International Journal of Infectious Diseases 82 (2019) 33–39

Contents lists available at ScienceDirect

International Journal of Infectious Diseases

journal homepage: www.elsevier.com/locate/ijid

Spatial clustering and socio-demographic determinants of HIV infection in Ethiopia, 2015–2017

Yalemzewod Assefa Gelaw[a,b,*], Ricardo J. Soares Magalhães[c,d], Yibeltal Assefa[a], Gail Williams[a]

[a] School of Public Health, Faculty of Medicine, The University of Queensland, Herston 4006, Brisbane, Queensland, Australia
[b] Institute of Public Health, College of Medicine and Health Science, University of Gondar, 196, Gondar, Ethiopia
[c] UQ Spatial Epidemiology Laboratory, School of Veterinary Science, Faculty of Science, The University of Queensland, Gatton 4343, Queensland, Australia
[d] Children's Health and Environment Program, Child Health Research Centre, Faculty of Medicine, The University of Queensland, Brisbane 4101, Queensland, Australia

ARTICLE INFO

Article history:
Received 10 January 2019
Received in revised form 24 February 2019
Accepted 26 February 2019
Corresponding Editor: Eskild Petersen, Aarhus, Denmark

Keywords:
HIV
Spatial clustering
Socio-demographic
Amhara Region
Ethiopia

ABSTRACT

Background: Amhara Region has the largest at-risk population in Ethiopia, with widespread traditional practices that are likely to increase transmission of HIV. However, the identification and characterization of HIV hotspots within this region have not been undertaken. This study aimed to explore and describe the geographical pattern of HIV infection using notification data in Amhara Region, Ethiopia.
Methods: Data on HIV infection at the district level were obtained from the Amhara Regional Health Bureau. A Bayesian conditional autoregressive (CAR) model was used to explore the association between HIV infection and socio-demographic variables in OpenBUGS.
Results: A total of 35 210 new HIV cases were reported during 2015–2017 in Amhara Region, Ethiopia. Metema and Mirab Armacho districts were found to be hotspots throughout the study period. There was a decrease in HIV infection in 2016 (odds ratio 0.77, 95% credible interval (CrI) 0.72–0.82) and 2017 (odds ratio 0.71, 95% CrI 0.60–0.76) as compared with HIV infection in 2015. HIV infection increased by 1.004 (95% CrI 1.001–1.008) and 1.47 (95% CrI 1.11–3.59) for a one-unit increase in the proportion of the population who had never attended school and migrants, respectively.
Conclusions: This study identified spatial clustering of HIV infection in Amhara Region, with a slight reduction in the annual infection rates from 2015 to 2017. The proportion of the population who were migrants or who had a low educational status was associated with a high risk of infection. Access to HIV counselling and the promotion of condom utilization, integrated with other health care services, targeting those with a lower level of education and seasonal migrants, are important strategies for the prevention of new HIV infections.

Introduction

Human immunodeficiency virus (HIV) persue to be a major global public health problem (Joint United Nations Programme on HIV/AIDS, 2018). Globally, 36.9 million (range, 31.1 million–43.9 million) people were living with HIV in 2017 (UNAIDS, 2018a). The burden of the epidemic varies considerably among countries and regions (World Health Organization, 2017). The vast majority of people living with HIV (PLHIV) are in low- and middle-income countries (UNAIDS, 2018b; World Health Organization, 2017). In 2017, about 50% (19.6 million) of PLHIV were living in eastern and southern Africa, and 1.8 million people were newly diagnosed with HIV (UNAIDS, 2018a).

In many high HIV prevalence settings, concerted measures have been taken to prevent and control HIV/AIDS since 2000 (Joint United Nations Programme on HIV/AIDS, 2018). However, many PLHIV remain undiagnosed or are diagnosed late, especially in Sub-Saharan Africa (SSA), where the burden of HIV is highest (Ghosn et al., 2018). In 2017, 34% of the total estimated PLHIV had no access to antiretroviral therapy (ART) (WHO Africa, 2017). Hence, an accelerated and targeted response is needed to achieve the 90–90–90 targets by 2020, defined as follows: (1) 90% of all PLHIV will know their HIV status, (2) 90% of all people with diagnosed HIV infection will receive sustained ART, and (3) 90% of all people

* Corresponding author at: School of Public Health, Faculty of Medicine, The University of Queensland, 288 Herston Road, Herston 4006, Brisbane, Queensland, Australia
E-mail addresses: y.gelaw@uq.edu.au, yalassefa@gmail.com (Y.A. Gelaw).

https://doi.org/10.1016/j.ijid.2019.02.046
1201-9712/

receiving ART will have viral suppression (Joint United Nations Programme on HIV/AIDS, 2014).

Ethiopia is one of the HIV high burden countries that has adopted the 90–90–90 fast-track targets (Joint United Nations Programme on HIV/AIDS, 2014). A recent study indicated that progress towards achieving the 2020 targets are on track: 79% PLHIV know their status, 90% PLHIV are on ART, and 88% of PLHIV have suppressed viral loads (Assefa et al., 2019). However, the prevalence of HIV and incidence of new infections remain high (Girum et al., 2018). In 2017, the number of PLHIV was estimated to be 610 000 and the number of newly HIV-infected people was estimated to be 16 000 (UNAIDS, 2018a). The national HIV prevalence in adults declined from 1.4 in 2005 to 0.9% in 2016 (CSA, 2018). However, there is a significant geographic variation in city administration and regional states, with the highest prevalence recorded in Gambela Region (4.8%) and Addis Ababa City Administration (3.4%). This is followed by Dire Dawa City Administration (2.5%) and the regions of Harari (2.4%), Afar (1.4%), and Amhara (1.2%) (CSA, 2018).

