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Spatio-temporal trends and forecasting of HIV Positivity rates at district level in the Amhara Region, Ethiopia

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Abstract

Background: Human Immunodeficiency Virus remains a significant global public health challenge, despite decades of hard work and remarkable scientific advances in prevention, diagnosis and antiretroviral therapy, the declines in numbers at the end of 2024 were not sufficient to end AIDS as a public health threat by 2030. Health systems disruptions, political and economic instability, and loss of social networks are common aspects of humanitarian crises that can contribute to a person's vulnerability to HIV infection. The current study aims to generate evidence by analysing district level spatio-temporal trends and forecast HIV positivity rate through 2030 in the Amhara region, Ethiopia.

Methods: A retrospective ecological study was conducted to investigate the spatio-temporal distribution of HIV positivity rate in the Amhara region from 2016 to 2024 using data from DHIS2, PHEM and SGBV. Spatial autocorrelation analysis, Hot spot analysis, Heat mapping, Neural network machine learning and exponential smoothing forecasting were performed.

Results: Analysis from the complementary datasets revealed temporal differences and geographic heterogeneity in HIV positivity rate during relative stable and conflict conditions. Analysis of a regional nine years DHIS2 data base revealed a clear pattern of initial rise, sustained decline, and subsequent resurgence of HIV positivity rates per 1,000 population in the Amhara region. In addition, analysis from SGBV program database and PHEM surveillance data further supports the presence of high HIV positivity rate within particularly vulnerable populations and a rapidly increasing number of newly identified HIV-positive cases respectively. Testing volume, conflict and year are predictors influencing HIV positivity rate and forecast analysis predicted HIV positivity rate in the Amhara region is expected to remain relatively at around 5% through 2030.

Conclusion: The Amhara region demonstrates substantial spatio-temporal heterogeneity in HIV positivity rate. Strengthening conflict-sensitive HIV programming including intensive support for high-burden District and reinforcing surveillance in low-burden areas are essential. Targeted, resilient interventions are urgently needed to help the region realign with national and global HIV elimination targets.

Keywords: *Amhara, DHIS2, Ethiopia, HIV, Rate, spatial, temporal*

Introduction

Human Immunodeficiency Virus (HIV) remains a significant global public health challenge, in spite of decades of hard work and remarkable scientific advances in prevention, diagnosis and antiretroviral therapy (ART) reduced the annual numbers of people acquiring HIV and dying from AIDS-related causes. However, at the end of 2024, the declines in numbers were not sufficient to end AIDS as a public health threat by 2030 (1) (2). Since the beginning of the epidemic, approximately 88.4 million people have been infected with HIV and about 42.3 million have died from AIDS-related illnesses (1) (2) (3). An estimated 40.8 million people were living with HIV, 630,000 died of HIV and 1.3 million people acquired HIV in 2024 (2), that is 40% less than in 2010 and the African region continues to bear 65% of people living with HIV and 50% new HIV infections (4) (5). A 56% decline in the number of new infections was achieved in sub-Saharan Africa, which is home to half of all people who acquired HIV globally in 2024 and some countries, from sub-Saharan Africa, were on track to achieve a 90% decline in new infections by 2030 compared with 2010 (6).

The Ethiopia Public Health Institute (EPHI) HIV-related estimates for 2024 showed, about 598,888 people were living with HIV, with 9,356 annual AIDS-related deaths and 7,255 new infections (5) (7). In the Amhara Region, the EPHI estimate for 2024 indicated approximately 171,308 people were living with HIV, with 2,271 annual AIDS-related deaths and 1,346 new infections (8). HIV test positivity rates in Amhara have fluctuated over time in year-based assessments, reflecting variations in transmission dynamics, testing uptake, case detection strategies, and program performance (7) (9). This temporal variability underscores the importance of continuous monitoring and data-driven planning at subnational levels.

Health systems disruptions, political and economic instability, and loss of social networks are common aspects of humanitarian crises that can contribute to a person's vulnerability to HIV infection (10) (11) (12) (13). In conflict settings, testing for HIV among those at risk for infection and maintaining adherence to ART may undertake lower priority than securing more urgent and basic needs such as food and shelter (14) (15). The use of alcohol and/or drugs as coping strategies may further increase the risk of HIV infection (16). Yet, evidence on the direction and scale to which humanitarian crises affect the epidemiology of HIV is often context-specific (12) (17) (18) (19). The occurrence of HIV might fluctuate before, during, and after times of conflict (18) (20)

(21). Previous research studies suggested that the good flow of humanitarian aid, and limited population mobility during conflict may slow the spread of HIV (18) (20). On the other hand, factors such as exposure to conflict-related traumatic events can increase HIV risk at the individual level during all stages of conflict (10) (18).

A recent external fund assistance limited by the United States, and conflict settings can worsen HIV vulnerability by increasing exposure to sexual violence, disrupting prevention and testing services, interrupting ART adherence, and weakening overall health system functionality that suggest without timely replacement of these funds, SSA could experience increases in HIV incidence and AIDS-related mortality, potentially reversing decades of progress (22). The United Nations programs on HIV/AIDS (UNAIDS) projections show that a withdrawal of support from the United States President's Emergency Plan for AIDS Relief (PEPFAR) for HIV treatment and prevention could lead to more than 4 million additional AIDS-related deaths and more than 6 million additional new HIV infections by 2030 (4) (6).

A UNAIDS report in 2025 showed that Ethiopia was on path to reach the three 95 targets (5). Though, this progress is at risk due to limited foreign assistance, which provides a significant portion of HIV funding in the country (23). In regions such as Amhara, where instability has affected health service delivery, these factors may challenge recent gains and further contribute to spatial and temporal disparities in HIV outcomes.

Furthermore, the period from 2020 and onwards has been marked by complex emergencies in northern Ethiopia, including the Amhara region, resulting in displacement, disruption of health services, and increased risk of HIV transmission that can aggravate HIV vulnerability by exposing populations to sexual violence, reducing access to HIV prevention and care services, and interrupting ART adherence (24) (25) (26) (27).

Recent studies in Northern Ethiopia indicated that HIV prevalence doubled following the onset of the conflict that further indicates HIV seropositivity exhibits spatial dependency that highlight the need for geospatial and spatiotemporal analyses to better understand localized transmission dynamics and to guide targeted interventions, particularly in high-burden district and vulnerable communities (9) (28).

Given the increasing number of people affected by humanitarian crises globally, the goal of reducing new HIV infections by 90% by 2030 (2) (3) (6), and the complexity of addressing HIV in humanitarian settings (12) (19), understanding district-level HIV positivity trends over time provides a critical opportunity to identify persistent hotspots, emerging high-burden areas, and temporal shifts associated with conflict, service disruptions, and recovery phases. Spatio-temporal analysis enables more precise targeting of prevention, testing, and treatment interventions. In a context of constrained resources and increasing uncertainty in external financing, up to date evidence is essential for optimizing programmatic decision-making and strengthening epidemic control. Moreover, forecasting future HIV positivity rate using projection modelling can also guide national and regional health authorities toward achieving the UNAIDS three 95 goals and reducing new HIV infections by 2030. This study aims to generate evidence by analysing the spatio-temporal trends of HIV positivity across the Amhara region districts and forecast HIV positivity rate through 2030, using data from the District Health Information System (DHIS2) and complementary sources.

Methods

Study area and period

This study was conducted in the Amhara Regional State of Ethiopia. According to the population projection in January 2024, the region has an estimate of 32,456,300 population (29). The demographic composition of the Amhara Region is characterized by a large youth population, a rising elderly demographic, and the rural-urban divide, significantly influences its health needs and the capacity of its healthcare system. The study considered 14 administrative zones, 8 city/town administrations, 158 district, 100 public hospitals and 933 health centers. The study area covers reporting district of the Amhara region from routine DHIS2 data (2016-2024), PHEM surveillance data (2021-2024) and Sexual Gender Based Violence (SGBV) data (2022-2024).

