Assessing spatial patterns of HIV knowledge in rural Mozambique using geographic information systems

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Abstract

OBJECTIVES To conduct a cross-sectional mapping analysis of HIV knowledge in Zambézia Province, Mozambique, and to examine spatial patterns of HIV knowledge and associated household characteristics.

METHODS A population-based cluster survey was administered in 2010; data were analysed from 201 enumeration areas in three geographically diverse districts: Alto Molócuè, Morrumbala and Namacurra. We assessed HIV knowledge scores (0–9 points) using previously validated assessment tools. Using geographic information systems (GIS), we mapped hot spots of high and low HIV knowledge. Our multivariable linear regression model estimated HIV knowledge associations with distance to nearest clinic offering antiretroviral therapy, respondent age, education, household size, number of children under five, numeracy, literacy and district of residence.

RESULTS We found little overall HIV knowledge in all three districts. People in Alto Molócuè knew comparatively most about HIV, with a median score of 3 (IQR 2–5) and 22 of 51 (43%) enumeration areas scoring ≥4 of 9 points. Namacurra district, closest to the capital city and expected to have the best HIV knowledge levels, had a median score of 1 (IQR 0–3) and only 3 of 57 (5%) enumeration areas scoring ≥4 points. More HIV knowledge was associated with more education, age, household size, numeracy and proximity to a health facility offering antiretroviral therapy.

CONCLUSIONS HIV knowledge is critical for its prevention and treatment. By pinpointing areas of poor HIV knowledge, programme planners can prioritize educational resources and outreach initiatives within the context of antiretroviral therapy expansion.

KEYWORDS HIV knowledge, geographic information systems, hot spot analysis, Mozambique, Getis-Ord Gi*, rural health

Introduction

Since 2004, the global community has invested significantly in HIV prevention and treatment through international programmes such as the US President’s Emergency Plan for AIDS Relief (PEPFAR) and the Global Fund to Fight AIDS, Tuberculosis and Malaria (De Cock et al. 2011; Moon et al. 2010, 2011; El-Sadr et al. 2012; Vermund et al. 2012; UNAIDS 2013). Yet, the burden of HIV remains disproportionate, with 68% of all people living with HIV residing in sub-Saharan Africa (SSA) (UNAIDS 2013) and the highest HIV prevalence noted among women of reproductive age (UNAIDS 2013). In Mozambique, the latest 2009 adult HIV prevalence estimate of 11.5% ranks it among the most heavily HIV-affected nations in the world (INSIDA 2010; UNAIDS 2013).

Knowledge of HIV infection is seen as a critical component to its prevention and treatment, where low knowledge often represents a barrier to engaging in care and the subsequent cascade of events needed to initiate antiretroviral therapy (ART) (Ciampa et al. 2012a,b). In SSA, young adults aged 15–24 represented 74% of global HIV infections in 2010, yet only 26% of women and 33% of men had correct and comprehensive knowledge about HIV prevention (Global HIV/AIDS Response 2011).

In previous studies in rural Mozambique, we found that while knowledge of basic HIV concepts, such as
sexual or maternal transmission, was relatively common, significant misperceptions existed which may impact HIV prevention and care delivery, including a belief that washing after sexual contact can protect against transmission and that HIV results from a curse (Ciampa et al. 2012a,b). These misperceptions have been subsequently linked to negative health seeking behaviours, such as delayed access to care or avoiding conventional HIV care altogether in favour of traditional healers (Audet et al. 2012). Conversely, increased HIV knowledge has been correlated with reduced stigma and increased uptake in HIV testing (Audet et al. 2012; Mukolo et al. 2013a,b).

Health outcomes can correlate with geography (Cromley & McLafferty 2012; Richardson et al. 2013). Past research suggests that proximity to health services is associated with primary care utilisation (Tanser et al. 2006), contraceptive use (Brauner-Orto et al. 2007) and higher vaccine rates (Al-Taiar et al. 2010; Blanford et al. 2012). A study in rural Malawi found that as distance from health facilities increased, people were less likely to receive their HIV test results (Thornton 2008). A similar study in Mozambique found that proximity to sexual and reproductive health services was associated with increased service utilisation (Yao et al. 2012). Our study is the first in Mozambique in which HIV knowledge has been studied with respect to proximity to health facilities.