Amhara Region is the second most populous and geographically diverse region in Ethiopia (Amahar Regional State BoFED, 2017). It has a large number of most-at-risk populations for HIV (MARPs), such as truckers, migrant day labourers, and female sex workers (Deribew, 2009). As reported in the Ethiopian Demographic and Health Survey (EDHS) 2016, there are marked differences in HIV risk behaviours and knowledge of HIV/AIDS prevention methods by region and city administration. Only 22% of women and 44% of men in Amhara Region have a comprehensive knowledge of HIV. Additionally, there are widespread traditional practices in the region that disproportionately increase the risk of HIV. It was estimated in 2018 that an average of 2.8 women and 5.2 men had sexual intercourse or cohabited in their life time with a mean number of 1.8 and 2.8 sexual partners, respectively (CSA, 2018). Furthermore, about 43% of the population had no access to HIV testing in Amhara Region in 2017 (Ethiopian Ministry of Health, 2016/7).

The estimation of HIV infection rates and identification of areas with the highest HIV infection is therefore essential (Wilson and Halperin, 2008), especially in settings such as border and agricultural investment areas where unsafe sex is potentially more likely to be practised. This could assist in increasing access to HIV counselling and testing (HCT) services, and targeting and prioritizing interventions (Coburn and Blower, 2013).

The aim of this study was to explore and describe the geographical pattern of HIV infection from 2015 to 2017 using government-reported notification data from the Amhara Regional Health Bureau, Ethiopia.

Methods

Geographical characteristics of the study setting

Amhara Region is the third largest region in Ethiopia with an area covering 157 127 km^2. The region is divided into 10 administrative zones and 167 districts (Amhara Regional State Finance and Economic Development, 2018). The district was used as the spatial unit of analysis.

To geolocate the districts of Amhara Region, the polygon shapefile obtained from the open Africa website (Code for Africa, 2019) was used. All spatial information was projected using Adindan_UTM_Zone_37 N, which is the geo-coordinate system in Africa (Figure 1). Data from 15 222 HIV cases in 2015, 10 059 in 2016, and 9926 in 2017 (all aged 15 years and above) obtained from the health management information system (HMIS) were geo-referenced. A total of 128 districts were included in the analysis.

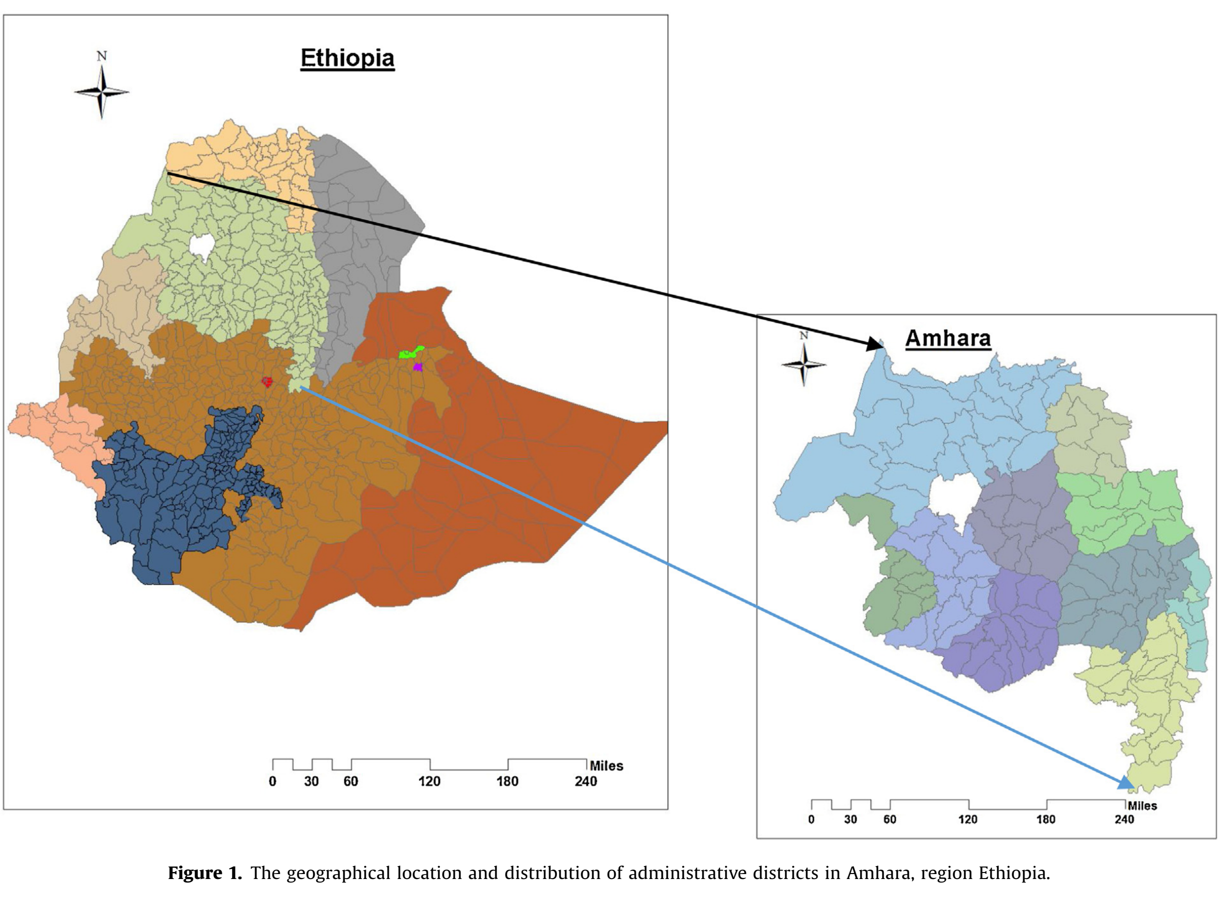

Figure 1. The geographical location and distribution of administrative districts in Amhara, region Ethiopia.