Study design

A retrospective ecological study design was used to assess the nine-year (2016 to 2024) spatio-temporal trends of HIV positivity rate per 1000 population from routine DHIS2 data, four years of new HIV cases from PHEM surveillance data, the three-year of HIV positivity rate per 1000 from SGBV data.

Sampling and sample size

The study used all reported HIV tests recorded in DHIS2, PHEM, and SGBV data systems in the Amhara Region. No sample size calculation was required, as the analysis relied on programmatic data.

Data extraction and Population

Data extraction was conducted between 1 July and 30 October 2025 using routinely collected surveillance and program data. The source population comprised all individuals residing in the districts of the Amhara Region who were eligible for HIV testing, irrespective of age, sex, or testing entry point. The study population therefore included all persons who accessed HIV testing services and whose test results were recorded in the respective data systems within the specified timeframe.

Study variables

The key study variables included year and district as the primary temporal and spatial identifiers. Outcome and explanatory variables included the total number of reported HIV tests, the total number of reported HIV-positive cases, and the calculated HIV positivity rate per 1,000 population for each district in each year of the reporting period.

Data management and analysis

Raw datasets were extracted from the respective systems in aggregated annual formats and underwent a standardized data processing workflow prior to analysis. Data cleaning included verification of variable consistency across data sources, harmonization of district names and administrative codes, removal of duplicate records, and correction of obvious reporting errors like negative values and implausible counts.

Annual district-level HIV positivity rates were calculated using the number of HIV-positive test results as the numerator and the total number of HIV tests performed as the denominator, expressed per 1,000 tests. To ensure comparability across years, administrative boundary changes were reviewed and reconciled using regional administrative reference lists; where boundary changes occurred, data were aggregated to maintain consistent spatial units.

All data processing, aggregation, and management were performed using Microsoft Office Excel 2016, and arc GIS.

Spatial and temporal Analysis

Temporal trends were assessed through year-to-year comparisons of HIV positivity rates at regional and district levels. Trends were examined across three analytically defined periods: pre-conflict (2016 to 2020), early conflict (2020 to 2022), and post-escalation (2022 to 2024). Line graphs trend plots were generated to visualize changes over time and identify periods of decline, stagnation, or resurgence.

Spatial autocorrelation analysis

Global spatial autocorrelation of HIV seropositivity was assessed at the district level using Global Moran's I statistic to evaluate the spatial distribution of HIV positivity across the Amhara Region.

Hot spot analysis

Local spatial clustering was further examined using the Getis-Ord Gi statistic to identify hot spots and cold spots of HIV seropositivity at the district level.

Heat mapping

Heat maps were generated to visualize the intensity and District level geographic distribution of HIV seropositivity across district over time. District were classified into high(red), moderate(yellow), and low(green)-positivity rate categories based on average positivity rates over the study period.

Neural network machine learning

Neural network Machine learning was performed to predict predictors of HIV positivity rate.

Exponential smoothing forecasting

We used exponential smoothing forecasting method to forecast HIV positivity rate from 2025 to 2030, where each forecast is weighted by past observations. Older observations are given less weight than recent observations. This implies that the weights decrease exponentially as the values get older (30). The rate of HIV positivity across time did not exhibit apparent trend and seasonality. As a result of this we used simple exponential smoothing method, particularly Multiplicative Error, None Trend, and None Seasonality (ETS (M, N, N)) which is appropriate for time series data with no trend and seasonal effects but increasing variance over time (31) (32).

The equation for ETS (M, N, N) is given by:

Equation of Measurement: $y_t = \ell_{t-1}(1 + \epsilon_t)$

Equation of State: $\ell_t = \ell_{t-1}(1 + \alpha\epsilon_t)$

Forecast equation: $\hat{y}_{t+h|t} = \ell_t$

Where the mean of the error term, ϵ_t is zero; ℓ_t is the level of time series at time t (it is the baseline or smoothed value after eliminating random noise); α is the smoothing constant with values 0 to 1.

Ethical considerations

Ethical clearance was not required for this study as it used secondary data that were first collected for routine program monitoring and public health surveillance. The dataset was fully anonymized and contained no personally identifiable information. Permission to access and use the data was obtained from the Amhara Public Health Institute.

Results

In this study, a total of 158 district were reported HIV testing data through DHIS2 and between 2016 and 2024, a total of 9,438,324 HIV tests were performed, of which 42,719 HIV-positive cases were reported. The mean HIV positivity rate over the nine-year period was 4.5 per 1,000 tests. The regional level 9 years trend analysis of HIV positivity rates per 1,000 population from 2016 to 2024 revealed a clear pattern of initial increase, sustained decline, and subsequent resurgence (Figure1). HIV positivity rose from 4.83 per 1,000 population in 2016 to an early peak of 5.84 per 1,000 in 2017 followed by a steady decline between 2018 and 2020, reaching the lowest observed level in 2020 (3.58 per 1,000). Following 2020, the trend upturned. A certain rise was observed in 2021 (3.87 per 1,000), followed by a slight decline in 2022 (3.76 per 1,000). From 2023 onward, HIV positivity increased markedly, rising to 4.34 per 1,000 in 2023 and reaching 5.08 per 1,000 in 2024, nearly returning to pre-decline levels (Figure1).

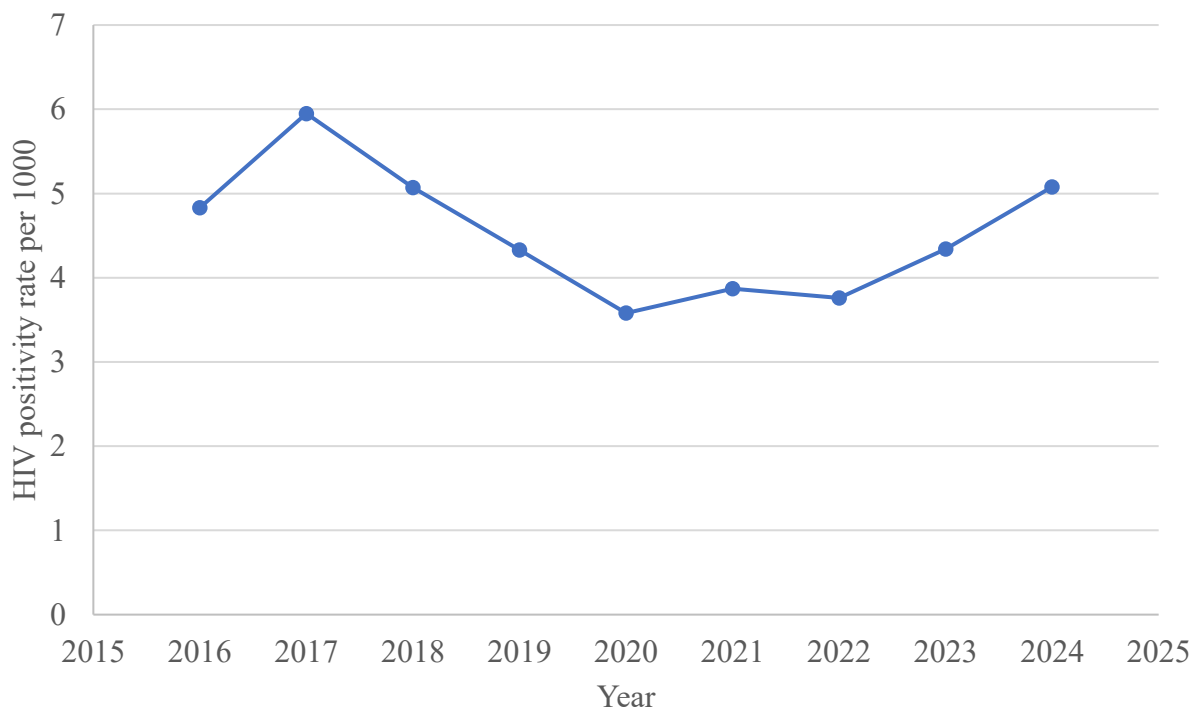


Figure 1. Regional temporal trend of HIV positivity rate per 1,000 population in the Amhara Region, Ethiopia (DHIS2 data, 2016-2024).