As scaling-up of global HIV/AIDS activities continues, efficient and evidence-based health planning and evaluation tools are needed. Recent developments within geospatial technologies enable the creation of maps with spatial and temporal data relevant to health planning, implementation and research (Richardson et al. 2013). Geographic information systems (GIS) can characterise locations with geographic data, allowing users the ability to conduct spatial analyses that provide insights into geographic relationships. For example, spatial distribution of HIV infection was recently mapped across SSA (Cuadros et al. 2013) as part of the concept of ‘Know your epidemic, know your response’ (UNAIDS 2007). This study found evidence of clustering of HIV infection at a microgeographic scale (Cuadros et al. 2013). Additionally, the incidence of sexually transmitted infections (STIs) has been investigated and found to be associated with geographic areas of high HIV prevalence (Ramjee & Wand 2014). Analyses using GIS, such as spatial clustering methods, have been used for disease and epidemic surveillance to not only better monitor HIV infection (Cuadros et al. 2013), but also malaria incidence and prevalence (Yeshiwondim et al. 2009; Haque et al. 2014), depression prevalence (Salinas-Pérez et al. 2012), drug adherence (Hoang et al. 2011), obesity (Turi et al. 2013) and create eco-epidemiological models to analyse gene–environmental interactions (Torbick et al. 2014). GIS allows one to make sense of geographic patterns in space and time, and help identify and analyse correlates of health behaviour and outcomes (Cromley & McLafferty 2012).

In this study, we examine the spatial patterns and clustering of HIV knowledge within three districts of Zambezia Province, Mozambique. We hypothesise that geographic patterns of higher and lower HIV knowledge can be identified, ultimately illuminating areas where enhanced HIV education interventions are needed.

**Methods**

**Study context**

Zambezia Province, located in north-central Mozambique (Figure 1), is predominantly rural and depends almost entirely on subsistence farming and fishing (Moon et al. 2010). Of 11 provinces, Zambezia is one of the country’s poorest performing province in terms of health indicators and continues to have high rates of tuberculosis (TB) and malaria, poor maternal and child health (MCH) indices, high levels of malnutrition and low literacy rates (Ciampa et al. 2012a,b; Instituto Nacional de Estatistica Ministério da Saúde 2013). In 2009, Zambezia also had the highest estimated number of persons living with HIV in Mozambique (nearly 20% of the HIV-infected adult population) (INSIDA 2010). Additionally, a 16-year civil war (1976–1992), fought disproportionately in Zambezia Province, resulted in destruction of many of its hospitals and clinics. In 2009, World Vision United States was awarded a United States Agency for International Development (USAID) grant called Strengthening Communities through Integrated Programming (SCIP), which is a 5-year multisector programme aimed at improving the health and livelihoods of children, women and families in Zambezia. Known locally as Ogumaniba, which means ‘united for a common purpose’, SCIP is a consortium of five international organizations.

**Survey data**

At programme initiation, Ogumaniba conducted a baseline population-based survey from August 8 to September 25, 2010. The protocol for data collection was approved by the Mozambican National Bioethics Committee for Health (Comité Nacional de Bioética em Saúde [CNBS]) and the Institutional Review Board of Vanderbilt University. The survey collected information on >500 variables in eight dimensions and was designed to gather household information from the female heads of households.
The design and implementation of this survey are detailed elsewhere: http://globalhealth.vanderbilt.edu/manage/wp-content/uploads/phase1and2_report.pdf. Briefly, survey teams completed 3749 interviews in 259 enumeration areas (EAs) across Zambézia Province. A large representative sample (201 EAs) from three diverse districts (Alto Molócuè, Namacurra and Morrumbala) in Zambézia was obtained to increase the precision of survey results while minimising cost. This survey will be repeated at the programme’s end in mid-2014, allowing for an interrupted time-series analysis of the impact of this large-scale, multisector intervention.

Of the 43 health facilities in our three focus districts, 15 were in Alto Molócuè, 11 in Namacurra and 17 in Morrumbala. At the time of survey administration, Alto Molócuè and Namacurra had only two facilities offering a complete package of HIV care and treatment services and Morrumbala had one. This complete package includes pre-ART and ART care, prevention of mother-to-child transmission (PMTCT), care for HIV-exposed children, voluntary counselling and testing (VCT), provider-initiated testing and counselling (PTC), care for TB/HIV coinfected patients, ART adherence support and a variety of psychosocial support activities including HIV education.