Data sources

In 2016, there were 841 functional health centres and 68 hospitals providing health care (including HCT) in Amhara Region, of which about 168 (20%) health centres provided HIV care and treatment services (Ethiopian Ministry of Health, 2016/7). In this study, regional data on HIV cases were obtained for the years 2015–2017 from the HMIS, Ministry of Health, Amhara Regional Health Bureau. These data comprise HIV cases reported by health centres through district health offices to the zonal health department, which in turn reports to the regional health bureau every quarter.

New HIV notification infection rates were calculated by dividing the number of test-positive cases by the total population undergoing HCT, multiplied by 1000 to obtain a rate per 1000 population for each year in each district. Data were aggregated by age (<1 year, 1–4 years, 5–9 years, 10–14 years, 15–19 years, 20–24 years, 25–49 years, ≥50 years), sex, and HCT approach (voluntary counselling and testing (VCT) and provider-initiated HIV counselling and testing (PICT)). Socio-demographic variables (proportions of those who were unemployed, never attended school, or migrant) were obtained from the latest Ethiopian Census reports, collected in 2007 (Population Census Commission, 2010).

HIV service delivery

In Ethiopia, two major models are implemented for HCT service delivery: health facility and community based. The health facility-based model is the routine model, using client-initiated (voluntary) HIV testing and counselling (VCT) and provider-initiated HIV testing and counselling (PITC) approaches (Frehiwot et al., 2014). HIV blood tests were done using KHB, STAT-PAK, and Uni-Gold assays (World Health Organization, 2012).

Spatial cluster analysis

Spatial analyses of HIV were conducted in two phases. First, district boundaries were geo-referenced and linked to the district HIV infection rates for 2015, 2016, 2017, and for 2015–2017 and choropleth maps were developed for visualization. Global tests of geographical clustering of HIV in the region for each year were performed using spatial autocorrelation (Moran's *I* index) (Lai et al., 2008). A spatial weight matrix was used to specify the spatial relationships of districts. Neighbours were defined using inverse distance, whereby contiguous districts were considered neighbours. Negative values of Moran's *I* indicate an over-dispersed distribution, while positive values indicate clustering, with zero corresponding to a spatially random distribution (Odland, 1988).

Second, local indicators of spatial analysis (LISA) were used to identify locations with high rates of HIV and outlier districts. The significance of LISA statistics led to the classification of districts into five classes: high–high (hotspot), low–low (low rates of HIV infection surrounded by others also with low rates of HIV), low–high (low rates of HIV infection surrounded by others with high rates of HIV), high–low (high rates of HIV infection surrounded by others with low rates of HIV), and not significant (Anselin, 1995). A separate LISA analysis was performed for each year. ArcMap software was used to generate maps of the spatial distributions (ESRI Inc., Redlands, CA, USA).

Data analysis

Three separate binomial regression models were constructed in a Bayesian framework using OpenBUGS software, version 3.2.3 (Medical Research Council Biostatistics Unit, Institute of Public Health, Cambridge, UK). HIV infections for 2015–2017 were used for modelling. The first model (model I), assumed that odds ratios of HIV infection were not spatially autocorrelated. This model was developed using sex, years, proportion of migrants, proportion of those who had never attended school, proportion unemployed, and health facility coverage as explanatory variables, with unstructured random effects for districts. The second model (model II) added a spatially structured random effect with a Bayesian smoothing conditional autoregressive (CAR) model for the random effects. The final model (model III) contained both unstructured and spatially structured models. Model III assumed that the observed number of HIV cases (Y) for the i^{th} district followed a binomial distribution with sample size (n) and true rate (p):

$$Y \tilde{} \text{Binomial (ni, pi), where pi} = \exp(\alpha + \beta xi) / (1 + \exp(\alpha + \beta xi)$$

$$\text{Logit (pi)} = a + Ui + u\ [Loc[i]] + v\ [Loc[i]]$$

$$Ui = \beta 1^{*}year2\ [i] + \beta 2^{*}year3\ [i] + \beta 3^{*}male[i] + \beta 4^{*}School[i] + \beta 5^{*}Unemploy[i] + \beta 6^{*}Migrant[i] + \beta 7^{*}HFcoverage[i]$$