A region level HIV positivity rate per 1,000 SGBV in 2022, 2023 and 2024 was 23.3, 8.6 and 8.0 respectively (Figure2).

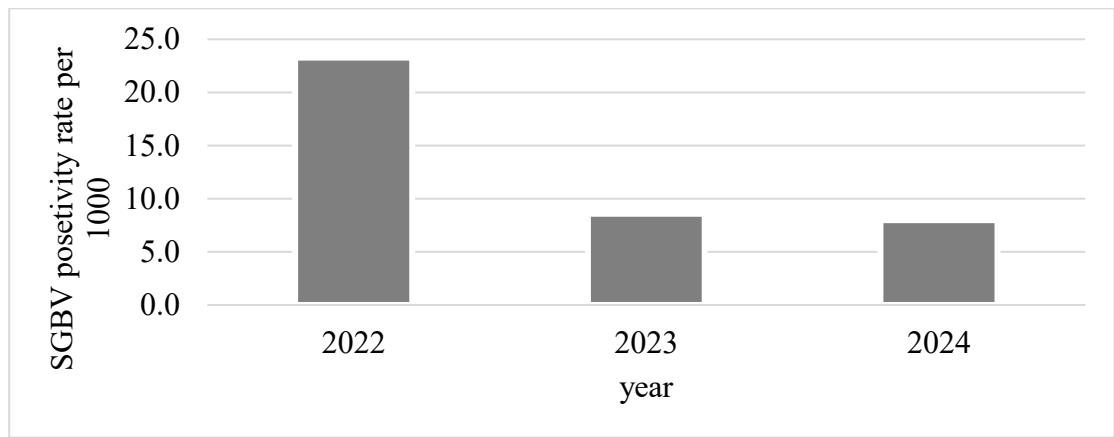


Figure 2. Regional HIV positivity rate per 1,000 among SGBV clients in the Amhara Region, Ethiopia (SGBV data, 2022-2024)

A region level PHEM surveillance data revealed a total of 1,649, 1,829, 2,977 and 4,788 new HIV cases reported from 2021 to 2024 respectively (Figure3).

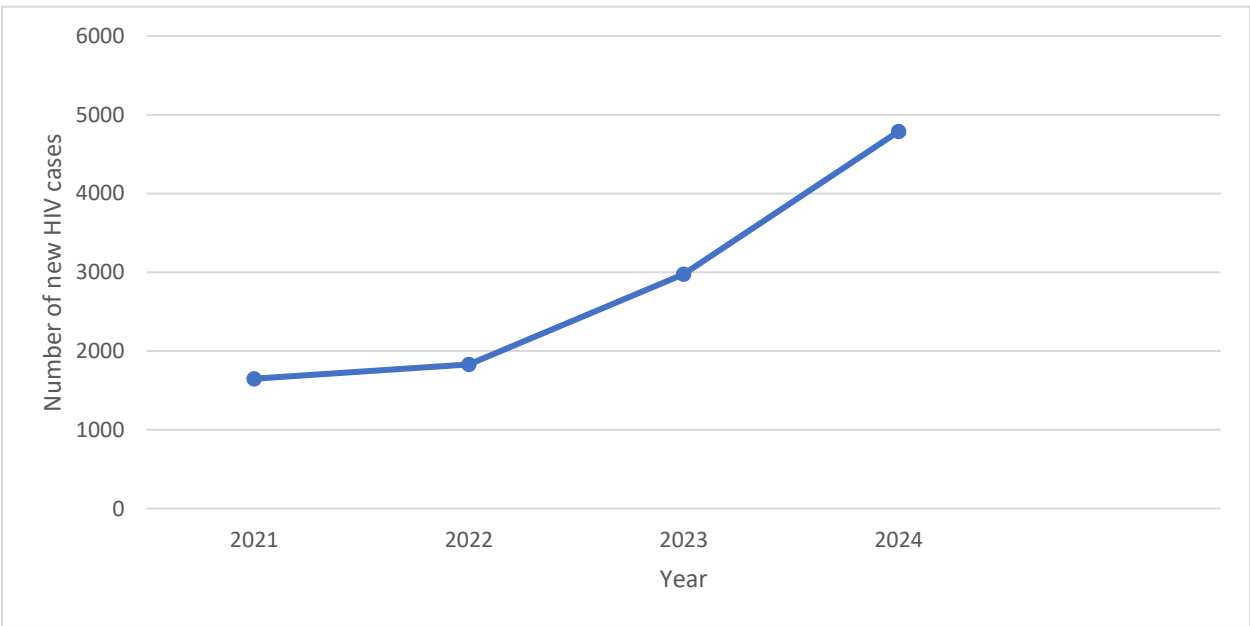


Figure 3. Regional level yearly trend of newly identified HIV positive cases in the Amhara Region, Ethiopia (PHEM data, 2021-2024)

Heatmap visualization

District level heatmap visualization of HIV positivity rates in the Amhara Region reveals marked spatial and temporal heterogeneity, demonstrating that HIV dynamics follow distinct local trajectories rather than a uniform regional pattern (Figure4). Red, yellow, and green colours indicate high (>11%), moderate (1-11%) and low (<1%) HIV positivity rates.

Name of Districts	2016	2017	2018	2019	2020	2021	2022	2023	2024
Abergele District	4.3	1.3	1.6	1	0.8	2	1.5	3.7	4.7
Adi Arkay District	4.4	7.5	4.1	2.6	1.4	4.1	1.9	10	10
Albuko District	5.9	3.6	3.8	2.9	2	2.8	1.9	2.3	4.3
Alefa District	1.7	6.7	4.9	1.8	1.8	2.2	2.5	3.2	1.5
Ambasel District	3.7	5	3.7	2.8	1.4	3.2	1.2	3.8	2.5
Amhara Sayint District	3.5	4.2	1.6	1.7	1.4	2.9	1.9	1.6	1.3
Aneded District	6.1	9.7	11	4.4	5.5	6.4	1.8	3.9	4
Angolela Tara District	2.2	2.7	1.9	1	0.8	0	0.2	3.7	4.6
Ankasha Guagusa W.	3.5	2.4	2.2	1	1.6	2.9	1.8	1.8	0.7
Ankober District	4.3	9.9	9	10	5	3.5	3.4	8.1	6.6
Antsokia Gemiza District	4.4	6.3	3.5	2.5	2.1	2.3	1.5	2.1	2.5
Argoba District	0.4	1.4	2.3	23	2	1.6	0.6	1	2.3
Artuma Fursi District	7.8	6.5	5.1	2.2	2.1	2.6	1.6	2.4	2.3
Asagirt District	3.1	1.9	0.2	1.9	2.8	1.1	2.1	3.2	5
Awabel District	5.7	5.4	9.9	6.2	8.7	8.8	6.9	17	20
Bahir Dar Zuria District	0.7	0.7	0.7	1	0.7	0.9	0.7	0.9	0.6
Banja District	2.8	3.5	1.1	1.9	1.2	1.4	1.3	0.8	1.3
Basoliben District	7.6	2.1	4.4	57	3.5	7.9	7.1	4.8	6.1
Bassona Worana	1.3	3.9	2	1.5	1.5	1	0.7	1.8	6.2
Bati Town District	20	26	20	12	13	16	8.8	11	12
Bati District	2	0.8	0.9	0.5	0.9	1.1	1.4	0.6	0.2
Berehet District	3.8	4.8	15.99	1.1	6.9	8.9	7.2	7	3.2
Beyeda District	3.7	2.1	3.4	1.2	2.1	2.5	3.7	2.8	2.2
Bibugne District	3.3	2.1	4.9	1.4	2.4	2.4	2.2	1.3	0.7
Borena District	2.4	3.9	4.1	1.5	0.9	1.9	1.7	3.4	3.2
Bugina District	5.9	8.1	8.7	4.3	5.2	5.2	4.9	4.3	5.6
Bure Town	38	33	24	13	16	11	18	17	27
Bure Zuria District	4.6	4.1	5.5	3.9	4.5	5.9	6.2	7.7	9.4
Chagni Town	24	13	18	14	14	13	9.7	9.7	15
Chilga District	7.9	11	5.5	0.8	1.6	3.4	3.4	2.8	3.7
Dabat District	4.5	4.7	3.6	3.8	0.7	5.9	1.6	3.1	6
Dangla Town	27.99	11	13	8	8	7.1	10	12	21
Dangla Zuria District	8.1	6.6	1.5	1.9	2.6	0.9	1.9	2.2	5.2
Dawa Chefa District	0.9	2.3	1.6	1.3	1.5	1.5	0.7	2.4	1.7
Dawa Harewa District	5.8	1.6	5.2	1.8	1	2.3	0	2.3	0.4

