Journal of Affective Disorders Reports 10 (2022) 100433

Contents lists available at ScienceDirect

Journal of Affective Disorders Reports

journal homepage: www.sciencedirect.com/journal/journal-of-affective-disorders-reports

Research Paper

Depression onset and its association with community HIV prevalence: A geospatial and panel analyses of nationally representative South African data, 2015–2017

Kwabena Asare[a,b,c,*], Andrew Tomita[d,e], Nigel Garrett[a,b], Rob Slotow[f,g], Jonathan K Burns[h,i], Frank Tanser[a,b,j], Diego F. Cuadros[k]

[a] Discipline of Public Health Medicine, School of Nursing and Public Health, University of KwaZulu-Natal, Durban, South Africa
[b] Centre for the AIDS Programme of Research in South Africa (CAPRISA), University of KwaZulu-Natal, Durban, South Africa
[c] Health Economics and HIV and AIDS Research Division (HEARD), University of KwaZulu-Natal, Durban, South Africa
[d] Centre for Rural Health, School of Nursing and Public Health, University of KwaZulu-Natal, Durban, South Africa
[e] KwaZulu-Natal Research Innovation and Sequencing Platform (KRISP), College of Health Sciences, University of KwaZulu-Natal, Durban, South Africa
[f] School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa
[g] Department of Genetics, Evolution and Environment, University College, London, UK
[h] Institute of Health Research, University of Exeter, Exeter, UK
[i] Department of Psychiatry, School of Clinical Medicine, University of KwaZulu-Natal, Durban, South Africa
[j] Centre for Epidemic Response and Innovation (CERI), School of Data Science and Computational Thinking, Stellenbosch University, Stellenbosch, South Africa
[k] Digital Epidemiology Laboratory, Digital Futures, University of Cincinnati, Cincinnati, USA

ARTICLE INFO

Keywords:
Depression
HIV
Community
Prevalence

ABSTRACT

The scaling up of antiretroviral therapy services over the past decades has led to a remarkable reduction in HIV infections and HIV-related deaths in South Africa (SA). While this is a step in the right direction, it brings a new public health challenge into focus, namely psychological challenges associated with such chronic and often stigmatising condition in SA, home to the largest HIV epidemic. Given the current lack of national-level evidence, we investigated the role of the HIV epidemic on depression onset in SA using nationally representative panel data from the South African National Income Dynamics Study (SA-NIDS). Our incident cohort consisted of 13,020 sampled adult participants who were depression-free in Wave 4 (baseline year of 2015). We then measured the risk of depression onset in Wave 5 (year 2017) based on the level of HIV prevalence in the community where study participants resided at baseline. A High-resolution map of HIV spatial heterogeneity (i.e., community HIV prevalence) was generated using ordinary kriging mapping methods from a separate nationally representative data source that corresponded to the investigation period. Geospatial analyses were conducted to identify the spatial structure of HIV and depression onset, and generalised estimating equations (GEE) regression models were fitted to determine the risk of depression onset over time based on community HIV prevalence. Our geospatial analyses indicated that HIV and depression onset prevalence spatially overlapped in the eastern part of the country, particularly in Gauteng, KwaZulu-Natal, Mpumalanga, and Free State province. The GEE regression analyses indicated that individual residency in a community with high HIV prevalence was significantly associated with a higher risk of depression than a low HIV prevalence community (adjusted odds ratio =1.45, 95% CI=1.12-1.48). For the first time, we identified a geospatial overlap between HIV and depression, with a greater risk of depression onset in high HIV prevalence communities, at a national scale in SA. There is a need for place-based policy interventions that prioritise the availability of and access to mental health services in high HIV prevalent SA communities, in an ageing HIV epidemic.

* Corresponding author at: Discipline of Public Health Medicine, School of Nursing and Public Health, University of KwaZulu-Natal, Durban, South Africa.
E-mail address: Kwabena.Asare@outlook.com (K. Asare).

https://doi.org/10.1016/j.jadr.2022.100433
Received 15 July 2022; Received in revised form 26 October 2022; Accepted 14 November 2022
Available online 15 November 2022

1. Introduction

The World Health Organisation (WHO) categorises depression among the most frequently occurring mental health disorders, and a leading cause of disability globally (Murray et al., 2012). Consequently, mental health was an integral part of the sustainable development goal (SDG) three (United Nations, 2019). Depression, a mood disorder that causes persistent feelings of sadness and loss of interest, can lead to debilitating interference with daily functioning, and fatal outcomes when left untreated (World Health Organisation, 2021). Despite the danger of untreated mental health, timely access to mental health services can be a big challenge in resource-limited, HIV endemic, sub-Saharan African (SSA) settings, where the consequence of untreated depression among people living with HIV (PLHIV) includes non-adherence to Anti-retroviral treatment (ART) (Cook et al., 2002; Nakimuli-Mpungu et al., 2012; Truong et al., 2021) as well as risky sexual practices (Kelly et al., 1993; Murphy et al., 2001) that might contribute to onward transmission of HIV. In South Africa, fewer than one in ten people with mental health challenges receive the care they need (Chisholm et al., 2006). Relatedly, depression is approximately 3-fold more frequent among PLHIV (Bernard et al., 2017). According to systematic reviews/meta-analyses, between 16.8%-24.0% of PLHIV experience clinically diagnosed major depressive disorder in SSA (Bernard et al., 2017; Lofgren et al., 2020) or 25.5%–36.0%, based on depressive symptomatology screening with varied depression scales (Lofgren et al., 2020; Zhu et al., 2019). In South Africa, between 11 and 53.8% prevalence of depressive symptomatology is estimated among PLHIV (Van Coppenhagen and Duvenage, 2019; MacLean and Wetherall, 2021).