District of Alto Molócuè

Alto Molócuè is one of the more economically developed districts of Zambézia with several commercial enterprises. The national highway, one of the few paved roads in the country, connects Alto Molócuè with commercial centres to the south and the deep-sea ports of Nampula Province to the north. The capital has better established HIV care and treatment services (since 2006) that are housed within the main district referral hospital. Nauela, a much smaller peripheral health facility, began offering HIV services in January 2010, approximately 7 months before survey administration. The national highway is integral to Zambézia’s commerce, and as such, Alto Molócuè inherently receives more commercial exchange because of its geographic location relative to the national highway and its proximity to neighbouring commercial centres.

District of Namacurra

Namacurra district is located in the south of Zambézia Province, approximately 45 min by car on the national highway from the provincial capital Quelimane. The district hospital in the capital, Vila da Namacurra, has been offering HIV services since 2007. Macuze, the district’s second facility was capacitated with ART services in 2009. The port at Macuze is one of only a handful of natural deep water ports on Africa’s eastern coastline and is slated for large investments in infrastructure over the next 5–10 years, and as such, the surrounding areas have received significant focus in both development and health interventions over the last decade. The southern and eastern regions of the district can be difficult to reach with
roads that flood and suffer significant washout during the rainy season.

**District of Morrumbala**

Morrumbala district lies on the western border of Zambezia Province. At the time of survey administration, only Vila da Morrumbala was offering HIV services (initiated 2006). The national highway crosses Morrumbala’s south-western tip, which allows for significant commercial exchange for persons living in proximity. Geographically, much of the district is isolated from government investments because of poor road accessibility. However, the north-western edge of the district shares a border with Malawi, which hosts substantial commercial exchanges for this region. It is not uncommon for Mozambicans to seek health services across the border in Malawi where health facilities are better resourced.

**Household characteristics and calculation of HIV knowledge score**

Household characteristics and data pertaining to HIV knowledge from the three focus districts were analysed. HIV knowledge scores were measured using a previously validated HIV knowledge assessment tool with five questions (Ciampa et al. 2012a,b; Mukolo et al. 2013a,b). Scale domains included adult-to-adult and mother-to-child transmission routes as well as potential transmission by casual contact (Mukolo et al. 2013a,b). HIV knowledge scores ranged from 0 to 9 points (Table 1). For GIS mapping, data were aggregated at the EA-level to maintain respondent anonymity. Median values of HIV knowledge scores were calculated for each EA.

**Determination of literacy and numeracy score**

Literacy and numeracy scores were determined using a modified version of the WRAT-3, a validated English language measure of reading and arithmetic (Ciampa et al. 2012a,b). Scores for literacy ranged from 0 to 57. Respondents were characterised as having low literacy if they had scores 0–15 (US grade level: kindergarten or less), intermediate literacy if their scores were 16–56, and high literacy if they had scores of 57, corresponding to reading the entire word list properly (Ciampa et al. 2012a,b). The numeracy subscale consisted of 15 orally administered items augmented by a visual aid card, scores ranged from 0 to 15. A perfect score of 15 was the US equivalent of 1st grade mathematics skills. Both items were field tested prior to the start of data collection (Ciampa et al. 2012a,b).

**Spatial analysis**

Mapping analyses were conducted using ArcGIS® version 10.2 (ESRI, Redlands, CA, USA). Data were projected into Moznet_UTM_Zone_36S. District boundaries, administrative units and road data were obtained from DIVA-GIS Free Spatial Data (www.diva-gis.org/gdata). These data were originally obtained from Global Administrative Areas (GADM) (www.gadm.org) and the Defense Mapping Agency (DMA) Digital Chart of the World, Fairfax, Virginia, 1992.

A database containing aggregated household characteristics and median HIV knowledge scores from each EA was joined to the EA layer polygon shape file. Records were joined based on each EAs unique identification code. Distance to nearest facility offering ART was calculated as minimum Euclidean distance between each EA feature and the nearest ART facility. This was calculated with the ‘Near’ tool in the ‘Analysis’ tab of ArcToolbox. Only health facilities offering complete HIV care and treatment services were included in this analysis.