Dawunt District	2.3	1.7	4.2	2.9	2.3	1	0.8	1.5	1.1
Debark Town District	13	13	12	9.3	4.3	18	15	19	16
Debark Zuria District	0.7	0.2	0.5	0.5	0.5	0	0.2	0.4	0.7
Debaytilatgin District	6.1	9.2	7.6	5.2	7.4	6.3	9	9.8	8.9
Debre Elias Worda	2.8	2.8	3.3	2.9	2	2.8	2.8	3.8	6.8
Dega Damot District	1.9	2.2	0.7	0.6	1.7	1.8	1.5	1.7	0.9
Dehana District	7.1	4	3	3.6	4	2.5	2.3	7.7	6.1
Dejen District	9.8	11	11	12	12	4.8	9.3	8.1	14
Delanta District	2.4	2.9	1.9	2.2	1	2	1.3	4	4
Dembecha District	3.4	4.9	7	7.8	7.3	6.7	9.2	7.6	9.9
Dera District	4.1	3.1	2.6	1.8	0.8	1.4	2.1	1.7	1.4
Dessie Zuria District	1.8	2	2.8	1.4	1	2	1.5	2.7	3.2
East Belesa District	4.4	7.4	4.1	7.2	6.8	2	2.2	3.4	4.6
East Dembia District	5.1	4.8	3.3	1.2	1.9	1.6	1.4	1.2	4.2
Ebinat District	5.9	4.9	6.2	3	4	4.6	2.2	1.6	5.9
Efratana Gidim District	2.6	6.1	4.9	7.3	4.3	6.9	5.4	6.2	6.6
Enarje Enawga District	4.4	3.8	5.7	7.1	7.6	11	9	5.3	11
Enebse Sar Mider W	7.2	6.3	5.7	9.2	6.7	3.2	5.6	6.1	5.6
Enemay District	11	10	12	8	11	12	14	17	20
Ensaro District	0.8	2.1	4	0.6	2.1	0.7	1.5	2.6	4.3
Estie District	3.1	4.2	2.5	1.2	1.5	1.8	2	1.1	1.8
Fagitalekoma District	3.2	5.8	2.7	1	2.1	2.4	2.8	3.5	0.8
Farta District	1.6	4.1	1.4	0.7	0.4	0.8	0.1	0.7	0.1
Finote Selam Town	27	55.99	45.01	10	9.9	12	13	13	12
Fogera District	3	1.8	1.5	1.3	1.2	1.3	0.5	1.8	1.8
Gazgibla District	10	7.3	3.7	3.4	5.6	4.7	3.3	3.2	3.4
Gendawuha District	34.01	22	13	5.4	5	9.9	7.9	5.9	19
Gidan District	5.4	6.7	8.2	1.8	6.5	4.3	7.7	8.5	5.4
Gishe District	2.9	5.7	11	2	4.1	2.2	1.9	6	3.4
Goncha WorHO	3.7	3	3.4	3.4	2.8	5.2	3.7	3.8	4.6
Gondar Zuriya District	2.2	5.1	3.5	2.2	3.4	4.5	1.5	2.5	2.6
Gonji Kollala District	5.4	3.6	2.5	1.5	5.3	2.1	2.1	4.2	1.5
Gozamin District	3.1	2.4	2.6	3.7	2.4	2.1	2.4	4	3.1
Guagusa Shikuda District	11	12	5.1	5.4	3.2	4.4	3.1	5	5.7
Guangua District	1.5	1.1	1.6	1.6	0.1	0.5	0.3	0.4	0.9
Guba Lafto District	4.7	7.2	11	8	7.5	3.9	3.8	3.8	3.4
Habru District	27	24	18	18	12	8.3	11	5.9	7.5
Hagere Mariam District	0.9	1.5	1.4	1.5	0.5	2.2	1.6	2.7	2.4
Hulet Eju Nese WorHO	2.6	3.5	2.2	1.5	1.6	3.4	1.7	3	1.3
Injibara Town	36.99	17	20	12	10	5.8	7.6	7.1	16
Jabi Tehnan District	2.1	4	3.7	4.1	5	2.6	3.7	4.1	5.4
Jamma District	1.1	5.2	5.1	4.3	3.1	2.5	1.7	4.5	4.4
Janamora District	1.7	2.7	2.6	1.5	1.6	1.1	1.2	0.3	2.2
Jawi District	8.9	8	7.6	3.5	3.5	4.1	3.5	3.4	2.2

Jile Timuga District	6.5	3.6	6.5	3.2	2.3	2	1.8	0.5	1.4
Kallu District	3.7	4.9	5.5	4.7	4	3.6	6.4	5.6	7.1
Kelala District	0.9	2.4	5.5	3.8	3.9	5.4	5.1	5.7	4.9
Kemisie Town	24	15	16	9.5	12	43.01	27	22	17
Kewot District	7.2	4.9	5.4	3.9	1.5	3	2.9	3.9	4.3
Kobo Town District	22	42	29	13	13	17	25	22	19
Kutaber District	1.6	2.1	1	1.4	1.9	1.9	0.7	1.3	1.1
Lalibela Town	15.99	16	20	10	8.4	6.8	2.9	7.9	6.8
Lasta District	8.2	14	6.2	12	3.2	3.7	4.2	3.6	3.6
Lay Armacho District	4.9	7.5	4.5	6	3	0.7	1.8	1.2	2.8
Lay Gayint District	13	7.2	6.8	4.4	6.2	4.1	2.7	3	4.6
Legambo District	4	1.4	3.4	6.6	3.8	4.6	11	6	6.7
Legehida District	5	7.2	5.3	5.2	4.4	2.5	1.7	5.2	4.8
Libokemkem District	7.4	5.6	4.6	2.9	2.7	3.4	4.3	4.7	4.4
Machakel District	4.3	2	7.8	5.7	3.4	4.3	3.4	2.4	5.1
Mehal Saint District	1.3	1.7	1.2	0.5	0.5	0.6	0.7	0.6	0.9
Mekdela District	2.9	2.5	5.7	3.1	2.6	1.7	1.6	2	4.8
Meket District	2.2	4.2	3.3	2.9	3.8	2.5	2.1	3.2	5.2
Menz Gera Midir District	7.6	2.3	21.98	1.5	1.2	1.6	2.5	1.7	2.8
Menz Keya Gebreal District.	1.5	1.2	8.4	2.6	0	1.1	0.5	2.6	2.9
Menz Lalo Midir District	10	1.3	4.9	1.5	2.4	2	0.8	0.8	1.3
Menz Mama Midir District.	2.8	2.1	3.3	1.5	2.2	0.7	1.2	1.4	1
Merhabete District	6.3	7.5	2.9	2.2	2.2	3.2	4.9	3.4	2.6
Metema District	30	20	7.9	5.6	3.5	5.9	4.9	6.4	13
Mida Woremo District	4.5	5.9	5.7	8	7.2	3	4.3	5.7	5.8
Minjar Shenkora District	18	7.9	12	6.4	4	6	4.7	3.8	7.3
Mojana Wodera District	3.7	7.3	5.1	2	2.4	2.4	3.8	4.6	4.5
Mortena Jiru District	4.3	6.8	1.7	0.4	3	1.2	1	1.9	2.6
Motta town	16	9.5	13	16	9.2	11	11	17	26
North Achefer District	1	3.8	1.3	1	1.4	1.2	1.8	0.8	1
North Mecha District	4	4.1	2.5	2.1	2.5	1.2	1.5	2	2.3
Quara District	5.2	5.6	5	2.3	1.4	1.9	2	1.3	1.2
Quarit District	1	0.9	1.9	1.6	1.7	1.8	2.9	3.1	4.2
Raya Kobo District	6.6	8.8	9.4	4.6	3.4	3.6	3.1	4.4	4.4
Saya Deberna Wayu District.	3.6	9.9	11	4.8	3.6	2.9	1.9	5.3	3.4
Sehala District	5.9	0	3.3	0.9	2.2	0.4	2	4.5	1.3
Sekela District	1.4	2.8	1.8	1.8	2.2	1.7	1.9	2.1	1.9
Sekota Town	5.8	3	5.8	2.3	5.1	5.4	13	6.7	8.7
Sekota Zuria District	4	2.3	1.7	3	2.3	4.4	2.6	2.3	3.1
Shebel Berenta District	3.9	4.5	8.4	6.1	7.3	13	8	7.9	4.4
Shewarobit Town	54.01	9.5	30	17	18	23	23	18	15
Simada District	7.1	4.1	3.9	2.6	1.6	2	0.8	2.1	2.5
Sinan District	1.2	2.2	3	1.7	3.6	2	0.5	1.9	9.4
South Achefer District	3.1	3.1	4	2.8	2.3	2.6	2.9	5	4.8