The relationship between HIV and depression has been well established at the individual level (MacLean and Wetherall, 2021), with risk factors categorised under biological and psychological origins (World Health Organisation, 2021). Biologically, inflammatory cytokine-induced anxiety and appetite loss among PLHIV may help exacerbate depression (Kelley et al., 2003). In terms of psychosocial factors, marginalisation, disease stigma, social isolation, and fear of disclosure of HIV status are also known to contribute to depression onset among PLHIV (Nanni et al., 2015; Simoni et al., 2011; Herek and Capitanio, 1993; Obermeyer et al., 2011). Although the vast majority of interventions are individually targeted, over the last few decades, there has been a considerable shift in the fight against HIV that goes beyond addressing individual-level risk factors (UNAIDS, 2015; Chippindale and French, 2001) with a focus on the potentially important role of the community as part of HIV intervention strategies (UNAIDS, 2015). This is due to the growing realisation of the critical relevance of community structure in relation to the extent of the HIV challenge and mitigation efforts (Ve, 2005). However, the strategic importance of the community can be threatened by the degree to which the intricacies of the HIV epidemic affect the psychosocial functioning of its members in general (vE, 2005). It has been established that the social stigma and anxiety that come with HIV infection may have adverse repercussions, not only for the individual but also for their family (Demi et al., 1997), partners (Ve, 2005), and caregivers (Vandevanter et al., 1999), which might eventually lead to depression onset. Recent evidence has also demonstrated the effects of spatially clustered HIV outcomes, such as community viral load, on subsequent HIV incidence among residents (Tomita et al., 2020).

We, therefore, hypothesise that community HIV prevalence can be linked with depression onset among residents. This investigation is critical for addressing mental health challenges that contribute to a sustained HIV epidemic, but are not well understood due to the lack of large-scale national-level evidence from SSA countries, including South Africa. This study addresses this research gap by quantifying the impact of the spatial heterogeneity of HIV community prevalence on depression onset, using unique nationally representative datasets from South Africa.

2. Methods

2.1. Data sources

We used data from wave 4 (year 2015) and wave 5 (year 2017) of the South African National Income Dynamics Study (SA-NIDS) and spatial information from a published study (Kim et al., 2021) that used data from the 2016 South Africa Demographic and Health Survey (SA-DHS-2016). The SA-NIDS is a population-based longitudinal surveillance study that collects unique information on trends in household living and health conditions in South Africa (Leibbrandt et al., 2009). A wave in the SA-NIDS refers to a round or panel of data collection. The sampling design of SA-NIDS takes a two-stage cluster sampling approach to attain a nationally representative sample of households (Leibbrandt et al., 2009). From its inception in 2008 (wave 1 or base wave), the first sampling stage involved the selection of 400 out of the 3000 Primary Sampling Units (PSUs) from Statistics South Africa's (Stats SA) Master Sample, with proportional allocations based on the population sizes of the 53 district councils in South Africa. A PSU in SA-NIDS geographically consisted of at least one Enumeration Area (EA) from the SA 2001 census with a minimum of 74 households (Leibbrandt et al., 2009). The second stage sampling involved dividing each PSU into clusters consisting of eight households (dwelling units). Two clusters from each of the PSU were allocated to the SA-NIDS (Leibbrandt et al., 2009). In each household or dwelling unit from the selected clusters, all consenting study participants were administered the SA-NIDS questionnaire, which included psychometric evaluation of depressive symptomatology. Further details of the SA-NIDS methodology are provided in a technical report (Leibbrandt et al., 2009).

The publicly available (de-identified) SA 2016 Demographic and Health Survey (SA-DHS, 2016), another nationally representative sample of households in South Africa, collected blood samples for HIV testing and other relevant behavioural, demographic, socio-economic, and geospatial variables (National Department of Health, ICF, 2019). In the SA-DHS-2016, HIV status was determined based on a parallel ELISA (enzyme-linked immunosorbent assay) testing algorithm. E411 Cobas HIV 1/2 Combi Assay (Roche) and Genscreen HIV 1/2 Combi Assay (Bio-Rad) were used for concordant/discordant confirmatory rapid test results. Further details of the HIV testing and the SA-DHS-2016 methodology can be found in the SA-DHS report (National Department of Health, ICF, 2019).

2.2. Primary outcome

Depression, the primary outcome of this study, is based on the abridged 10-item version of the Center for Epidemiologic Studies Depression Scale (CES-D) from the SA-NIDS Adult questionnaire in wave 4 (year 2015) and wave 5 (year 2017). The CES-D is a valid and reliable instrument for psychometric assessment that captures self-reported symptoms indicative of depression during the past seven days (Nicola and Martin, 2019; Cole et al., 2004). It involves a four-point Likert scale ranging from 0 = rarely/none of the time (less than 1 day) to 3 = almost/all the time (5–7 days) for each of the 10 items. We used a composite score of the 10 items (Cronbach's $\alpha = 0.75$) per study participant, with a threshold of $\geq$10 scores to indicate depressive symptomatology, similar to a previous investigation (Andresen et al., 1994). To obtain a better effect of the community level HIV prevalence on the risk of depression onset (and minimise reverse causation), we created an *incident-cohort* by including only study participants without depression at baseline (SA-NIDS, wave 4, year 2015) for all analyses in this study.

2.2.1. Spatial mapping of HIV and depression

We generated continuous surface maps of both HIV prevalence and depression onset prevalence. The primary exposure of our study was community HIV prevalence from the SA-DHS-2016 as reported in the

already mentioned study that assessed the association between socio-economic and behavioural indicators and spatial structure of HIV in SA (Kim et al., 2021). The first step in the spatial mapping of HIV prevalence, from the original study (Kim et al., 2021), was to perform a gender-stratified multivariable logistic regression model (outcome=HIV, exposures=socio-economic, demographic, and behavioural factors selected based on previous association with HIV risk (Cuadros et al., 2017, 2019)). Afterwards, continuous surface maps for each significant variable in the gender-stratified multivariable logistic regression model were generated using ordinary kriging mapping methods. In the second step, raster format HIV prevalence maps with a 5 km grid resolution were generated by substituting values from all continuous surface maps based on the multivariable logistic regression model by gender. In the final step, HIV prevalence maps with the gender stratified density maps were combined to generate a 5 km × 5 km pixel resolution map of the community HIV prevalence, which we imported for this study. The imported HIV prevalence map was then overlayed with global positioning system (GPS) coordinate locations of the SA-NIDS households at DataFirst's Secure Data Centre at the University of Cape Town, where each participant was assigned to the general HIV prevalence of their community (i.e., HIV community prevalence extracted from the HIV prevalence map in the corresponding EA).