Clustering of HIV knowledge scores was assessed using Optimized Hot Spot analysis within the ‘Spatial Statistics’ tool of ArcToolbox. The Optimized Hot Spot analysis uses the Getis-Ord Gi* statistic, which has been used in a

<table>
<thead>
<tr>
<th>Question</th>
<th>Possible Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>In what ways can one adult man or woman transmit HIV to another man or woman?</td>
<td>0 = DK/none, 1 = 1 correct, 2 = 2 correct</td>
</tr>
<tr>
<td>In what ways can a woman with HIV pass it to her baby?</td>
<td>0 = DK/none, 1 = 1 correct, 2 = 2 correct</td>
</tr>
<tr>
<td>How can HIV transmission from an adult man or woman to another be prevented?</td>
<td>0 = DK/none, 1 = 1 correct, 2 = 2 correct</td>
</tr>
<tr>
<td>How can HIV transmission from mother to a child be prevented?</td>
<td>0 = DK/none, 1 = 1 correct, 2 = 2 correct</td>
</tr>
<tr>
<td>Do you think there is a cure for HIV/AIDS?</td>
<td>0 = DK/no, 1 = correct</td>
</tr>
<tr>
<td>Total Possible Range</td>
<td>0–9</td>
</tr>
</tbody>
</table>

HIV knowledge was measured with five items adapted from the Demographic Health Survey V that assess knowledge of HIV transmission, transmission prevention and HIV treatment (Ciampa et al. 2012a,b). Scores ranged from 0 to 9.

DK, do not know.
variety of public health studies to determine spatial clustering (Ord & Getis 1995; Yeshiwondim et al. 2009; Hoang et al. 2011; Turi et al. 2013; Haque et al. 2014). The full technical aspects of this model are also described elsewhere (ESRI. ArcGIS Resources: Optimized Hot Spot Analysis (Spatial Statistics) 2014; Ord & Getis 1995).

Briefly, locational outliers more than three standard deviations away from their closest non-coincident neighbour were identified and removed from analysis. A standard distance calculation was used to determine the optimal distance band based on the average distance to 30 nearest neighbours (after correction for outliers). To determine whether features with high values or features with low values cluster in a geographic area, each feature, within the context of its neighbouring features, was analysed. The local sum for a feature and its neighbours was compared proportionally to the sum of all features. When the local sum was much different than the expected local sum, the feature was characterised as a hot spot (or a cold spot) and a large Z-score was produced (Ord & Getis 1995). Large Z-scores of ±1.96 and ±2.58 correspond to 95 (% < 0.05) and 99 (% < 0.01) percentiles, respectively, suggesting that an observed pattern is unlikely to be due to random chance.

Hot spots and cold spots of higher and lower HIV knowledge scores and their proximity to the health facilities offering ART are represented in Figures 2–4. EAs with larger positive Z-scores (hot spots) signify a more intense clustering of higher HIV knowledge score values (red). Conversely, larger negative Z-scores (cold spots) indicate a more intense clustering of lower HIV knowledge score values (blue). For scale, a 10-km radius around each ART facility represents the travel distance by foot in Mozambique that is thought acceptable for purposes of ART adherence and retention in care.

Statistical analysis

Multivariable linear regression allowed for covariate-adjusted estimation of the relationship between distance to nearest clinic offering ART and HIV knowledge. Covariates included district, respondent age, years of education, number of children <5 years living in the house, household size, literacy and numeracy score. Robust covariance matrix estimates were used to correct for correlated responses within EA. Missing values of covariates were multiply imputed to prevent casewise deletion (Rubin & Little 1987). To account for non-linearity, respondent age, years of education, children <5 living in home and distance to health facility were included in the model using restricted cubic splines (Harrell 2001). Covariates in the multivariable model were chosen a priori to analyse socio-demographic characteristics which may influence one’s health knowledge (Ciampa et al. 2012a, b). R-software 3.0.2 (www.r-project.org) was used for statistical analyses.