South Mecha District	1.1	0.3	1.1	2.8	0.3	0.3	1.3	1.1	0.4
Tach Armacho District	6	8.9	5.1	2.2	2.5	2.2	1.2	1.8	2.7
Tach Gayint District	5.1	5.3	4.7	2.6	3.3	3.9	2	2.2	2.1
Takusa District	2.5	5.2	1.7	1.8	1.1	0.7	1.4	1.1	0.3
Taremaber District	9.1	9.9	4.4	3.1	6.4	6.6	7.6	5.9	2.9
Tegede District	6.2	12	11	3.7	5.4	3.7	3.2	3	4.3
Tehuledre District	8.1	8.6	9.7	8.8	10	7.9	9.4	8.3	8.2
Telemt District	1	0	2.5	0.8	1.5	1.5	1.31	2.4	1.8
Tenta District	3.3	2.4	3	2.5	3.5	2.7	1.8	5.3	4.4
Wadila District	3.8	5.2	7.5	5.7	4.1	3.2	2.7	4.3	5.1
Wenberma District	7.1	3.1	5	3.8	2	3.2	3.8	4.1	7.4
West Armacho District	46.01	28	7.3	9.1	8	9.2	6	6.2	9.5
West Belesa District	2.5	1	1.5	2	1.2	1	1.2	2	1.6
Wogera District	3.9	1.8	1.3	1.3	0.1	1.9	0.6	1.2	1.8
Wogidi District	2.4	7.2	4.4	4.5	2.6	4.4	2.4	4.1	2.6
Worebabo District	4.9	6.4	10	9.4	5.7	2.5	3.4	3.9	3.5
Woreillu District	6.4	11	9.3	6.6	6.3	3.7	4.3	5.5	6.3
Woreta Town	36	19	16	6.4	5.3	8	6.9	11	7.8
Yilmana Densa District	7.8	6.9	5.7	3.2	3.9	2.6	2.9	4.2	2.9
Zigem District	0.9	2.8	1.3	1	0.2	0.6	0.9	0.1	1.8
Ziquala District	4.4	3.9	2.6	2.4	0.8	0.4	0	4.3	2.4

Figure 4. District level temporal heat map visualization of HIV positivity rate per 1,000 population in the Amhara Region, Ethiopia (DHIS2 data, 2016-2024)

Geospatial distribution

The geospatial patterns indicate in the northwest and eastern parts of the region, tend to exhibit higher HIV positivity rates, often appearing as red or high-intensity yellow zones. Central Amhara, including areas around the Lake Tana basin, displays a higher concentration of green and lower-positivity rates districts, with some moderate-positivity pockets (Figure5).

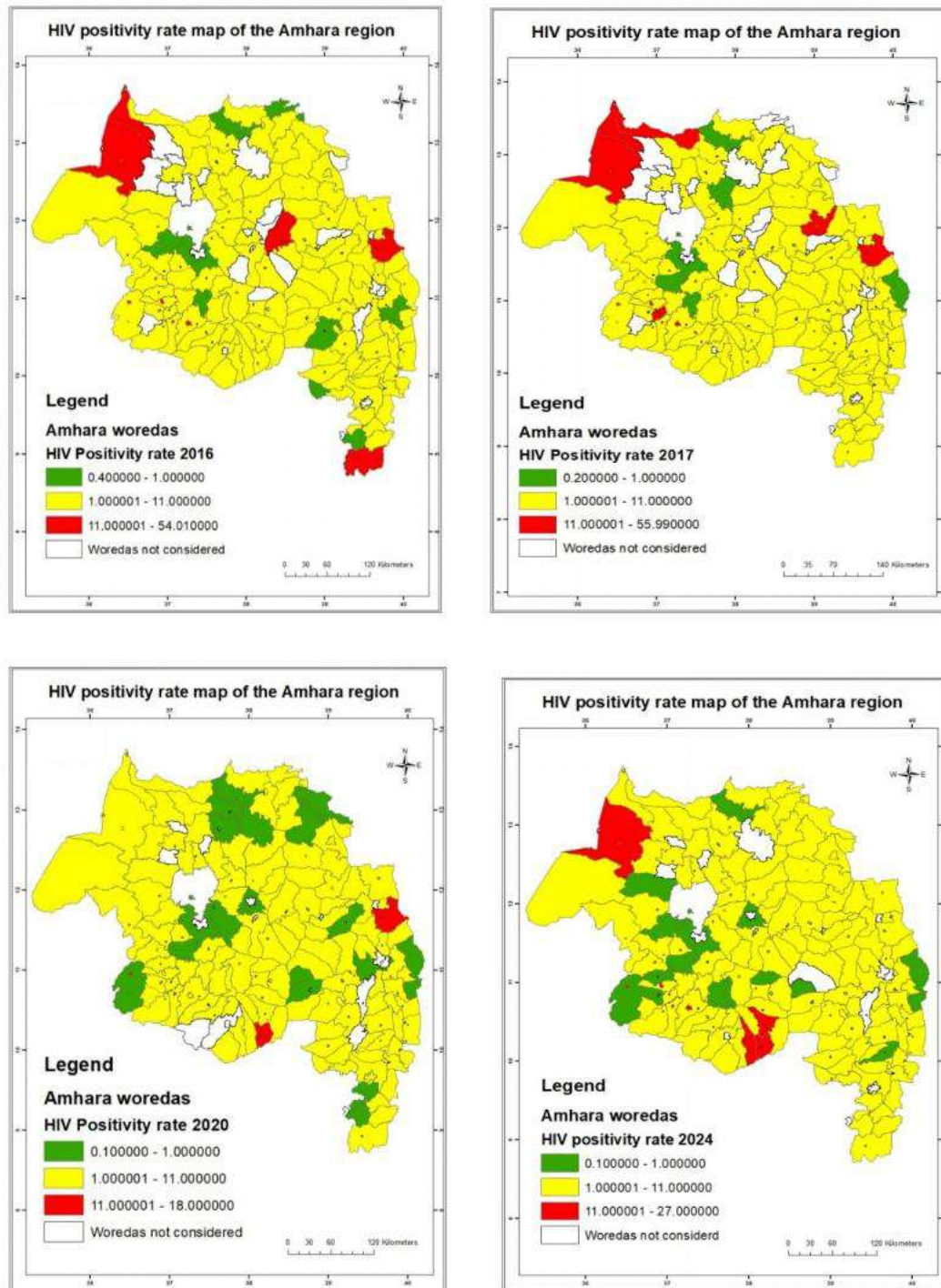


Figure 5. Geospatial distribution of HIV positivity rates across District of the Amhara Region, Ethiopia, 2016,2017,2020 and 2024

Spatial autocorrelation analysis

The Global Moran's I statistic for HIV positivity rates at the district level in Amhara Region (2024) was 0.0016, with an expected index of -0.002. The z-score (0.168) and p-value (0.866) indicate that HIV positivity rates are largely randomly distributed (Figure6).