Afterwards, a continuous surface map of the prevalence of depression onset using the *incident-cohort* dataset was generated using the standard kernel interpolation technique (Waller and Gotway, 2004). This measure was computed using a moving two-dimensional Gaussian kernel of a 30-km search radius. First, all participants were located to the exact household of residence, and the measurements (depression onset) were superimposed on a geographic representation of the study area consisting of a grid of 1-km × 1-km pixels. Next, the kernel moved systematically across the grid and calculated a Gaussian-weighted estimate of the different measures for the unique neighbourhood around each pixel on the grid. The spatially smoothed averages of both HIV prevalence and depression onset prevalence were then aggregated at the district level for further spatial analyses.

2.2.2. Spatial data analyses: geospatial structure of HIV and depression onset prevalence

The geospatial structure of HIV prevalence and depression onset prevalence was assessed using spatial univariate and multivariate analyses with geospatial GeoDa and ArcGIS Pro environment (Anselin et al., 2022; ESRI, 2020). First, spatial clustering (hot spot identification) of HIV prevalence and depression onset prevalence were identified using the Optimised Hot Spot Analysis in the ArcGIS Pro environment. Briefly, this method can identify statistically significant spatial clusters of high values (hot spots) and low values (cold spots) using the Getis-Ord-Gi* statistics (Songchitruksa and Zeng, 2010; Alene et al., 2019). This method works by looking at each feature within the context of neighbouring features. The local sum for a feature and its neighbours is compared proportionally to the sum of all features and calculates statistically significant z-score results. For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot) (Stopka et al., 2014; Meyers et al., 2014). Maps were generated to illustrate the locations of the statistically significant hot spots or cold spots of HIV and depression onset prevalence. Second, multivariable spatial associations between both variables, HIV prevalence and depression onset prevalence, were estimated using K-means clustering analysis. K-means is a partitioning clustering method in which the data are partitioned into k groups (i.e., four groups). In this clustering method, the n observations are grouped into k clusters such that the intra-cluster similarity is maximised (or dissimilarity minimised) and the between-cluster similarity minimised (or dissimilarity maximised). A further detailed description of these geospatial methods can be found elsewhere (Anselin et al., 2006; Murray and Grubesic, 2013). Estimations for each variable, HIV prevalence, and the onset of depression in each cluster identified were reported. All maps were generated using ArcGIS Pro (ESRI, 2020).

2.3. Statistical data analyses: association between community HIV prevalence and depression onset

We summarised the baseline socio-demographic details of the *incident-cohort* and examined the association between community HIV prevalence and depression onset with generalised estimating equations (GEE) regression modelling (Zeger et al., 1988). We modelled HIV prevalence as an ordinal binary variable of three levels (bottom, middle, and top terciles), with each tercile representing a unique category. In the multivariable GEE regression model, we adjusted for socio-demographic variables (e.g., gender, race, age, educational attainment, employment status, income, urban/rural). Also, considering the survey design of the SA-NIDS (Leibbrandt et al., 2009), we adjusted all proportion and regression-based estimates with post-stratification weights to allow our results to better represent the latest South African population. A methodological description of the construction of post-stratification weights for the SA-NIDS is published elsewhere (Nicola and Martin, 2019).

2.4. Ethics statement

The SA-NIDS study was approved by the Ethics Committee of the University of Cape Town (697/2016). The use of SA-NIDS data for this manuscript was approved by the University of KwaZulu-Natal Biomedical Research Ethics Committee (BE 111/14). The use of SA-DHS data for this manuscript was also approved by the University of KwaZulu-Natal Biomedical Research Ethics Committee (00007107). This study follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

3. Results

3.1. Socio-demographic profiles of study subjects

The baseline (wave 4, year 2015) socio-demographic details of the 13,020 study participants of the *incident-cohort* are presented in Table 1. To highlight some background. Most of the study participants (41.2%) were adults aged less than 30, and 55.3% indicated they were not married. About half of the respondents (52.5%) were unemployed, and 41.0% were in rural areas, 49.5% in formal-urban, and 9.6% in informal-urban areas, based on residential type.

3.2. Geospatial distribution of HIV and depression onset prevalence

The spatial distribution of HIV prevalence and depression onset prevalence in SA is illustrated in Fig. 1. A hot spot of high HIV prevalence was identified in the provinces of Gauteng and KwaZulu Natal and parts of the Mpumalanga, Free State, Northwest, and Eastern Cape (red areas in the second map on the left in Fig. 1). Likewise, a hot spot of depression onset was identified covering similar hot spot areas of HIV prevalence, including Gauteng, KwaZulu-Natal, Mpumalanga, Free State, and Eastern Cape (red areas in the second map on the right in Fig. 1). Multivariable clustering analysis identified an area with the highest burden of both diseases (HIV and depression) where the hot spots of both locations were identified. This cluster of the high prevalence of both diseases (Cluster 1 illustrated in dark purple in the map at the bottom in Fig. 1) had an HIV prevalence of 22.9% and a depression onset prevalence of 29.3% (Table 2). Conversely, a cluster of low HIV and depression onset prevalence (Cluster 3) was identified in the southwestern part of the country, within the provinces of Northern Cape and Western Cape (light blue areas in the map at the bottom of Fig. 1), with an HIV prevalence of 12.8% and a depression onset prevalence of 12.6% (Table 2).