where *Ui* is the mean log odds ratio (OR); α is the intercept; $\beta 1$, $\beta 2$, $\beta 3$, $\beta 4$, $\beta 5$, $\beta 6$, and $\beta 7$ are the coefficients for year 2016, year 2017, sex, percentage of illiterate, percentage of unemployment, percentage of new migrant, and percentage health facility coverage, respectively; *ui* is an unstructured random effect with a mean zero and inverse variance $1/\sigma_u^2$; and *vi* is a spatially structured conditional autoregressive random effect (CAR) with mean zero and inverse variance $1/\sigma_v^2$. The CAR was defined using an adjacency matrix to determine the spatial relationships between districts. The adjacency matrix for each district was generated using the adjacency for WinBUGS add tool of ArcGIS version 10.3.1. A weight of 1 was given if two districts were neighbouring and zero weight was given if two districts were not neighbouring. Two districts were neighbouring if they shared the same edges or corners (i.e., queen contiguity). Prior probability distributions for the coefficients (β) were assumed to have normal distributions, with mean zero and precision (i.e., inverse of variance) equal to 10^{-6}. For the intercept (α), a flat prior distribution was used (i.e., a non-informative, improper prior with bounds −1 and +1). Precision of the unstructured and spatially structured random effects were assigned non-informative gamma distributions with shape and scale parameters of 0.001. See **Supplementary material** for further model details.

Posterior parameters were estimated from the prior distributions and the data likelihood functions using a Bayesian Markov Chain Monte Carlo (MCMC) simulation approach with Gibbs sampling, employed by Open BUGS version 3.2.3 rev 1012. After an initial burn-in of 1000 iterations, the models were run for 200 000 iterations. For all models (as evidenced from visual inspection of posterior kernel densities and history plots), convergence occurred within the first 100 000 iterations. Two hundred thousand values from the posterior distribution of each parameter were stored for summary measures such as the posterior mean, standard deviation, and the 95% credible interval (CrI) for the odds ratio (OR). The deviance information criterion (DIC) was also used for model selection, whereby a lower DIC indicates a preferred model fit (model III).

Results

Descriptive analysis

A total of 35 210 new HIV infections were notified among 5 469 580 individuals aged 15 years and above who underwent HCT from July 2015 to June 2017. The annual notification rate for new HIV infections was 6.63 per 1000 tested adult population. The

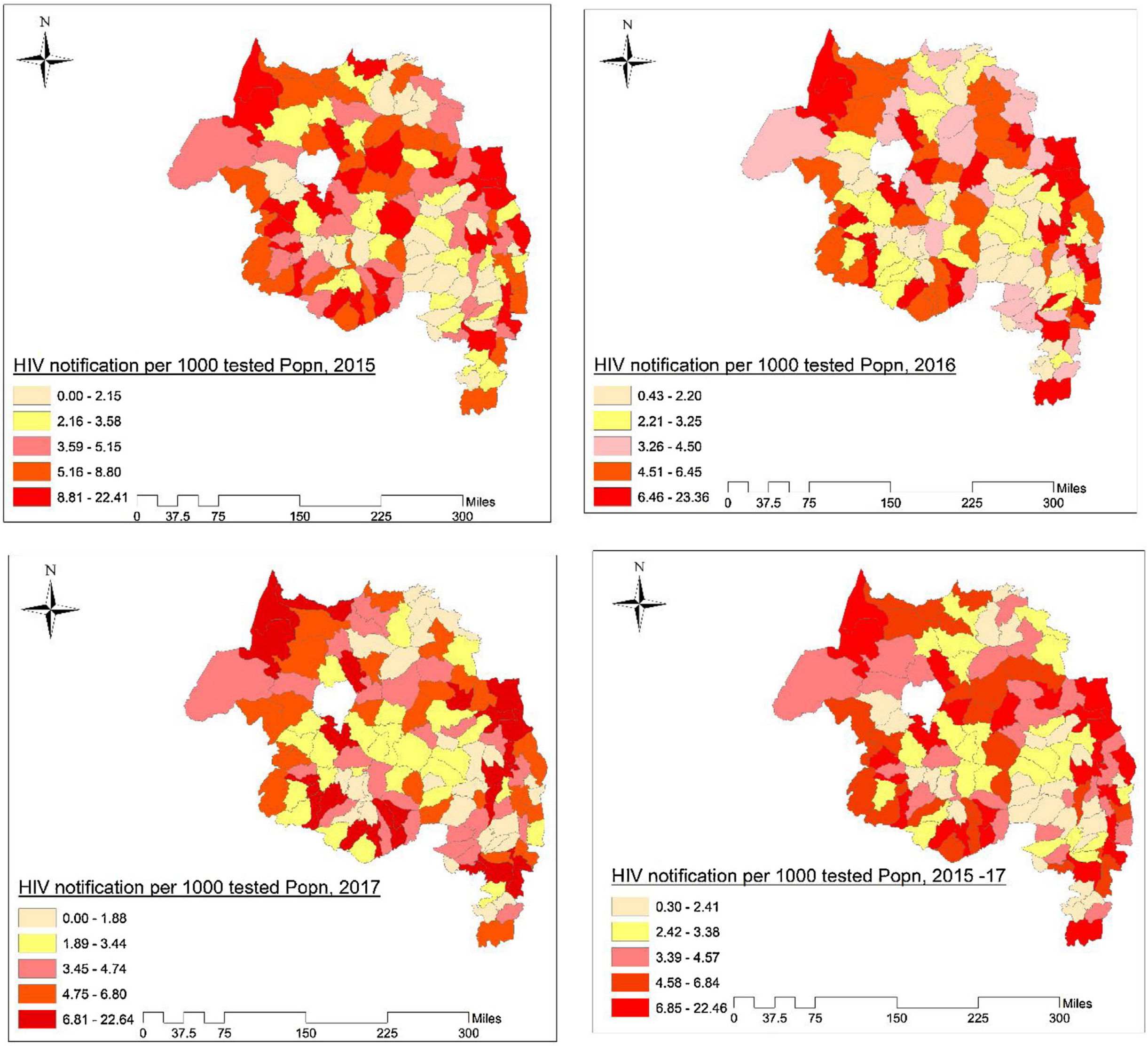

Figure 2. Annual HIV infection rates per 1000 HIV tested population in Amhara region, Ethiopia, 2015–2017.

infection rate was higher in women (6.65) than in men (6.15) and highest in the 25–49 years age group (9.09) compared to the 15–24 years age group (2.9).