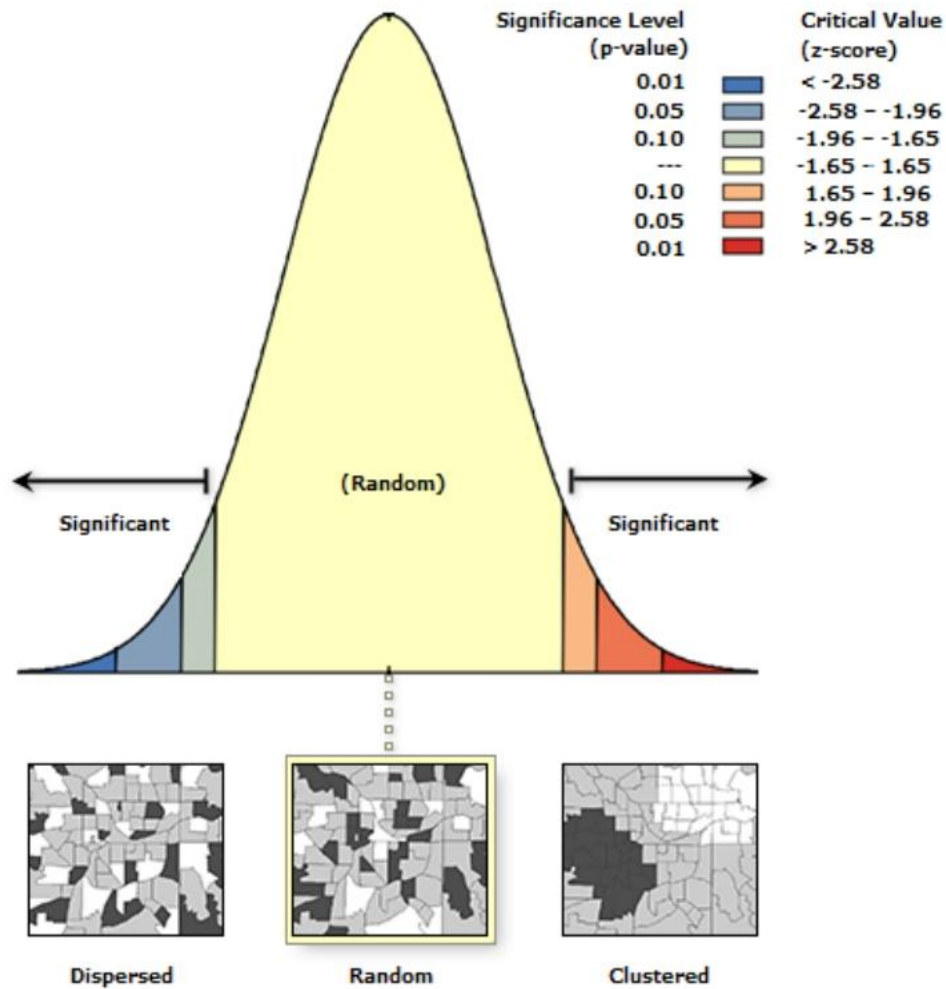


Figure 6. Spatial autocorrelation analysis of HIV positivity rates in the Amhara Region, Ethiopia, 2024.

Spatial Hotspots analysis

The integration of Inverse Distance Weighted (IDW) interpolation and Hotspot Analysis (Getis-Ord Gi*) provides complementary spatial insights for understanding the geographic distribution of HIV hot spots (Figure7).

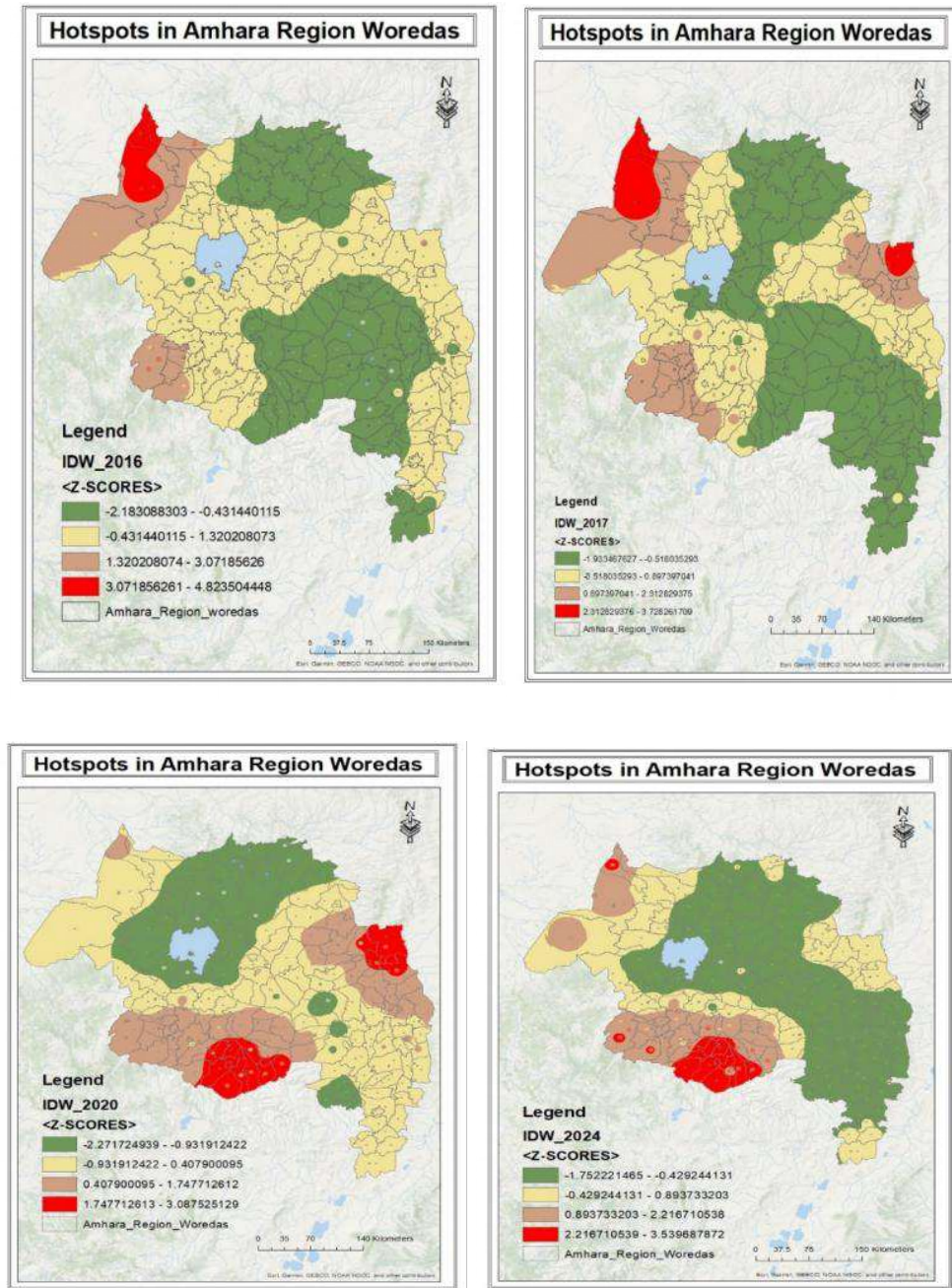


Figure 7. Spatial analysis of Hotspots of HIV positivity rates in the Amhara Region, Ethiopia, 2016, 2017, 2020 and 2024.