Table 1
Sociodemographic profiles of study subjects ($N = 13,020$).

Variable	Category	n	%
Gender:	Male	5327	46.3%
	Female	7691	53.7%
Race:	White	10,747	81.2%
	African	1898	8.5%
	*Coloured	111	2.4%
	Asian/Indian	264	7.9%
Age category:	15-19	2326	14.7%
	20-24	1896	12.9%
	25-29	1617	13.6%
	30-34	1296	12.1%
	35-64	4855	39.9%
	65+	1025	7.0%
Marital status:	Married	3169	29.5%
	Living with partner	938	5.8%
	Widow/Widower	1100	6.6%
	Divorced or separated	267	2.8%
	Never married	7540	55.3%
Highest educational attainment:	Below High School	994	4.9%
	Completed High School	8562	60.7%
	Beyond High School	3459	34.4%
Employment status:	Unemployed	7889	52.5%
	Employed	5108	47.5%
Household income:	1st quintile	2573	18.4%
	2nd quintile	2505	16.0%
	3rd quintile	2548	17.4%
	4th quintile	2703	21.1%
	5th quintile	2691	27.0%
Location:	Rural	6838	41.0%
	Urban formal	5279	49.5%
	Urban informal	903	9.6%

* The "coloured" is a term used by Statistics South Africa (Statistics South Africa, 2004), a South African ethnic label that includes children/descendants from black-white, black-Asian, black-coloured, and white-Asian unions (Brown and College, 2000). Percentages adjusted for post-stratification weight. Percentages may not add up to 100 due to rounding.

Spatial distribution and hot spot detection for HIV prevalence (maps on the left) and depression onset prevalence (maps on the right). K-means clustering analysis map for the spatial association between HIV and onset of depression prevalence (Map at the bottom).

3.3. Association between community HIV prevalence and depression onset among individual residents

A 23.9% of the sampled population experienced a new depression episode in 2017 (wave 5). Table 3 presents the unadjusted and adjusted GEE regression results, which describe the association between community HIV prevalence and depression onset risk. Generally, residents in communities with higher HIV prevalence demonstrated an increased likelihood of incident depression in wave 5 (2017). Specifically, we found individuals living in communities in the middle (adjusted odds ratio [aOR]=1.28, 95% confidence interval [CI]: 1.12-1.48) and top (aOR=1.45, 95% CI: 1.26-1.66) HIV prevalence terciles, with higher odds of depression onset, compared to individuals living in communities in the bottom tercile.

4. Discussion

We investigated the association between community HIV prevalence and risk of depression onset among individual residents using two nationally representative datasets from SA. Here, we found a geospatial overlap between the burden of HIV and depression onset in SA. Moreover, and for the first time, we found a significant association between higher community HIV prevalence and increased likelihood of depression onset at a national scale in SA, a country suffering the one of the largest HIV epidemics in the world. Our findings illustrate that the extent of community challenges in terms of disease burden matters when it comes to mental health and underscores the need for community-based interventions to prioritise mental health support, particularly in higher HIV endemic settings.

Regarding plausible explanations about our main finding, the impact of community HIV burden on depression risk among community members may parallel their collective economic hardship experienced. Within the UNAIDS 90-90-90 global targets, SA has made less progress (in the middle 90) in sustained ART among PLHIV (CDC, 2022). The pressure for adherence and sustained care for chronic conditions such as HIV can, no doubt, inflict a burden, particularly in impoverished communities, which can be financially and psychologically taxing for both PLHIV and the caregivers (with and without HIV) who support them (Ve, 2005; Schulz et al., 1995; Pinquart and Sorensen, 2007). A previous study from SA has shown that households spend a considerable amount of time and money to obtain ART from an overwhelmed healthcare system (Schulz and Sherwood, 2008). Another survey from SA reported a higher prevalence of depressive symptoms among the family members of PLHIV (Nyirenda et al., 2013). In addition to collective economic hardship and caregiver burden, HIV-related stigma and depression onset risk (Ashaba et al., 2019) might be parallel at the community level. Stigma, as a social construct, is a dehumanising social label placed due to deviation from a cultural ideal or expectation (Visser et al., 2009). Although HIV is an endemic challenge in SA, we argue that HIV stigma is still relevant, which may help explain its impact on depression onset in high prevalence communities (Jacob et al., 1987; Ross, 1988). To hasten the pace of reaching HIV milestones such as the 95-95-95 UNAIDS targets in SA by 2030 (UNAIDS, 2015), and based on the evidence of the geospatial overlap of both health challenges observed in our study, we advocate that the SDG goal three on mental health (United Nations, 2019) must be addressed based on geographically prioritised evidence-based interventions that are focused on HIV related depressive precursors such as stigma, anxiety, and limited family support (Breuer et al., 2011). Therefore, mental health services should be a major part of routine HIV care, with easy access by the wider endemic community to help reduce related depression and improve HIV implementation outcomes such as adherence to ART (Cook et al., 2002; Truong et al., 2021) and safe sexual behavioural practices (Kelly et al., 1993; Murphy et al., 2001). This, by extension, can improve the associated intervention outcomes such as viral suppression and promote a consistent reduction in new HIV infections over time (UNAIDS, 2015). Although easier said than done, more human resources (i.e. training at primary health care) and large-scale evidence on community-based mental health services that are part of routine HIV care are needed (World Health Organization, 2004).

Several studies have assessed the impact of life-threatening diseases such as HIV on the mental health of infected individuals (Valente, 2003; Evans et al., 2002; Myer et al., 2008). The evidence indicates that the stress and physical deterioration caused by HIV infection have prominent negative influences on the mental health of an individual (Sulehri et al., 2010). Depression may alter cellular immunity through related non-adherence to ART (Truong et al., 2021) and may contribute to disease progression in certain immune diseases, such as HIV infection (Evans et al., 2002). This association may generate a synergistic relationship between depression and the HIV epidemic, a collision that emerges as a major public health challenge that needs to be addressed, and highlights a significant compounding challenge for the health care system. Accordingly, understanding the potential association between infectious agents like HIV and the development of depression could provide means to improve both depression outcomes and prevention in high HIV endemic settings like SA.