Spatial cluster analysis

Figure 2 shows the spatial distribution of HIV infection, with the highest notification rates detected in northwest, central, and eastern parts of Amhara Region. There was a significant spatial autocorrelation for HIV infection at the district level during the study period, except for 2016 ($p = 0.07$). Moran's I values indicated that the HIV infection rate was clustered in 2015, 2017, and for the whole period 2015–2017 (Table 1).

Maps from LISA analysis identified hotspots and outliers of HIV infection in Amhara Region. From 2015 to 2017, HIV infection was mainly concentrated in Mirab Armacho District and Metema District, except in 2015. Guba Lafto, Kobo, Habru, and Gidan districts were additionally observed as hotspots in 2017 (Figure 3). The annual infection rate of HIV in hotspot districts (Metema, Mirab Armacho, and Habru) during 2015–2017 was 14.30 per 1000 tested population.

Table 1
Spatial autocorrelation analysis for annual HIV infection in Amhara Regional, Ethiopia from 2015 to 2017.

Year	Moran's *I*	*p*-Value
2015	0.0506	0.046
2016	0.0432	0.077
2017	0.0948	0.001
2015–2017	0.0718	0.006

Spatio-temporal model

When the three models were compared using the DIC, the convolution model (model III), which contained both unstructured and structured CAR random effects, was preferred (Table 2).

The results demonstrate a significant decrease in HIV infection in 2016 (OR 0.767, 95% CrI 0.716–0.821) and 2017 (OR 0.712, 95% CrI 0.6644–0.7617) compared to HIV infection in 2015. This implies that there was a temporal variation in HIV infection across Amhara Region during the study period, after accounting for the proportions of individuals who had never attended school, were unemployed, and were new migrants, health facility coverage,