Results

Alto Molócué had the highest median HIV knowledge score of the three districts, with 22 of 51 EAs (43%) having median HIV knowledge ≥4 points. Two EAs had median scores of 6.0 and were located <1 km from the main capital health facility Vila da Alto Molócué. Significant clustering (P < 0.05) of higher HIV knowledge exists within the 10-km radius of Vila da Alto Molócué (Figure 2). In the south-west region of the district, one distal EA (about 50 km away by road from Vila da Alto Molócué) had a median score of 1.0. This EA was identified as a significant cold spot. No significant clustering of EAs with either higher or lower HIV knowledge scores was located near the Nauela health facility.

In comparison, only three of 57 EAs (5%) in Namacura (compared to 43% in Alto Molócué) had HIV knowledge scores ≥4 points. These higher scoring EAs were located within 2 km of the Macuze health facility. Unsurprisingly, significant hot spots (P < 0.05) were also identified within the 10-km radius of Macuze (Figure 3). The most frequently occurring knowledge scores in Namacura were between 0.0 and 1.0 (n = 31) with 15 of 57 EAs (25%) have knowledge scores of 0.0. A majority of EAs with scores ≥3.0 were isolated in the south-east region of the district. This region was also identified as an area containing significant cold spots (P < 0.05) of lower HIV knowledge scores. No significant clustering of either higher or lower knowledge scores was located near the main district health facility at Vila da Namacurra.

Within Morrumbala, eight of 93 EAs (9%) had median HIV knowledge scores ≥4 points. Of those eight EAs, five EAs were located in the north-west corner of the district, two EAs were located <2 km from the district capital health facility, and one EA was located west of the district health facility on the border of the Zambezi River. Almost half (43%) of the EAs in Morrumbala (40 of 93) had median HIV knowledge scores of 0.0. Hot spots (P < 0.05) of higher HIV knowledge scores are in proximity to the 10-km radius around the district capital and along the national highway (Figure 4). Hot spots of higher HIV knowledge were also located in the north-west region of the district, where it is known that residents seek HIV services across the border in Malawi.

Of 2920 female heads of household interviewed in the three focus districts, the median age was 32 years, the median household size was four persons, and the median
number of children <5 living in the home was one. Respondents from Alto Molócuè had higher educational attainment as well as higher literacy and numeracy scores compared with Namacurra and Morrumbala (Table 2).

Of the women interviewed in our study, age, higher education, increasing household size and closer proximity to a health facility correlated with higher HIV knowledge. A respondent aged 30 years scored on average a half a point higher on the HIV knowledge scale compared with a 20-year-old respondent [0.43 (95% CI: 0.20–0.66)]. Compared with no education, a respondent with an eighth-grade education scored on average 1.3 points higher. For every one person in the household, HIV knowledge increased 0.05 points [0.05 (95% CI: 0.01–0.10)].

While literacy scores were not significantly correlated with higher HIV knowledge, numeracy scores were (P < 0.001). For every 5-point increment in the numeracy score, HIV knowledge increased almost half a point [0.41 (95% CI: 0.30–0.51)]. Respondents in EAs closer to a health facility offering ART were significantly (P < 0.001) more likely to have higher HIV knowledge. There is a sharp decrease in HIV knowledge as travel distance to a health facility offering HIV services increased from 0 to 25 km. At a distance of 5 km from a health facility, respondents scored half a point higher on the
HIV knowledge scale compared to those living over 35 km [0.59 (95% CI: 0.36–0.82)] (Table 3; Figure 5).

Misperceptions about HIV have been linked to negative health seeking behaviours, such as delay in seeking testing and care. Pinpointing cold spots with lower HIV knowledge scores. A 10-km radius around each health facility shows walking distance considered appropriate for ART care and retention.

**Figure 3** Clusters of Higher and Lower HIV Knowledge Scores, District of Namacurra. EAs in red indicate a hot spot of higher HIV knowledge scores. EAs in blue indicate a cold spot of lower HIV knowledge scores. A 10-km radius around each health facility shows walking distance considered appropriate for ART care and retention.

HIV knowledge scale compared to those living over 35 km [0.59 (95% CI: 0.36–0.82)] (Table 3; Figure 5).

Misperceptions about HIV have been linked to negative health seeking behaviours, such as delay in seeking testing and care. Pinpointing cold spots with lower HIV knowledge scores. A 10-km radius around each health facility shows walking distance considered appropriate for ART care and retention.