We also found that the burden of depression onset is clustered in specific geographic locations in SA, mainly in KwaZulu-Natal, Gauteng, Mpumalanga, and Free State Provinces. More importantly, the identified hot spots of depression geographically overlapped with areas where the highest burden of HIV was concentrated, particularly in KwaZulu-Natal Province, which has one of the highest HIV prevalence rates (Kharsany

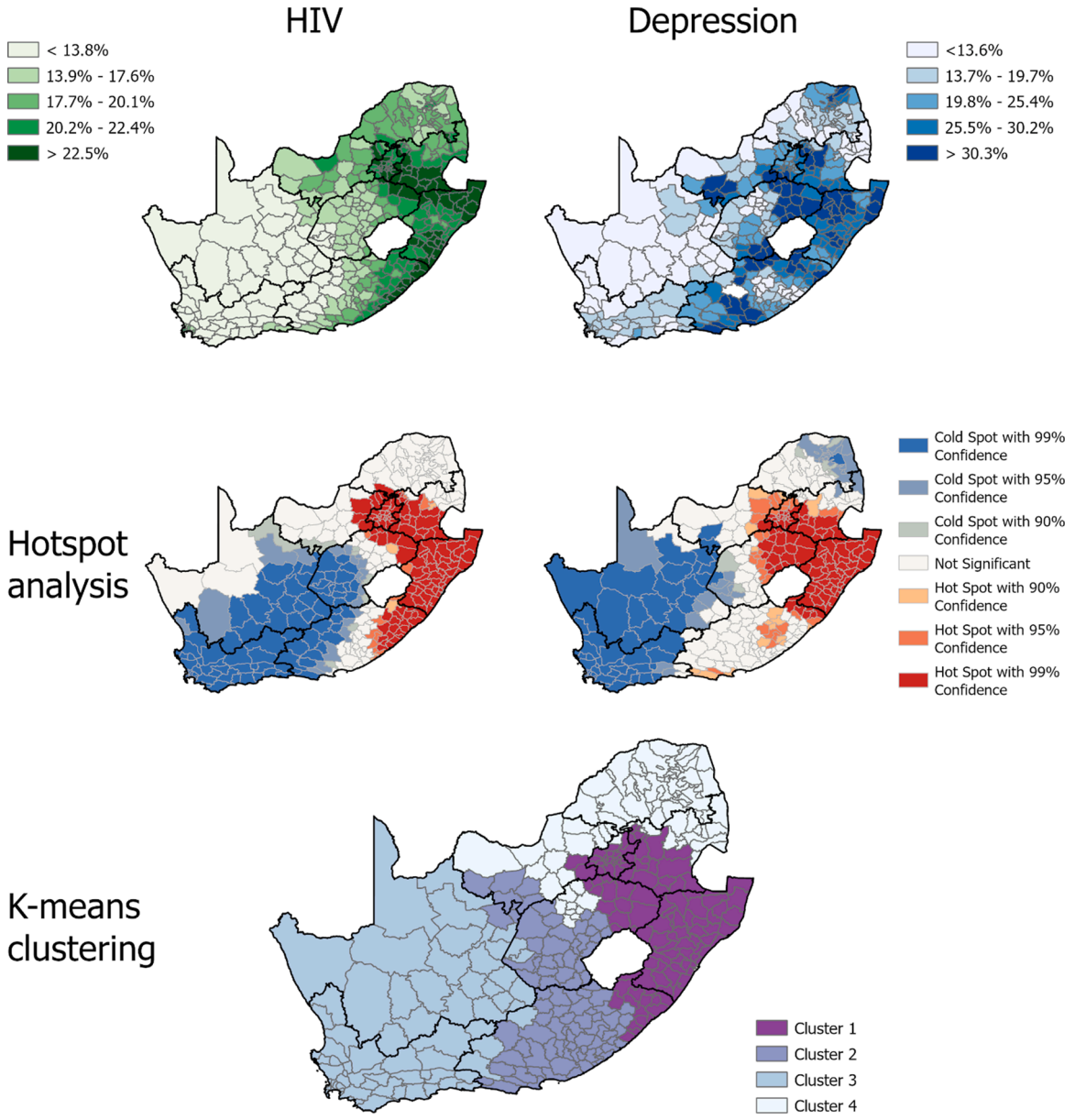

Fig. 1. Geospatial structure of HIV and depression onset prevalence in South Africa.

Table 2
K-means multivariate clustering estimations for HIV prevalence and depression onset in South Africa.

Cluster	HIV prevalence (%)	Depression onset prevalence (%)
1	22.9	29.3
2	17.0	23.5
3	12.8	12.6
4	18.7	16.9

et al., 2018), and where the two infections collide (Kasprowicz et al., 2011). The large HIV epidemic that is currently affecting SA might have a direct or indirect impact on the mental health of its population, paving the way for the emergence of a significant depression epidemic concentrated in the higher HIV burden areas. The identification and geographical location of these areas where HIV and depression collide should play a key role in enabling well-informed policy decisions. This evidence may be critical in allocating resources and organising healthcare services to address the depression epidemic in the country, such as the inequality in access to primary healthcare facilities and healthcare services for PLHIV (Kim et al., 2021). Likewise, this information can assist with the development of effective tools required to promote mental health and maintain efficient and safe mental health services. These could be allocated in geographical areas where the burden of this mental disorder is concentrated and where there may be strong interactions with HIV.

