Is it *who you are* or *where you live*? An exploration of associations between people and place in the context of HIV in rural Malawi

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Abstract:

Few studies use a spatial approach to explore relationships between people and place in sub-Saharan Africa or in the context of Human Immunodeficiency Virus (HIV). This paper uses individual-level demographic and behavioral data linked to area-level, spatially-oriented socio-economic and access data to determine how the relationship between area- and individual-level risks and individual HIV status vary in rural Malawians using geographically weighted regression. The Political Economy of Health theoretical framework aids interpretation. Area-level factors include income inequality, absolute poverty, and access to roads, cities, and health clinics. Individual-level factors include high risk sex and sexually transmitted infections. Stratified analysis reveals the role of gender. Spatial models show significant, local-level variation and indicate that area-level factors drive patterns of HIV above individual-level contributions. In distinct locations, women who live further from health clinics, major roads, and major cities are less likely to be infected. For men, HIV status is strongly associated with migration patterns in specific areas. The paper thus concludes that local-level, gender-specific approaches to HIV prevention are necessary.

INTRODUCTION

Where an individual lives matters for overall health and wellness (Mayer 1989; Diez Roux 2001; Dietz 2002; Sampson, Morenoff et al. 2002; Diez Roux 2004; Cummins, Curtis et al. 2007; Entwisle 2007; Lachaud 2007), and similar people behave differently in different places (Duncan, Jones et al. 1998). Contextual, hierarchical, or multilevel models used to examine place-based effects on individuals typically address only the attributes of a specific location, neglecting the spatial distribution and proximity of factors between people and neighborhoods (Chaix, Merlo et al. 2005). As a result, non-spatial models provide only a partial explanation of associations between area- and individual-level predictors and outcomes. In contrast, spatial studies do more than reveal the existence or location of an association: spatial analysis shows where differences are and provides a visual, geographic representation of key associations (Weir, Pailman et al. 2003).

Use of spatial methods is gaining momentum in health research (Macintyre, Ellaway et al. 2002). Yet, only a few studies explore associations between health and place in developing countries (Bujakiewicz and Mulolwa 1993; Ezekiel 1993; Tanser 2001; Benson, Chamberlin et al. 2005; Kandala, Magadi et al. 2006; Kazembe, Kleinschmidt et al. 2006). Understanding of spatial relationships in sub-Saharan Africa or in the context of Human Immunodeficiency Virus (HIV) remains poor. In Malawi, a country where approximately 1 million people are infected with HIV (UNAIDS 2007), and rural infection rates are rising (Bello, Chipeta et al. 2006; Bryceson and Fonseca 2006), little is known about how characteristics of people and place interact to facilitate the spread of HIV. Spatial exploration of the area- and individual-level drivers of HIV may fill a critical gap in understanding by helping researchers answer the who and where questions of HIV transmission in Malawi (Chirwa 1997; Craddock 2000) and by enabling better targeted prevention and treatment efforts.

Previous studies of the drivers of HIV in rural Malawi focused on small geographic areas or on individual behavior (Barden-O'Fallon, deGraft-Johnson et al. 2004; Watkins 2004; Helleringer and Kohler 2005; Smith and Watkins 2005; Kohler, Behrman et al. 2007; Morah 2007). Area-level socio-economic and access factors that enable the spread of HIV receive less attention (Armour 2006; Mtika 2007). To move from an emphasis on individuals to complex economic, social, structural, and cultural drivers of the HIV epidemic (Hobfoll 1998; Craddock 2000; Parker 2001), spatial methods provide several advantages. Primarily, geographic information systems (GIS) technology makes linking databases using geographic information possible and simplifies integration of data from multiple sources into a comprehensive whole (Richards, Croner et al. 1999). Additionally, spatial regression reveals interactions and explores whether the direction, magnitude, and distributions of associations vary over space (Chaix, Merlo et al. 2005). Lastly, mapped results promote improved knowledge acquisition, potentially accelerating the transition from research into practice (Rytkonen 2004).

Two recent spatial studies elucidate variations in the relationships between area-level effects and area-level HIV prevalence in Sub-Saharan Africa. Kleinschmidt et al tested and mapped spatial associations between area-level socio-economic factors and area-level HIV prevalence among youth, concluding that unemployment, ethnicity, and urbanicity were associated with intra-province variations in HIV prevalence and that these associations varied by gender in South Africa (Kleinschmidt, Pettifor et al. 2007). Furthermore, Lachaud used spatial lag models to examine associations between individual- and aggregate-level poverty and provincial HIV prevalence in Burkina Faso (Lachaud 2007). Provincial HIV prevalence was significantly associated with spatial variation in migration, urbanization, and proximity to transportation routes, but the relationship with area-level poverty was not linear (Lachaud 2007).