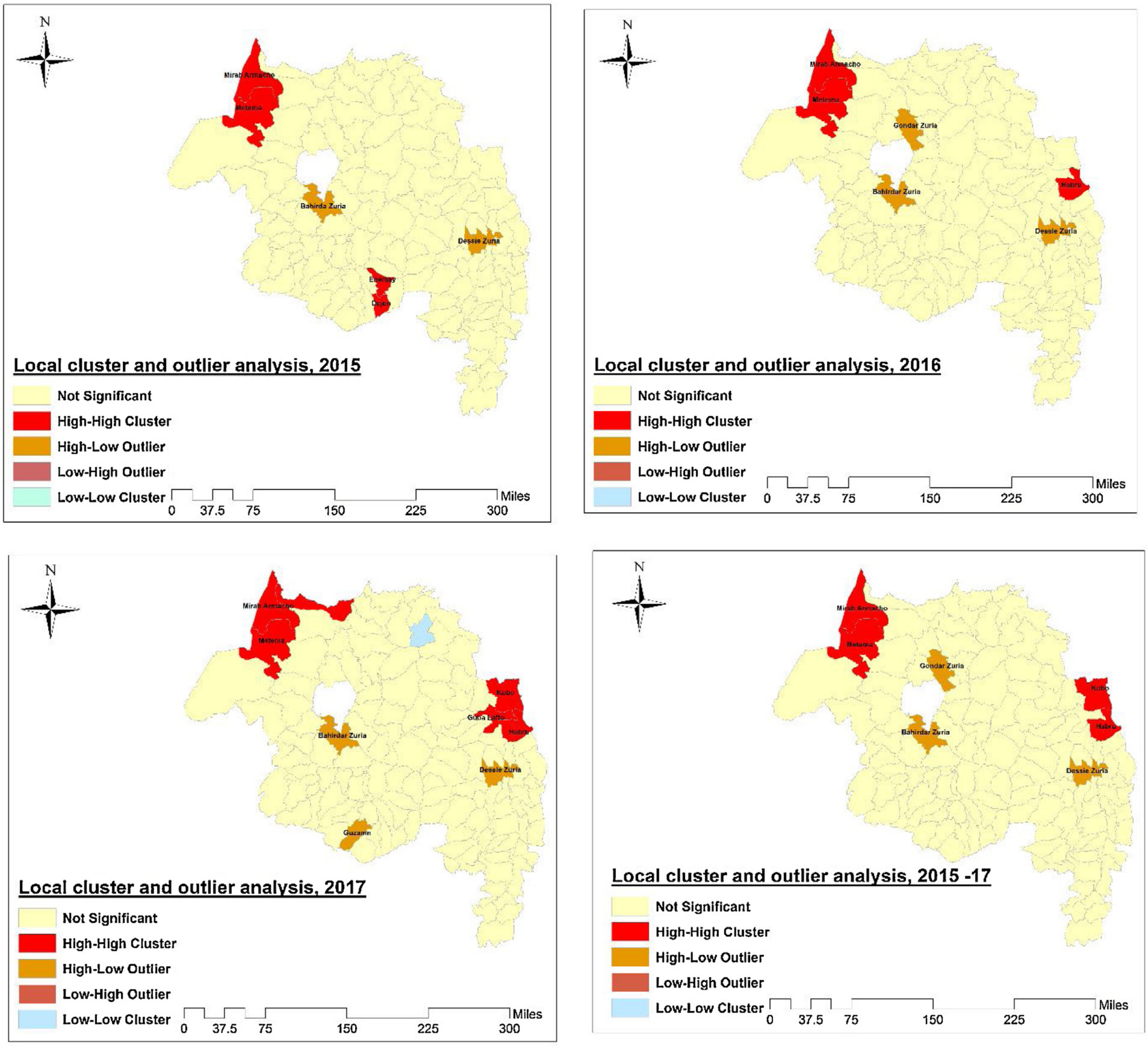

Figure 3. A local cluster and outlier analysis of HIV infection in Amhara region, Ethiopia: 2015–2017.

Table 2
Socio-demographic factors associated with HIV in the 15–49 years age group in Amhara Region, Ethiopia in the period 2015–2017.

District-level variable	Model I (unstructured) OR (95% CrI)	Model II (structured) OR (95% CrI)	Model III (unstructured and structured) OR (95% CrI)
Year_2016	0.76 (0.72, 0.81)	0.76 (0.71, 0.82)	0.77 (0.72, 0.82)
Year_2017	0.712 (0.66, 0.76)	0.71 (0.66, 0.76)	0.712 (0.66, 0.76)
Male	0.97 (0.91, 1.03)	0.97 (0.91, 1.03)	0.97 (0.91, 1.03)
Education status illiterate (%)	1.004 (1.08, 1.66)	1.004 (1.00, 1.01)	1.004 (1.001, 1.01)
Employment status unemployed (%)	1.01 (0.98, 1.02)	1.003 (0.98, 1.02)	1.003 (0.98, 1.023)
New migrant (%)	1.33 (1.08, 1.66)	1.104 (0.62, 1.44)	1.47 (1.11, 3.60)
Health facility coverage (%)	1.01 (0.99, 1.04)	1.014 (0.99, 1.04)	1.014 (0.99, 1.04)
DIC	954.6	275.0	250.6

OR, odds ratio; CrI, credible interval; DIC, deviance information criterion.

and spatial structured and unstructured random effects. The proportion of individuals who had never attended school 1.004 (95% CrI 1.001–1.008) and proportion of migrants 1.474 (95% CrI 1.114–3.597) were associated with increased HIV rates. The maps of posterior means of spatially unstructured and structured random effects indicated a random distribution of HIV infection (Figure 4). There was no significant spatial clustering after accounting for socio-demographic variables (Moran's $I = 0.005$, $p = 0.61$).

Discussion

The results of this study indicate spatial clustering of HIV in Amhara Region over the 3-year period. In addition, the best-fitting multivariable Bayesian spatial model demonstrated a significant decrease in infection rates between 2015 and 2017 associated with spatial differences in key socio-economic factors.

The LISA analysis indicated that HIV was geographically clustered in the north-west districts of Amhara Region. A high