Notwithstanding these novel findings, our study is characterised by some limitations, the major one being the symptom-based evaluation of depression, which might not be as sensitive as clinically diagnosed major depressive disorder. The other limitation is the displacement process for the GPS coordinates in the SA-DHS to protect confidentiality. Although displacement is not an issue with SA-NIDS, as our study was conducted physically at the Secure Data Centre with access to raw GPS coordinates, it is possible that HIV prevalence (map) generated from the SA-DHS GPS coordinates can lead to potential spatial bias (Kim et al., 2021). Notwithstanding these limitations, we found an important association between depression onset and living in a community with HIV high prevalence in the era of the ageing HIV epidemic, based on nationally

Table 3
Multivariable GEE regression model examining the association between community HIV prevalence and depression onset risk among residents.

Variable	Category	aOR	SE	95% CI	
HIV prevalence terciles*: [Bottom third]	Middle third	1.28	0.09	1.12	1.48
	Top third	1.45	0.10	1.26	1.66
Gender: [Male]	Female	1.06	0.06	0.95	1.18
Race: [White]	African	1.11	0.24	0.72	1.70
	#Coloured	1.08	0.25	0.68	1.70
	Asian/Indian	0.64	0.26	0.29	1.41
Age category: (Kelley et al., 2003; Nanni et al., 2015; Simoni et al., 2011; Herek and Capitanio, 1993; Obermeyer et al., 2011)	20-24	1.69	0.19	1.35	2.11
	25-29	2.01	0.23	1.61	2.52
	30-34	2.22	0.28	1.74	2.84
	35-64	2.52	0.28	2.02	3.13
	65+	2.12	0.29	1.62	2.79
Marital status: [Married]	Living with partner	0.76	0.09	0.60	0.97
	Widow/ Widower	1.54	0.15	1.28	1.85
	Divorced or separated	1.73	0.26	1.29	2.31
	Never married	1.26	0.10	1.08	1.46
Education: [Below High School]	Completed High School	0.89	0.08	0.74	1.07
	Beyond High School	0.91	0.10	0.73	1.14
Employment status: [Unemployed]	Employed	0.85	0.05	0.76	0.96
Household income quintile: [1st]	2nd	0.99	0.08	0.85	1.16
	3rd	0.90	0.07	0.77	1.06
	4th	0.67	0.05	0.57	0.79
	5th	0.55	0.05	0.46	0.67
Location: [Rural]	Urban formal	1.13	0.07	1.01	1.26
—	Urban informal	1.15	0.10	0.96	1.37

* Prevalence tercile (actual ranges: Bottom<18.3%, Middle=18.3%-23.1%, Top> 23.1%). #The "coloured" is a term used by Statistics South Africa (Statistics South Africa, 2004), a South African ethnic label that includes children/descendants from black-white, black-Asian, black-coloured, and white-Asian unions (Brown and College, 2000). The regression model was adjusted based on poststratification weight (from final observation of the individual panel) to reflect more recent population estimates produced by Statistics South Africa. OR=Odds Ratio, aOR=Adjusted Odds Ratio, CI=Confidence Interval, SE=Standard Errors. Reference category in square brackets. Discussion

representative data sets (i.e., SA-NIDS and SA-DHS). Additionally, the application of the *incident-cohort* approach that minimised reverse causation attests to the strength of our findings.

Financial disclosure

The second author was funded by the UKRI GCRF (MR/T029803/1 for AT). The content is solely the authors' responsibility and does not necessarily represent the official view of the funders. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

CRediT authorship contribution statement

Kwabena Asare: Investigation, Methodology, Writing – original draft, Writing – review & editing. **Andrew Tomita:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Nigel Garrett:** Investigation, Writing – review & editing. **Rob Slotow:** Investigation, Writing – review & editing. **Jonathan K Burns:** Investigation, Writing – review & editing. **Frank Tanser:** Investigation, Writing – review & editing. **Diego F. Cuadros:** Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors have declared that no competing interests exist.

Acknowledgments

Our study utilised (secure) data from SA-NIDS. Waves 4-5 Data: Southern Africa Labour and Development Research Unit. National Income Dynamics Study 2017, Wave 5 [dataset]. Version 1.0.0 Pretoria: Department of Planning, Monitoring, and Evaluation. Cape Town: Southern Africa Labour and Development Research Unit [implementer], 2018. Cape Town: DataFirst [distributor], 2018. We thank Lynn Woolfrey at DataFirst and Secure Data Centre, University of Cape Town, Cape Town, South Africa.