Building upon previous research, this study provides insight into the drivers and distribution of HIV infection in rural Malawi by exploring spatial associations between area-level factors, individual risk behaviors, and individual HIV status using geographically weighted regression. The research uses a nationally-representative sample of rural Malawians and links individual-level demographic and behavioral data with area-level, spatially-oriented access and socio-economic indicators, creating a comprehensive database of individual- and area-level variables. Associations are mapped, providing a visual representation of geographically specific results. A theoretically-informed conceptual model using the Political Economy of Health (PEH) theoretical framework guides variable selection and clarifies interpretation. The role of area-level socio-economic (income inequality and absolute poverty) and access indicators (distance to roads, healthcare, and major cities) are explored, and individual-level factors including condom use, high risk sex, multiple partners, and migration are also considered. Gender is examined through stratified analysis. Because definition and measurement of *place-based* or *neighborhood-level* effects are complex (Kawachi and Berkman 2003), administrative boundaries may be used to approximate the boundaries of area-level influences on individuals (Macintyre 1997; Blacker 2004). For the purposes of this study, the boundaries for *area-level* will be defined at the aggregate enumeration area, a census-defined boundary that includes approximately 500 households.

BACKGROUND

An estimated 1 million people are infected with HIV in Malawi (USAID 2008): 10% of men and 13% of women are infected nationwide (National Statistical Office NSO Malawi and Macro 2005). Although the highest prevalence rates are in major urban areas (PEPFAR 2007), 80% of Malawi's approximately 13 million people, live in rural areas (UNICEF 2008) where HIV rates are rising (Bello, Chipeta et al. 2006). The absolute numbers of rural people who are infected currently outnumber urban residents by about 3 to 1 (National Statistical Office NSO Malawi and Macro 2005). Increased focus on HIV among rural populations is warranted.

Demographic factors such as education, religion, ethnicity, socio-economic status, and gender play key roles in HIV risk. In Malawi, marriage increases a woman’s risk of HIV, with the highest rates among those divorced or widowed (National Statistical Office NSO Malawi and Macro 2005). Women under age 24 are more than 3 times more likely than their male age peers to be infected in Malawi (National Statistical Office NSO Malawi and Macro 2005), showing clear gender and age dimensions to the epidemic. Infection rates increase among those with higher education and socio-economic status for men and women, and infection patterns vary by ethnicity and religion (National Statistical Office NSO Malawi and Macro 2005).

Behaviors like poor condom use (Munthali, Zulu et al. 2006) and multiple partnerships (Kaler 2004) affect the patterns and presence of HIV in Malawi. In Malawi, condoms are often reserved for sexual encounters with partners who are perceived as higher risk of HIV infection, especially extra-marital partners (Chimbiri 2007). As a result, overall condom use in Malawi is low: only 30% of women and 47% of men report using condoms with their last non-spousal/non-regular partner (National Statistical Office NSO Malawi and Macro 2005). Sexually transmitted infections (STI) are also related to an increased risk of HIV: in Malawi, over 20% of men and women who had an STI were infected with HIV in 2005(National Statistical Office NSO Malawi and Macro 2005). Furthermore, multiple, concurrent sexual partnerships are key determinants in the spread of HIV (Morris and Kretzschmar 1997), and extra marital partnerships are common in Malawi (Kuate-Defo 2004; Chimbiri 2007; Tawfik and Watkins 2007). Lastly, migration plays a role in the transmission and spread of HIV (Zuma, Gouws et al. 2003; Coffee, Garnett et al. 2005; Lurie 2006; Mtika 2007). HIV prevalence is 4% higher among men who migrated in 2005 than those who did not (National Statistical Office NSO Malawi and Macro 2005).

Framing space in the context of HIV

The PEH framework emphasizes how inequalities based on class, ethnicity, race, or gender exacerbate conditions of poor health by fostering social isolation, economic deprivation, power differentials, and insufficient healthcare (Minkler, Wallace et al. 1994; Farmer 1999; Krieger 1999; Farmer, Léandre et al. 2001; Parker 2001; Whiteside and De Waal 2004; Hunter 2007). Applying the PEH to spatial studies of HIV in sub-Saharan Africa may illuminate linkages between individual behavior and area-level socio-economic contexts (Altman 1999; Lindgren, Rankin et al. 2005; Hunter 2007; Mtika 2007; Parikh 2007).