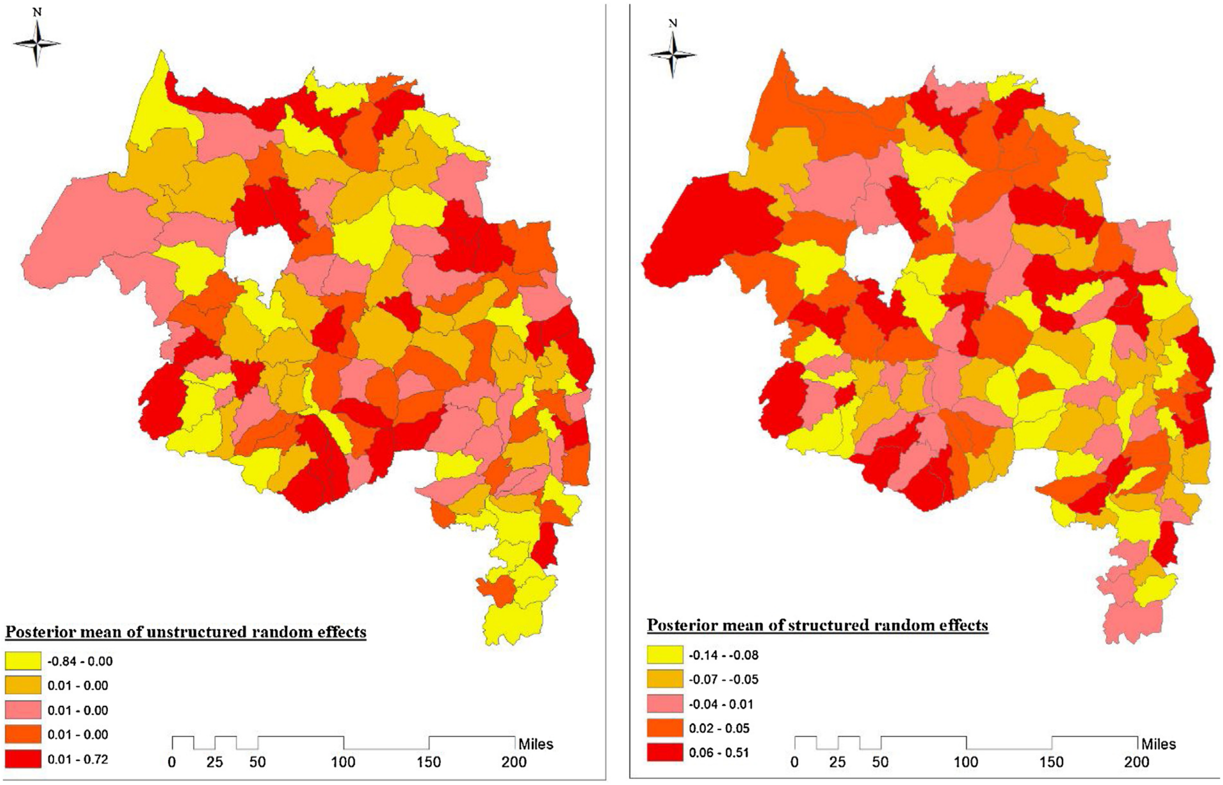

Figure 4. Unstructured and structured posterior mean distributions of HIV infection in Amhara region, Ethiopia: 2015–2017.

rate of HIV infection was found in Metema and Mirab Armacho districts, which share borders with Eretria and Sudan. Various studies have linked risk of infectious disease to agricultural activities and border areas in Ethiopia (Alemayehu et al., 2017; Alene et al., 2017; Deribew, 2009). Indeed the districts identified in this study as being important spatiotemporal HIV hotspots are known for being highly agricultural areas as well as transport corridors for truck drivers, with large numbers of other HIV MARPs such as day labourers during the harvesting season, commercial sex workers, and truckers. Furthermore, these districts are also known to constitute gateways for migrants, female returnees, and sex workers (Gezie et al., 2015). The detection of high HIV infection rates in these districts implies that HIV-related knowledge and condom promotion and distribution services are likely to be sub-optimal in these districts. Therefore, this study could inform and strengthen current HIV control policy in areas where MARPs are concentrated.

The results of this study showed temporal patterns in HIV infection with a decline of infection from 2015 to 2017. The Ethiopian health data analytics platform also shows that HIV notification decreased in the region (Ethiopian Ministry of Health, 2016/7). Scale up of ART, expansion of HCT, and integrated HIV care and support in the country likely contributed to this reduction (Assefa et al., 2014; WHO, 2015).

It was found that HIV infection is higher in districts with a higher proportion of individuals who have never attended school. Prior findings have also shown educational status to be associated with HIV prevalence, in that the risk of HIV infection was found to be higher in the less educated groups (Bradley et al., 2007; Fontanet et al., 2000; Glynn et al., 2004). Educated populations may be more likely to use condoms compared to those less educated, which may help lower HIV transmission. Less educated populations often live in rural areas and commonly travel to engage in income-generating activities such as sex work (Bradley et al., 2007). In contrast, a study done using individual EDHS data demonstrated that HIV prevalence was higher among educated groups compared to less educated groups (Lakew et al., 2015). The present study used data aggregated at the district level, which might not be generalizable for individuals. It would be valuable to examine the association of education and HIV using individual-level data.

Districts with a higher proportion of migrants were statistically at greater risk for HIV infection. This finding could be explained in part by risky sexual behaviours, such as multiple sexual partners or low and inconsistent condom use, likely to increase vulnerability to HIV infection (Federal and Prevention, 2007; Tiruneh et al., 2015). Seasonal migration of labour in the study area, largely undertaken by younger individuals (mean age 28.4 years), also contributes to HIV transmission.

There are several limitations of this study that need to be considered when interpreting the results. First, the findings are not representative of small administrative units (such as a Kebele or household) or even current administrative units, as surveillance data from 2015 to 2017 aggregated all HIV cases at the district level. Second, notification data were used, i.e., HIV-infected individuals who did not access HCT remained unreported. Access to HCT may vary across districts, leading to variation in reporting of HIV, so that data might not reflect the actual HIV incidence of the districts. Third, socio-demographic data (2007 census) may not reflect changes due to the demographic transition over the last 11 years.

In conclusion, the study results demonstrate that despite the HIV infection rate in the Amhara Region of Ethiopia exhibiting a small annual reduction between 2015 and 2017, residual district-level clustering still exist in the agricultural districts (Metema and Mirab Armacho) of the region border Eretria and Sudan in the north-west part of the country. The proportion of migrants and proportion with a low educational status were factors associated with a high risk of HIV clustering. This finding calls for public health action to focus on the districts highlighted in this study and increased investment to provide better access to HCT and to promote condom utilization to reduce the future risk of HIV incidence in the region.

Funding

None.

Ethical approval

Ethical approval was obtained from the School of Public Health Ethics Committee, School of Public Health, University of Queensland and permission to access the data was obtained from the Amhara Regional Health Bureau.

Conflict of interest

There is no conflict of interest.

Acknowledgements

We thank the Amhara Regional Health Bureau, Amhara Bureau of Economic Development, and Ethiopian Central Statistics Authority for providing access to the data to carry out this study.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ijid.2019.02.046.

References

Alemayehu M, Wubshet M, Mesfin N, Gebayehu A. Prevalence of human immunodeficiency virus and associated factors among visceral leishmaniasis infected patients in Northwest Ethiopia: a facility based cross-sectional study. BMC Infect Dis 2017;17(1):152.
Alene KA, Viney K, McBryde ES, Clements AC. Spatial patterns of multidrug resistant tuberculosis and relationships to socio-economic, demographic and household factors in northwest Ethiopia. PLoS One 2017;12(2)e0171800.
Amahar Regional State BoFED. AmharaInfo. 2017.
Amhara Regional State Finance and Economic Development. AmharaInfo. 2018 [Accessed 14 February 2019].
Anselin L. Local indicators of spatial association—LISA. Geog Anal 1995;27(2):93–115.
Assefa Y, Alebachew A, Lera M, Lynen L, Wouters E, Van Damme W. Scaling up antiretroviral treatment and improving patient retention in care: lessons from Ethiopia, 2005–2013. Glob Health 2014;10(1):43.
Assefa Y, Gilks CF, Dean J, Tekle B, Lera M, Balcha TT, et al. Towards achieving the fast-track targets and ending the epidemic of HIV/AIDS in Ethiopia: successes and challenges. Int J Infect Dis 2019;78:57–64.
Bradley H, Bedada A, Brahmbhatt H, Kidanu A, Gillespie D, Tsui A. Educational attainment and HIV status among Ethiopian voluntary counseling and testing clients. AIDS Behav 2007;11(5):736–42.
Coburn BJ, Blower S. Mapping HIV epidemics in sub-Saharan Africa with use of GPS data. Lancet Glob Health 2013;1(5):e251–3.
Code for Africa. Shapefiles for Ethiopia's administrative boundaries: regions, zones and woredas Available from: https://africaopendata.org/dataset/ethiopia-shapefiles. [Accessed February]. 2019.
CSA. In: ICF, editor. Ethiopia demographic and health survey 2016: HIV report [Ethiopia] and ICF. Addis Ababa, Ethiopia and Rockville, Maryland, USA: CSA and ICF; 2018.
Deribew A. Distribution of most-at-risk population groups and their perceptions towards HIV/AIDS: a baseline survey in Amhara region for the implementation of mobile HIV counselling and testing. Bethesda, MD: Private Sector Program-Ethiopia, Abt Associates Inc.; 2009.
Ethiopian Ministry of Health. Annual health sector performance report 2016/17. Addis Ababa, Ethiopia: MoH; 2017.
Federal H., Prevention A. Control Office. Report on progress towards implementation of the UN declaration of commitment on HIV/AIDS 2010. 2007.
Fontanet AL, Woldemichael T, Sahlu T, Van Dam G, Messele T, Rinke de Wit T, et al. Epidemiology of HIV and *Schistosoma mansoni* infections among sugar-estate residents in Ethiopia. Ann Trop Med Parasitol 2000;94(2):145–55.
Frehiwot N, Mizan K, Seble M, Fethia K, Tekalign M, Zelalem T. National guidelines for comprehensive HIV prevention, care and treatment. Addis Ababa: Ministry of Health; 2014.
Gezie LD, Taye BW, Ayele TA. Time to unsafe sexual practice among cross-border female sex workers in Metemma Yohannes, North West Ethiopia. BMC Public Health 2015;15(1):710.
Ghosn J, Taiwo B, Seedat S, Autran B, Katlama C. HIV. Lancet 2018;392(10148):685–97.
Girum T, Wasie A, Worku A. Trend of HIV/AIDS for the last 26 years and predicting achievement of the 90–90-90 HIV prevention targets by 2020 in Ethiopia: a time series analysis. BMC Infect Dis 2018;18(1):320.
Glynn JR, Carael M, Buve A, Anagonou S, Zekeng L, Kahindo M, et al. Does increased general schooling protect against HIV infection? A study in four African cities. Trop Med Int Health 2004;9(1):4–14.
Joint United Nations Programme on HIV/AIDS. 90-90-90: an ambitious treatment target to help end the AIDS epidemic. Geneva: UNAIDS; 2014.
Joint United Nations Programme on HIV/AIDS. Miles to go: closing gaps, breaking barriers, righting injustices. Geneva: UNAIDS; 2018.
Lai P-C, So F-M, Chan K-W. Spatial epidemiological approaches in disease mapping and analysis. CRC Press; 2008.
Lakew Y, Benedict S, Haile D. Social determinants of HIV infection, hotspot areas and subpopulation groups in Ethiopia: evidence from the National Demographic and Health Survey in 2011. BMJ Open 2015;5(11)e008669.
Odland J. Spatial autocorrelation. Newbury Park, CA: Sage Publications; 1988.
Population Census Commission. The 2007 population and housing census of Ethiopia. 2010.
Tiruneh K, Wasie B, Gonzalez H. Sexual behavior and vulnerability to HIV infection among seasonal migrant laborers in Metema district, northwest Ethiopia: a cross-sectional study. BMC Public Health 2015;15(1):122.
UNAIDS. Global HIV & AIDS statistics — 2018 fact sheet. 2018.
UNAIDS. The global HIV/AIDS epidemic. HIV gov; 2018.
WHO. In: HIV/AIDS, editor. HIV/AIDS Update|Ethiopia. Addis Abeba, ETHIOPIA: WHO Country Office for ETHIOPIA; 2015.
WHO Africa. HIV/AIDS. Factsheet. WHO; 2017.
Wilson D, Halperin DT. "Know your epidemic, know your response": a useful approach, if we get it right. Lancet 2008;372(9637):423–6.
World Health Organization. Service delivery approaches to HIV testing and conselling (HTC): a strategic HTC programme framework. 2012.
World Health Organization. Data and statistics 2017. 2017 Available from: http://www.who.int/en/news-room/fact-sheets/detail/hiv-aids. [Accessed 15 November 2018].