References

Alene, K.A., Viney, K., Moore, H.C., Wagaw, M., Clements, AC., 2019. Spatial patterns of tuberculosis and HIV co-infection in Ethiopia. PLoS One 14 (12), e0226127.
Andresen, E.M., Malmgren, J.A., Carter, W.B., Patrick, D.L., 1994. Screening for depression in well older adults: evaluation of a short form of the CES-D (Center for Epidemiologic Studies Depression Scale). Am. J. Prev. Med. 10 (2), 77–84.
Anselin, L., Syabri, I., Kho, Y., 2006. GeoDa: an introduction to spatial data analysis. Geogr. Anal. 38 (1), 5–22.
Anselin, L., Rey, S., Li, X., Koschinsky, J., 2022. Geoda, from the desktop to an ecosystem for exploring spatial data. Geographical Analysis 54 (3), 439. https://doi.org/10.1111/gean.12311.
Ashaba, S., Cooper-Vince, C.E., Vořechovská, D., Rukundo, G.Z., Maling, S., Akena, D., et al., 2019. Community beliefs, HIV stigma, and depression among adolescents living with HIV in rural Uganda. Afr. J. AIDS Res. 18 (3), 169–180.
Bernard, C., Dabis, F., de Rekeneire, N., 2017. Prevalence and factors associated with depression in people living with HIV in sub-Saharan Africa: a systematic review and meta-analysis. PLoS One 12 (8), e0181960.
Breuer, E., Myer, L., Struthers, H., Joska, JA., 2011. HIV/AIDS and mental health research in sub-Saharan Africa: a systematic review. Afr. J. AIDS Res. 10 (2), 101–122.
Brown, K., College, M., 2000. Coloured and black relations in South Africa: the Burden of Racialized Hierarchy. Macalester Int. 9 (1), 13.
CDC. Moving towards the UNAIDS 90-90-90 targets. Accessed 20 November 2022, https://www.cdc.gov/globalhealth/stories/moving-towards-unaids.html.
ESRI. ArcGIS Pro.x. Redlands, CA, USA: ESRI. 2020.
Chippindale, S., French, L., 2001. HIV counselling and the psychosocial management of patients with HIV or AIDS. BMJ 322 (7301), 1533–1535 (Clinical research ed).
Chisholm, D., Saxena, S., Ommeren, M.V., 2006. Dollars, DALYs and Decisions: Economic Aspects of the Mental Health System. World Health Organisation, Geneva, Switzerland.
Cole, J.C., Rabin, A.S., Smith, T.L., Kaufman, AS., 2004. Development and validation of a rasch-derived CES-D short form. Psychol. Assess. 16 (4), 360–372.
Cook, J.A., Cohen, M.H., Burke, J., Grey, D., Anastos, K., Kirstein, L., et al., 2002. Effects of depressive symptoms and mental health quality of life on use of highly active antiretroviral therapy among HIV-seropositive women. J. Acquir. Immune Defic. Syndr. 30 (4), 401–409.
Cuadros, D.F., Li, J., Branscum, A.J., Akullian, A., Jia, P., Mziray, E.N., et al., 2017. Mapping the spatial variability of HIV infection in Sub-Saharan Africa: effective information for localized HIV prevention and control. Sci. Rep. 7 (1).
Cuadros, D.F., Li, J., Mukandavire, Z., Musuka, G.N., Branscum, A.J., Sartorius, B., et al., 2019. Towards UNAIDS fast-track goals. AIDS 33 (2), 305–314.
Demi, A., Bakeman, R., Moneyham, L., Sowell, R., Seals, B., 1997. Effects of resources and stressors on burden and depression of family members who provide care to an HIV-infecetd woman. J. Fam. Psychol. 11, 35–48.
Evans, D.L., Ten Have, T.R., Douglas, S.D., Gettes, D.R., Morrison, M., Chiappini, M.S., et al., 2002. Association of depression with viral load, CD8 T lymphocytes, and natural killer cells in women with HIV infection. Am. J. Psychiatry 159 (10), 1752–1759.
Herek, G.M., Capitanio, JP., 1993. Public reactions to AIDS in the United States: a second decade of stigma. Am. J. Public Health 83 (4), 574–577.
Jacob, K.S., John, J.K., Verghese, A., John, TJ., 1987. AIDS-phobia. Br. J. Psychiatry 150 (3), 412–413.
Kasprowicz, V.O., Achkar, J.M., Wilson, D., 2011. The tuberculosis and HIV epidemic in South Africa and the KwaZulu-natal research institute for tuberculosis and HIV. J. Infect. Dis. 204 (4), S1099 suppl-S101.
Kelley, K.W., Bluthé, R.M., Dantzer, R., Zhou, J.H., Shen, W.H., Johnson, R.W., et al., 2003. Cytokine-induced sickness behavior. Brain Behav. Immun. 17 (1), S112–S118. Suppl.