**Discussion**

We used ArcGIS to characterise the spatial patterns of HIV knowledge with data from 201 enumeration areas collected in a 2010 population-based cluster survey. HIV knowledge scores (0–9 points) were determined for each EA. Hot spot analysis identified significant clusters of higher and lower HIV knowledge. Higher HIV knowl-
edge scores tended to be in closer proximity to a health facility offering ART. A multivariable linear regression model estimated HIV knowledge associations with distance to nearest clinic offering antiretroviral therapy, respondent age, education, household size, number of children under five, numeracy, literacy and district of residence.

It was disappointing to find very low overall HIV knowledge in all three districts (score values ≤4 points of nine points). Low HIV knowledge scores at baseline suggests that the investments in scaling-up HIV programmes in Zambézia Province, which began in 2006, had not yet translated into widespread knowledge about HIV/AIDS as of survey administration in 2010. Misperceptions about HIV can affect risk behaviours related to HIV transmission and can represent barriers to health care with delays in HIV testing and enrollment into care.

Household characteristics associated with higher HIV knowledge among our female respondents were not surprising: larger household size, increased years of education and increased age. This may reflect increased involvement in antenatal care of this age group and a source of HIV knowledge acquisition. Greater numeracy skills and closer proximity to a health facility offering ART were also associated with higher knowledge.
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**Spatial patterns of HIV knowledge**

### Table 2  Household and Respondent Characteristics by District in Zambézia Province

<table>
<thead>
<tr>
<th>Household characteristics median (IQR)</th>
<th>Alto Molócué (n = 815)</th>
<th>Namcurra (n = 810)</th>
<th>Morrumbala (n = 1295)</th>
<th>Total (n = 2920)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIV Knowledge score (per five points)</td>
<td>3 (2–5)</td>
<td>1 (0–3)</td>
<td>1 (0–4)</td>
<td>2 (0–4)</td>
</tr>
<tr>
<td>Age of respondent (years)</td>
<td>28 (22–37)</td>
<td>34 (25–43)</td>
<td>34 (27–45)</td>
<td>32 (24–41)</td>
</tr>
<tr>
<td>Years of education (years)</td>
<td>3 (2–5)</td>
<td>0 (0–3)</td>
<td>0 (0–2)</td>
<td>0 (0–3)</td>
</tr>
<tr>
<td>Distance of EA from health facility (km)</td>
<td>17.5 (11.4–24.3)</td>
<td>12.3 (8.8–16.2)</td>
<td>38.2 (22.6–69.3)</td>
<td>20.3 (12–38.2)</td>
</tr>
<tr>
<td>Number Children &lt;5</td>
<td>1 (0–2)</td>
<td>1 (0–1)</td>
<td>1 (0–2)</td>
<td>1 (0–2)</td>
</tr>
<tr>
<td>Household size (per one person)</td>
<td>4 (3–6)</td>
<td>4 (3–5)</td>
<td>5 (3–6)</td>
<td>4 (3–6)</td>
</tr>
<tr>
<td>Literacy score (57-point scale)</td>
<td>10 (0–57)</td>
<td>0 (0–3)</td>
<td>0 (0–0)</td>
<td>0 (0–5)</td>
</tr>
<tr>
<td>Numeracy score (15-point scale)</td>
<td>15 (11–15)</td>
<td>9 (6–13)</td>
<td>10 (6–11)</td>
<td>10 (7–14)</td>
</tr>
</tbody>
</table>

Continuous variables are reported as weighted estimates of median (IQR: interquartile range), with each observation being weighted by the inverse of the household sampling probability.

### Table 3  Effects from ordinary least squared modelling in assessing predictors of HIV knowledge in rural Zambézia Province, Mozambique (n = 2920)

<table>
<thead>
<tr>
<th></th>
<th>Effect (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 (ref)</td>
<td>0</td>
<td>0.002</td>
</tr>
<tr>
<td>30</td>
<td>0.43 (0.20, 0.66)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>40</td>
<td>0.38 (0.14, 0.62)</td>
<td></td>
</tr>
<tr>
<td>Education (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 (ref)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.41 (0.16, 0.66)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1.30 (0.90, 1.70)</td>
<td></td>
</tr>
<tr>
<td>Children under five: 4 vs. 2</td>
<td>−0.50 (−0.94, −0.07)</td>
<td>0.045</td>
</tr>
<tr>
<td>Household size (per one person)</td>
<td>0.05 (0.01, 0.10)</td>
<td>0.019</td>
</tr>
<tr>
<td>Literacy score (per five points)</td>
<td>−0.01 (−0.04, 0.02)</td>
<td>0.610</td>
</tr>
<tr>
<td>Numeracy score (per five points)</td>
<td>0.41 (0.30, 0.51)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Distance to nearest ART facility (km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.87 (0.57, 1.17)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>5</td>
<td>0.59 (0.36, 0.82)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.33 (0.11, 0.55)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>0.02 (−0.09, 0.12)</td>
<td></td>
</tr>
<tr>
<td>35 (ref)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>District</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alto Molócué (ref)</td>
<td>−1.10 (−1.33, −0.87)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Morrumbala</td>
<td>−0.97 (−1.19, −0.75)</td>
<td></td>
</tr>
<tr>
<td>Namcurra</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Continuous variables are reported as weighted estimates of median (IQR: interquartile range), with each observation being weighted by the inverse of the household sampling probability.

This model accounts for correlated responses from individuals in the same enumeration areas using the Huber–White robust method to adjust the variance-covariance matrix (Rubin & Little 1987; Harrell 2001).

Community characteristics were also predictive; more remote areas that were susceptible to flooding and/or isolation in the rainy season had residents who were less knowledgeable about HIV/AIDS.

Other studies in SSA have found that women aged 15–24 years had lower levels of accurate and comprehensive HIV knowledge than their male counterparts (UNAIDS 2013). Overall educational achievement among the women in our study was very low. Of women who attended school, HIV knowledge increased with increased schooling. A previous study in Zambézia found that people who learned about HIV prevention in school had the highest odds of knowing multiple ways to avoid infection (Audet et al. 2012). While schools are not the only venue for learning about how to avoid HIV infection, it does indicate that those who have less education are likely missing out on important HIV educational opportunities. The prevalence of illiteracy is substantial in Zambézia (Ciampa et al. 2012a,b). While literacy per se showed no association with HIV knowledge in our study, increasing numeracy score, the basic understanding of numeric concepts and computational skills, was found to be associated with higher HIV knowledge.

In a previous study, women who primarily spoke Echucobo, a local language, had lower levels of HIV knowledge than Portuguese-speaking women, the national language taught in schools (Ciampa et al. 2012a,b). HIV educational interventions that (i) focus on schools, (ii) are incorporated into income generation projects for women’s groups, (iii) are incorporated into interventions for female sex workers and (iv) promote the scale-up of interventions aimed at increasing access to antenatal care, and PMTCT programmes have been employed by Ogmunhiba to increase HIV knowledge in this target population. It will be important to assess in the planned 2014 post-intervention survey whether these interventions have had an impact.

### Strengths and limitations

A study strength includes the representative sampling scheme of our survey. We used GIS to ascertain geo-
graphic clusters of high or low HIV knowledge and identified household characteristics that were associated with higher or lower HIV knowledge. Contextualizing HIV knowledge geographically allows planners to allocate resources and focus community-based HIV outreach initiatives and ART expansion planning more strategically.

A study limitation includes our plausible but unvalidated assumption that people utilise the nearest health facility offering ART services within the district. Distance to health facility was calculated using Euclidean distance between the EA and the health facility offering ART in one dimension. We did not consider some spatial factors such as road type, road conditions or barriers such as mountains and rivers that influence true travel distance (Martin et al. 2008). Nonetheless, Euclidean distance has been a valid proxy for actual travel distance/time (Carlucci et al. 2008; Jones et al. 2010; Cudnik et al. 2012). We also did not consider non-spatial barriers to health care such as socio-economic status. Future work looking at both proximity and access (Yao et al. 2013) will be important, as all districts have both spatial and non-spatial factors that easily act as obstacles to accessing health care.

We found poor overall HIV knowledge in all three rural districts studied, suggesting little impact of prior HIV treatment and prevention investments on overall HIV knowledge. By establishing HIV knowledge scores at baseline (this 2010 survey), our anticipated 2014 survey at the end of the Ogumaniba interventions can help assess their impact on HIV knowledge in these communities.

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