The PEH identifies poverty as one of the most influential ecological risk factors for poor health status (Minkler 1999), and population patterns of good and poor health are highly correlated with areas of wealth and poverty (Krieger 2001). HIV infection is most prevalent among people in their economically productive years (FAO 2003; Heuveline 2004; Mather, Donovan et al. 2005), and poorer persons are less likely to access treatment and care (Phelan, Link et al. 2004). Also consistent with the PEH, the relative distribution of wealth affects health status (Kawachi and Kennedy 1997). Countries with higher levels of income inequality are among those with higher HIV prevalence (Fenton 2004), and income inequality is linked to increased risk for sexually transmitted infections (Holtgrave and Crosby 2003) and to concurrent sexual partnerships (Adimora and Schoenbach 2002). In Malawi, 67% of rural populations were below the poverty line in 2000 (National Economic Council Malawi 2000). The country-level Gini coefficient of 0.38 indicates relatively high overall income inequality, and the percent of people living below the poverty line remained relatively stable at 54% from 1997-2005 (World Bank 2008).

Access to health services, roads, and cities are also important factors in determining individual health choices and outcomes. Access to treatment and care often reflect class, gender, and racial disparities in social and economic systems (Doyal and Pennell 1979). Rural residents generally have less access to health facilities than residents of urban areas (UNAIDS 2008), and women frequently fare worse overall (Parker, Easton et al. 2000; Loewenson 2007). Moreover, roads serve as an indicator for access to livelihood opportunities and services (Smith, Gordon et al. 2001; Porter 2002) and serve as a proxy for mobility (Greig and Koopman 2003; Porter 2007), a factor associated with HIV (Doyal 2001). Roads to urban areas may also be associated with an increased risk of HIV transmission (Girdler-Brown 1998) while urban transit zones are associated with paid sex and multiple partners (Chirwa 1997).

Lastly, the gendered dimension of the AIDS epidemic warrants attention. Biological risk factors (Blocker and Cohen 2000; Glynn, Carael et al. 2001; Quinn and Overbaugh 2005), exacerbated by gender inequity and power differentials (Ghosh and Kalipeni 2005; Luke 2005), partially explain higher rates of HIV among women across much of sub-Saharan Africa (Luke 2003; Kim and Watts 2005; Wellings, Collumbien et al. 2006; Sa and Larsen 2007). Poverty and inequality force many women in rural Africa to depend on sexual relationships for financial support (Gregson, Nyamukapa et al. 2002; Gupta 2002; Luke and Kurz 2002; Kelly, Gray et al. 2003; Luke 2006; Masanjala 2007). In these relationships, women's decision making power is limited, reducing condom use and increasing vulnerability to HIV (Blanc 2001; Dunkle, Jewkes et al. 2004; Pettifor, Measham et al. 2004). The intersections of socio-economics and gender may produce an irony that women' short-term survival tactics may lead to HIV infection (Craddock 2000). Although a gender focus frequently centers on women, men generally control the specifics of sex (Sayles, Pettifor et al. 2006), and understanding the drivers of HIV infection among men is crucial.

STUDY DESIGN AND METHODS

Conceptual Model and Hypotheses:

The PEH informs the study's conceptual model (Figure 1). It is hypothesized that:

- Area-level factors, including income inequality and absolute poverty, will influence HIV such that persons in areas of *greater* relative or absolute poverty will be *more* likely to be infected while those in areas of *lower* relative or absolute poverty will be *less* likely to be HIV infected. Access to roads, healthcare, and urban centers also influence individual HIV status such that those with *greater* access to roads and urban areas will be *more* likely to be infected while those closer to Ministry of Health (MOH) clinics will be *less* likely to be infected.
- Individual-level risk factors such as condom use, previous sexually transmitted infection, multiple partners and migration (for men only) will *increase* the likelihood of infection.
- Relationships between both area- and individual-level factors will vary non-randomly in strength and magnitude over space.
- The strength of both area- and individual-level relationships will be greater for women than for men.

The study population is restricted to rural residents.