Kelly, J.A., Murphy, D.A., Bahr, G.R., Koob, J.J., Morgan, M.G., Kalichman, S.C., et al., 1993. Factors associated with severity of depression and high-risk sexual behavior among persons diagnosed with human immunodeficiency virus (HIV) infection. Health Psychol. 12 (3), 215–219.
Kharsany, A.B.M., Cawood, C., Khanyile, D., Lewis, L., Grobler, A., Puren, A., et al., 2018. Community-based HIV prevalence in KwaZulu-Natal, South Africa: results of a cross-sectional household survey. Lancet HIV 5 (8), e427–ee37.
Kim, H., Tanser, F., Tomita, A., Vandormael, A., Cuadros, DF., 2021. Beyond HIV prevalence: identifying people living with HIV within underserved areas in South Africa. BMJ Glob. Health 6 (4).
Leibbrandt, M., Woolard, I., de Villiers, L., 2009. Methodology: Report on NIDS Wave-1. University of Cape Town, South Africa, Cape Town, South Africa.
Lofgren, S.M., Bond, D.J., Nakasujja, N., Boulware, D.R., 2020. Burden of depression in outpatient HIV-Infected adults in Sub-Saharan Africa; systematic review and meta-analysis. AIDS Behav. 24 (6), 1752–1764.
MacLean, J.R., Wetherall, K., 2021. The association between HIV-stigma and depressive symptoms among people living with HIV/AIDS: a systematic review of studies conducted in South Africa. J. Affect. Disord. 287, 125–137.
Meyers, D.J., Hood, M.E., Stopka, T.J., 2014. HIV and hepatitis C mortality in Massachusetts, 2002–2011: spatial cluster and trend analysis of HIV and HCV using multiple cause of death. PLoS One 9 (12), e114822.
Murphy, D.A., Durako, S.J., Moscicki, A.B., Vermund, S.H., Ma, Y., Schwarz, D.F., et al., 2001. No change in health risk behaviors over time among HIV infected adolescents in care: role of psychological distress. J. Adolesc. Health 29 (3), 57–63. Suppl.
Murray, A.T., Grubesic, T.H., 2013. Exploring spatial patterns of crime using non-hierarchical cluster analysis. Crime Modeling and Mapping Using Geospatial Technologies. Springer, pp. 105–124.
Murray, C.J., Vos, T., Lozano, R., Naghavi, M., Flaxman, A.D., Michaud, C., et al., 2012. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the global burden of disease study 2010. Lancet 380 (9859), 2197–2223.
Myer, L., Smit, J., Roux, L.L., Parker, S., Stein, D.J., Seedat, S., 2008. Common mental disorders among HIV-infected individuals in South Africa: prevalence, predictors, and validation of brief psychiatric rating scales. AIDS Patient Care STDs 22 (2), 147–158.
Nakimuli-Mpungu, E., Bass, J.K., Alexandre, P., Mills, E.J., Musisi, S., Ram, M., et al., 2012. Depression, alcohol use and adherence to antiretroviral therapy in sub-Saharan Africa: a systematic review. AIDS Behav. 16 (8), 2101–2118.
Nanni, M.G., Caruso, R., Mitchell, A.J., Meggiolaro, E., Grassi, L., 2015. Depression in HIV infected patients: a review. Curr. Psychiatry Rep. 17 (1), 530.
National Department of Health, ICF, 2019. South Africa Demographic and Health Survey 2016. National Department of Health - NDoH - ICF, Pretoria.
Nicola, B., Martin, W., 2019. Longitudinal and Cross-Sectional Weights in the NIDS Data 1-5. University of Cape Town, Cape Town, South Africa.
Nyirenda, M., Chatterji, S., Rochat, T., Mutevedzi, P., Newell, ML., 2013. Prevalence and correlates of depression among HIV-infected and -affected older people in rural South Africa. J. Affect. Disord. 151 (1), 31–38.
Obermeyer, C.M., Baijal, P., Pegurri, E., 2011. Facilitating HIV disclosure across diverse settings: a review. Am. J. Public Health 101 (6), 1011–1023.
Pinquart, M., Sorensen, S., 2007. Correlates of physical health of informal caregivers: a meta-analysis. J. Gerontol. Ser. B Psychol. Sci. Soc. Sci. 62 (2), P126–PP37.
Ross, M.W., 1988. AIDS phobia: report of 4 cases. Psychopathology 21 (1), 26–30.
Schulz, R., Sherwood, PR., 2008. Physical and mental health effects of family caregiving. AJN Am. J. Nurs. 108 (9), 23–27.
Schulz, R., O'Brien, A.T., Bookwala, J., Fleissner, K., 1995. Psychiatric and physical morbidity effects of dementia caregiving: prevalence, correlates, and causes. Gerontologist 35 (6), 771–791.
Simoni, J.M., Safren, S.A., Manhart, L.E., Lyda, K., Grossman, C.I., Rao, D., et al., 2011. Challenges in addressing depression in HIV research: assessment, cultural context, and methods. AIDS Behav. 15 (2), 376–388.
Songchitruksa, P., Zeng, X., 2010. Getis–ord spatial statistics to identify hot spots by using incident management data. Transp. Res. Rec. 2165 (1), 42–51.
Statistics South Africa, 2004. Concept and Definitions. Statistics South Africa, Pretoria, South Africa.
Stopka, T.J., Krawczyk, C., Gradziel, P., Geraghty, E.M., 2014. Use of spatial epidemiology and hot spot analysis to target women eligible for prenatal women, infants, and children services. Am. J. Public Health 104 (S1), S183–S1S9.
Sulehri, M.A., Dogar, I.A., Sohail, H., Mehdi, Z., Azam, M., Niaz, O., et al., 2010. Prevalence of Depression Among Tuberculosis Patients. Eds.. APMC.
Tomita, A., Cuadros, D.F., Mabhaudhi, T., Sartorius, B., Ncama, B.P., Dangour, A.D., et al., 2020. Spatial clustering of food insecurity and its association with depression: a geospatial analysis of nationally representative South African data, 2008-2015. Sci. Rep. 10 (1), 13771.
Truong, M., Rane, M.S., Govere, S., Galagan, S.R., Moosa, M.-Y., Stoep, A.V., et al., 2021. Depression and anxiety as barriers to art initiation, retention in care, and treatment outcomes in KwaZulu-Natal, South Africa. EClinicalMedicine 31, 100621.
UNAIDS. Understanding fast-track: accelerating action to end the AIDS epidemic by 2030. 2015.
UNAIDS, 2015. Stop AIDS Alliance. Communities Deliver: The Crucial Role of Communities in Reaching Global Targets to End the AIDS Epidemic. UNAIDS, Geneva and Hove.
United Nations, 2019. Sustainable Development Goal 3: Ensure Healthy Lives and Promote Well-Being for All at All Ages Geneva. The United Nations [cited 2019 December 17]. Available from: https://sustainabledevelopment.un.org/sdg3.
Valente, S.M., 2003. Depression and HIV disease. J. Assoc. Nurses AIDS Care 14 (2), 41–51.
Van Coppenhagen, B., Duvenage, H.S., 2019. Prevalence of depression in people living with HIV and AIDS at the Kalafong Provincial Tertiary Hospital Antiretroviral Clinic. S. Afr. J. Psychiatry 25.
Vandevanter, N., Thacker, A.S., Bass, G., Arnold, M., 1999. Heterosexual couples confronting the challenges of HIV infection. AIDS Care 11 (2), 181–193.
Ve, P., 2005. What is the Impact of HIV on Families? WHO Regional Office for Europe, Copenhagen.
Visser, M.J., Makin, J.D., Vandormael, A., Sikkema, K.J., Forsyth, B.W.C., 2009. HIV/AIDS stigma in a South African community. AIDS Care 21 (2), 197–206.
Waller, L.A., Gotway, C.A., 2004. Applied Spatial Statistics for Public Health Data. John Wiley & Sons.
World Health Organisation. (2021). *Depression*. Retrieved 23 November 2021 from https://www.who.int/health-topics/depression#tab=tab_1.
World Health Organization, 2004. Prevention of Mental Disorders. Effective Interventions and Policy Options. World Health Organization, Geneva.
Zeger, S.L., Liang, K.Y., Albert, P.S., 1988. Models for longitudinal data: a generalized estimating equation approach. Biometrics 44 (4), 1049–1060.
Zhu, Q.Y., Huang, D.S., Lv, J.D., Guan, P., Bai, X.H., 2019. Prevalence of perinatal depression among HIV-positive women: a systematic review and meta-analysis. BMC Psychiatry 19 (1), 330.