Neural network Machine learning

A neural network machine learning workflow shows a predictor analysis to determine factors influencing HIV positivity rate. The upper diagram illustrates the data processing and modelling pipeline that ensures the data are properly imported from excel, predictor variables and target outcomes are identified, data are transformed in to the data set and variables are prepared for modelling before producing predictive results. The lower bar chart shows total testing volume, conflict and year are predictors influencing HIV positivity rate (Figure8).

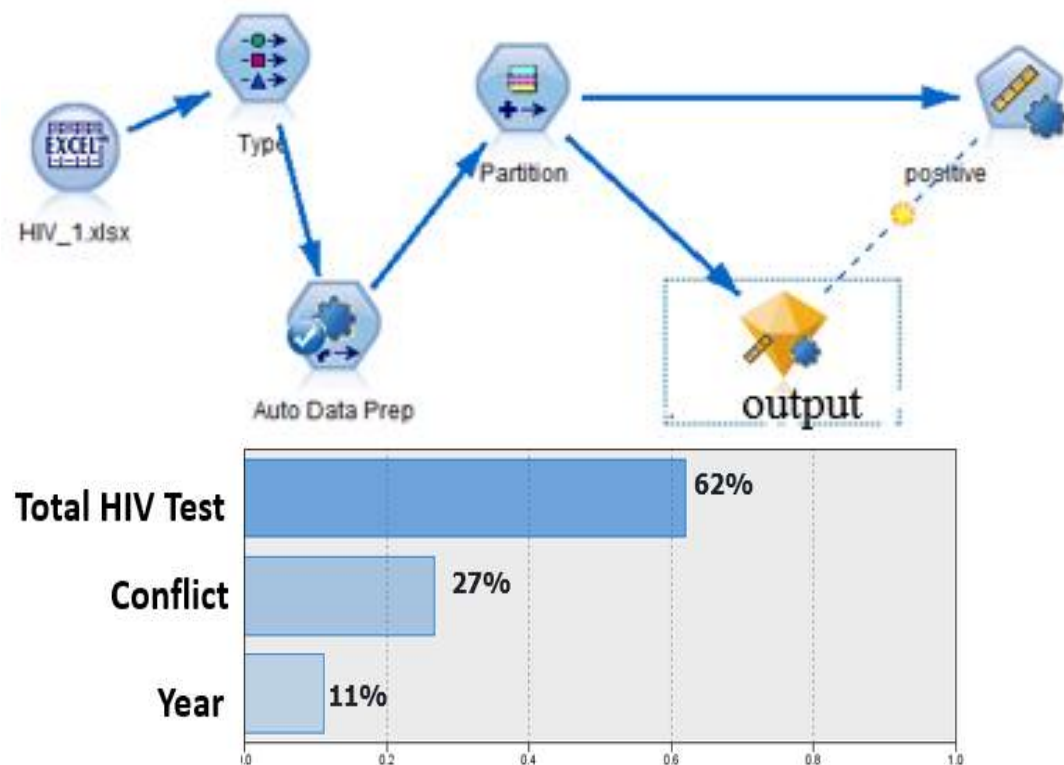


Figure 8. Neural network Machine learning to predict predictors of HIV positivity rate in the Amhara Region, Ethiopia

Exponential smoothing forecasting

The model analysis predicts HIV positivity rate in the Amhara region is expected to remain relatively unchanged at around 5%, as shown by the central forecast blue line under current conditions and programmatic efforts. By 2030, the lower bound of the forecast declines to approximately 1%, while the upper bound rises to above 8%(Figure9).

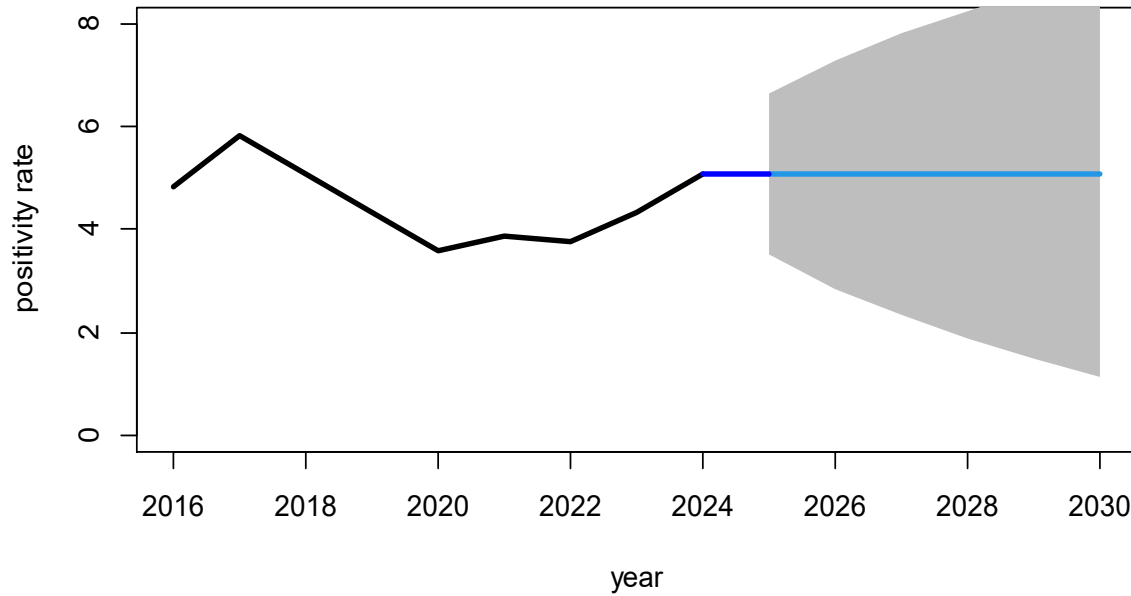


Figure 9. Exponential smoothing modelling to forecast HIV positivity rate in the Amhara Region, Ethiopia (2025-2030)

Discussion

This study provides a detailed district level spatial-temporal HIV positivity trends in the Amhara Region, Ethiopia, by leveraging nearly a decade routine data source from DHIS2, PHEM, and SGBV data bases. By triangulating these complementary datasets, the study offers a clear understanding of both temporal dynamics and geographic heterogeneity in HIV positivity rate during relative stable and conflict conditions. Analysis of a regional nine years DHIS2 data base revealed a clear pattern of initial rise, sustained decline, and subsequent resurgence of HIV positivity rates per 1,000 population in the region over nine years. In addition, analysis from SGBV program database and PHEM surveillance data further supports the presence of high HIV positivity rate within particularly vulnerable populations and a rapidly increasing number of newly identified HIV-positive cases respectively, that supports the upward trends seen in the DHIS2 datasets.

The trend of the HIV positivity rate over the study period revealed temporal dynamics and geographic heterogeneity in HIV positivity rate during relative stable and conflict conditions. This finding is comparable in many conflicts affected countries like Ethiopia, Somalia, South Sudan, Democratic Republic of Congo, Afghanistan, and others where ongoing conflict led to forced closure of treatment facilities that result in interruption of HIV service provision and collapses of HIV prevention and control programs (33) (34) (35) (36) (37). Another possible explanation may be the effect of conflict on patient follow-up (feeling insecurity), lack of transportation, perceived understanding on looting and vandalizing of health facilities (34) (35).

Integrating such triangulated analytic approaches into routine planning cycles aligns closely with global recommendations for strengthening HIV strategic information systems in the context of the 2030 agenda (3) (36) (38) (37). Although the rate decreased over time in SGBV program database, it remained substantially higher than the general population rates observed in DHIS2, highlighting the disproportionate HIV risk among SGBV survivors and emphasizing the importance of strengthening HIV testing and prevention services within SGBV response programs. The triangulated result from the three independent data systems provide converging evidence of a recent resurgence in HIV detection and potential transmission in the region from 20220 and onwards, may be due to a combination of factors, including restoration and expansion of HIV testing services following COVID-19 disruptions, intensified surveillance and case-finding activities, population displacement and social disruption related to conflict, reduced prevention coverage, and interruptions in treatment and follow-up services (31) (39) (35).

District level analysis reveal a dual reality in the regional HIV response. Sustained epidemic control appears achievable in stable settings, as evidenced by prolonged declines in HIV positivity in selected district prior to 2020. Several district, including Finote Selam, Metema, and South Mecha, demonstrated sustained declines in HIV positivity across much of the study period. These trends are consistent with strong performance in case identification, effective linkage to and retention on antiretroviral therapy, and likely high levels of viral suppression (31) (32). Similar district-level successes have been documented in Ethiopia and other sub-Saharan African countries where provider-initiated testing and counselling (PITC), index case testing, community-based outreach, and uninterrupted ART supply chains were effectively implemented (40) (30) (34) (35). The sustained decline observed in Metema a high-mobility border district traditionally considered at elevated risk underscores the feasibility of epidemic control even in complex epidemiological settings when interventions are tailored to local risk profiles. This finding aligns with growing evidence that district-level micro-planning, stratification by burden, and data-driven targeting are critical for accelerating progress toward the 2030 targets, particularly in heterogeneous epidemics (2) (36).

In contrast, the onset of armed conflict in Northern Ethiopia (2020-2022) and the subsequent escalation of conflict within the Amhara Region (from 2022 onward) might be emerged as the dominant drivers of HIV program reversal. The predictor importance analysis from the machine learning model indicates that total HIV targeted testing volume is the most influential determinant of HIV positivity, accounting for approximately 62% of the model's predictive importance. This finding suggests that variations in testing coverage strongly influence the number of HIV-positive cases detected, as increased targeted testing improves the likelihood of identifying previously undiagnosed infections. Conflict status also plays a substantial role, contributing about 27% to the model's predictive importance, highlighting the impact of health service disruption, population displacement, and reduced access to care in conflict-affected areas (31) (32) (39) (33).

Conflict-related disruptions undermined all three pillars of the 95-95-95 cascade. Reduced access to facility and community-based testing weakened progress toward the first 95; interruptions in ART delivery and follow-up compromised retention and adherence, affecting the second 95; and treatment discontinuity likely led to viral rebound, threatening gains toward the third 95 (24) (25) (26) (27).

The slight fluctuations observed during the early conflict period (2020-2022) are likely attributable to reduced testing volumes, selective testing of symptomatic individuals, and reporting interruptions rather than true reductions in transmission. Similar patterns have been documented in fragile and conflict-affected settings, where apparent declines in case detection often mask worsening underlying transmission dynamics (24) (37). Following 2022, the pronounced resurgence in HIV positivity may coincided with widespread service disruption, population displacement, and exposure to high-risk behaviors, suggesting a genuine epidemiologic strengthening rather than surveillance errors (31) (32) (39) (33) (34) (35) (36).

The geographic heterogeneity identified in this study highlights a critical equity challenge for Ethiopia's HIV response. While some district approached epidemic control, others such as Chagni Town, Nebaru Chilga, and Minjar Shenkora functioned as persistent or resurgent transmission reservoirs. Plateauing or unstable trends in some district further suggest that standardized, uniform approaches are insufficient in the face of diverse local drivers of transmission. These findings support the UNAIDS and WHO warnings that national and regional averages can obscure localized epidemics, and that failure to address high-burden district can undermine overall progress toward elimination goals (1, 2). Differentiated service delivery models, intensified index testing, hotspot-focused prevention, and targeted re-engagement of individuals lost to follow-up are therefore essential to address sub-national inequalities

To realign progress with national and global targets, HIV programs in conflict-affected and high-mobility settings must adopt conflict-sensitive and flexible service delivery models. Evidence from humanitarian and post-conflict contexts supports the strengthening of mobile ART distribution, decentralized drug refills, community ART groups, HIV self-testing, and integration of HIV services within humanitarian and protection responses, particularly for internally displaced populations and survivors of sexual violence (31) (39) (38). Without such adaptations, localized epidemics are likely to persist and continue to undermine regional and national progress toward ending AIDS by 2030.

In this study a model-based forecast indicated that, without conflict-responsive and geographically targeted interventions, HIV positivity rates in high-resurgence districts may remain elevated through 2030, potentially undermining progress toward national and global HIV control targets. The model incorporated historical data to forecast future patterns while accounting for temporal dependencies in the HIV testing and positivity data. Forecast results from 2025-2030 suggest that

HIV positivity in the Amhara region is expected to remain relatively stable at about 5% under current conditions. While the central forecast line indicates stability, the model shows a widening confidence interval over time, reflecting increasing uncertainty in long-term forecasts. By 2030, the lower bound of the forecast approaches about 1%, while the upper bound exceeds approximately 8%. This broad interval suggests that future HIV positivity trends could vary substantially depending on changes in program implementation, testing strategies, epidemic dynamics, and contextual factors such as conflict or population movement.

This study may have limitations due to aggregated routine data nature, absence of individual-level data, and conflict or population movement that should be considered when interpreting the findings. Despite the limitations, the convergence of findings across multiple data sources and analytic approaches including descriptive trend analysis, spatial clustering, and district level stratification strengthens confidence in the overall conclusions and supports the robustness of the observed patterns.

In conclusion, the Amhara Region exemplifies both the promise and fragility of HIV epidemic control in districts during conflict settings. This study demonstrates that sustained progress toward the UNAIDS 95-95-95 and 2030 targets is achievable in stable environments through data-driven, geographically targeted HIV programming. However, these gains remain highly vulnerable to armed conflict, population displacement, and systemic health-service disruptions. The observed resurgence in HIV positivity following periods of instability highlights how quickly hard-won achievements can be reversed when access to testing, treatment, and continuity of care is compromised. Importantly, the sustained declines observed in some districts provide compelling evidence that epidemic reversal is not inevitable even in high-risk and mobile populations when interventions are well-adapted to local situations and supported by resilient service delivery systems. Nevertheless, without urgent, targeted, and conflict-responsive interventions, localized resurgent epidemics in some districts may continue to undermine regional and national progress toward ending AIDS as a public health threat. Strengthening district level HIV surveillance, prioritizing high-burden and resurgent districts, and embedding flexibility into HIV service delivery will be critical to sustaining gains and restoring momentum toward the 2030 agenda.

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Competing interests

The authors have no competing of interest to declare.

Author contributions

GY, contributed to the conceptualization, supervision, methodology, writing of original draft and review and revision of final manuscript draft. AK, EK, AA, SM contributed to the conceptualization, methodology, writing of original draft and review and revision of final manuscript draft. DA, MT, GMB, AA, AS, AS, HM, HA, methodology, analysis and review and revision of final manuscript draft. AA, SM, YA, JB, ZR, TS, MG, BBB contributed to the conceptualization, methodology, review and revision of final manuscript draft.

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Disclaimer

The opinions expressed in this manuscript are those of the authors and do not necessarily represent the official position of the institutions.

Ethics approval statement

Ethical clearance was not required for this study as it used secondary data that were first collected for routine program monitoring and public health surveillance. Permission to access and use the data was obtained from the Amhara Public Health Institute.

Data availability statement

Publicly reported data were used and presented within the manuscript.

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Dear Editor-in-Chief,

I am pleased to submit our manuscript entitled “**Spatio-temporal trends and forecasting of HIV Positivity rates at district level in the the Amhara Region, Ethiopia**” for consideration for publication in the Journal of BMC infectious disease.

This manuscript presents original, has not been published previously, and is not under consideration for publication elsewhere, and addresses critical gaps in understanding HIV program performance in fragile and resource-limited settings and provides evidence that can inform targeted interventions, policy decisions, and programmatic improvements.

All authors have read and approved the final version of the manuscript and have agreed to its submission to your journal.

Thank you for considering our manuscript for publication. We look forward to your feedback.

Sincerely,
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On behalf of all co-authors