Individual-Level Data

All individual-level data come from the Malawi Demographic and Health Survey, 2004 (MDHS). A summary of individual-level variables is presented in Table 1. The 2004 MDHS is a nationally-representative survey of demographic and health information for men and women of reproductive age. The standard DHS survey methodology is available from ORC Macro (ORC Macro 1996). The MDHS uses the master sample frame from the Malawi 1998 census, and enumeration areas serve as primary sampling units for stage one of the two-stage clustered sampling design (National Statistical Office NSO Malawi and Macro 2005). With a target of approximately 15,000 households, 522 clusters were randomly selected, 64 in urban and 458 in rural areas, and households were systematically sampled from those clusters (National Statistical Office NSO Malawi and Macro 2005). All women aged 15-49 years who usually lived in the household were interviewed; every third household for the women's interview was selected for the male questionnaire. All households selected for the male questionnaire were selected for the HIV test. For the overall 2004 MDHS, the response rate was 98%. For HIV testing, 2,485 rural women (response rate 71%) and 2,056 rural men (response rate 65%) accepted (National Statistical Office NSO Malawi and Macro 2005). A study on the effect of non-response on population-level HIV estimates in Malawi found no significant bias (Mishra, Barrere et al. 2008). For the current research, the full MDHS HIV sample is restricted to rural residents and to those who have sexually debuted and are at risk of HIV through sexual transmission: 2,091 women and 1, 827 men.

The MDHS collects detailed information on myriad subject areas including fertility, sexual health, nutrition, and children's health (Aliaga and Ren 2006). Interviewers received extensive training before implementing the survey, and consent procedures were approved in Malawi and the USA. As part of the MDHS, HIV results were voluntarily obtained and dried blood spots tested using a standard protocol (ORC Macro 2005; MEASURE DHS 2008). The MDHS also collected Global Positioning System (GPS) data for all selected clusters (Montana and Spencer 2004). To protect the confidentiality of individuals, all clusters were randomly offset by up to 5km, with one point moved up to 12 km (MEASURE DHS 2008), a minimal error unlikely to affect influences at the area-level scale. GPS coordinates for Malawi are available for 456 rural clusters. Following standard protocols for visualizing data points on a spatial map, the points were projected in ArcGIS using UTM grid zone 36 south and referencing the WGS84 datum.

Several individual-level variables require elaboration. The variable for individual SES is a wealth index incorporating household assets (e.g., bicycle, car, television), dwelling characteristics, and infrastructure (e.g., housing materials, type of water and sanitation facilities). The combined rural and urban samples were divided into population wealth quintiles (National Statistical Office NSO Malawi and Macro 2005). Also, in settings with low overall condom use, *actual use* of a condom reflects higher perceived risk of, or susceptibility to, HIV from an infected partner (Adih and Alexander 1999; Pranitha and Cleland 2005). Therefore, condom *use* with a recent sex partner, spouse or otherwise, is considered a risk factor.

Area-Level Data

A summary of area-level variables is described in Table 1. The area-level socio-economic data come from the Poverty Mapping Project at Columbia University (Columbia University 2008). The project was supported by the World Bank and completed in 2005. Experts at the World Bank created small area estimates of welfare and poverty, using poverty mapping methods that are complex. General details on the methodology are available from Elbers, Lanjouw, and Lanjouw (Elbers, Lanjouw et al. 2003), and specific information for the Malawi study is available from the International Food Policy Research Institute (Benson 2002; Benson, Chamberlin et al. 2005). The spatial units for the poverty mapping exercise are rural aggregated enumeration areas (EA) devised by the National Statistical Office of Malawi for the 1998 National Population and Housing Census, the same sampling frame utilized by the MDHS. Each unit for the poverty mapping exercise aggregates 2 or 3 EAs from the census, creating spatial units with a minimum of 500 households. The complete poverty mapping dataset of Malawi includes 20 measures of poverty and welfare, including the poverty headcount and Gini index, linked to GIS shapefiles for each of 3004 aggregate EAs (Benson 2002; Benson, Kanyanda et al. 2002). The poverty mapping dataset includes only rural populations and excludes the four major urban centers of Malawi - Blantyre, Zomba, Lilongwe, and Mzuzu. Towns and cities in rural areas are included.

Several socio-economic variables require elaboration. The Gini index is a measurement of income inequality in a given area (Coudouel 2008) and can be used to show the influence of economic disparities on health (Lindstrom and Lindstrom 2006). