. This design highlights neighborhoods where *low* PrEP accessibility coincides with *high* HIV prevalence or *high* poverty, as well as the converse combinations.

Accessibility × HIV Prevalence. Figure 2 displays the joint distribution of PrEP accessibility (by public transit) and HIV prevalence. The most concerning pattern is the concentration of **low-access/high-prevalence** neighborhoods in the southwestern periphery, overlapping known HIV hotspots, indicating compounded barriers to prevention and care. In contrast, the Atlanta city core shows **high-access/high-prevalence** cells (purple), consistent with a dense transit network but persistent disease burden. Northern and eastern outer areas contain scattered **high-access/low-prevalence** cells (blue), suggesting relatively favorable conditions for reaching HIV care where demand pressure is lower.

Accessibility × Poverty. The bivariate map for PrEP accessibility and the percentage of residents living below the federal poverty threshold (Figure 3) reveals a broadly similar geography: **low-access/high-poverty** clusters are again most prevalent along the southwest corridor, whereas **high-access/low-poverty** combinations appear more frequently in northern and eastern suburbs. This resemblance is consistent with the significant spatial association between HIV burden and poverty that we quantified using the global bivariate Moran's I ($I = 0.453$, $p = 0.001$), indicating that ZIP codes with higher HIV prevalence tend to be situated adjacent to higher-poverty ZIP codes.

3.3 HIV Vulnerability Index (HVI): Integrating Access, Poverty, and Burden

Figure 4 presents the HIV Vulnerability Index (HVI), a composite, unitless score scaled from 0 to 1 that summarizes *epidemiological burden* (HIV prevalence), *socioeconomic disadvantage* (poverty), and *structural barriers* (transit-based PrEP accessibility) into a single measure of place-based vulnerability. Composite indices of this form are widely used in hazards and health geography to synthesize multiple risk dimensions for screening and prioritization [4, 8]. As detailed in the Methods, inputs were normalized to a common 0–1 range and combined via a weighted additive scheme; thus, values

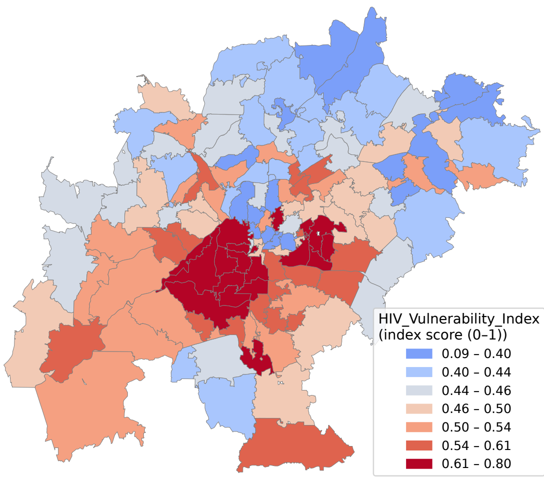

Figure 4: HIV Vulnerability Mapping using HIV Vulnerability Index (HVI)

near 0 indicate relatively low vulnerability (low poverty, strong access to PrEP, low HIV prevalence), whereas values approaching 1 indicate high vulnerability where these disadvantages converge. As a *relative* measure, the HVI enables rank-ordering and detection of spatial concentrations of risk. The map reveals a contiguous cluster of elevated vulnerability (HVI $\gtrsim$ 0.6) across the southwestern arc immediately south–southwest of the Atlanta core, with a smaller but similar high-risk cluster to the east of the core. In contrast, many northern and eastern peripheral ZIP codes display comparatively lower HVI values. These patterns are consistent with the bivariate results reported above—specifically, the co-location of low transit access with higher poverty and HIV burden

4 Conclusion and Implications

We integrated three disparate measures—transit-based spatial accessibility, socioeconomic disadvantage, and epidemiologic burden—to identify neighborhoods most vulnerable to HIV in the Atlanta metro region. By applying the E2SFCA method with public transit travel times, bivariate choropleth mapping, and an HIV Vulnerability Index (HVI), we demonstrate a clear spatial pattern: areas with limited PrEP access often coincide with areas of high poverty and high HIV prevalence (notably in an arc-like pattern along the southwestern edge of the study area), in contrast to the Atlanta city core, which exhibits high HIV prevalence despite relatively better PrEP access. Although high HIV prevalence may not result directly from limited PrEP access or poverty, their co-occurrence highlights neighborhoods where overlapping vulnerabilities may exacerbate the public health burden of HIV.

The findings point to concrete, geographically targeted actions that local health departments, transit agencies, and community partners can implement to advance the goals of Ending the HIV Epidemic (EHE). One strategy is to bring services directly to high-HVI clusters by deploying mobile or community-based PrEP programs, pop-up clinics, and pharmacy-based PrEP initiation, as well as fostering partnerships with Federally Qualified Health Centers (FQHCs)—community-based clinics that provide comprehensive primary care regardless of patients' ability to pay—and other local clinics in the southwest corridor and the eastern cluster. Another priority is reducing travel-time and first–last-mile barriers by coordinating clinic hours with transit schedules, piloting microtransit or demand-responsive shuttles to connect neighborhoods with bus and rail networks, and offering transit fare support for PrEP visits. Finally, co-siting and network design can be optimized by prioritizing new provider locations near high-frequency transit nodes and major employment or medical centers, while using scenario analysis with the HVI as a targeting layer to evaluate where added capacity would generate the greatest accessibility gains.

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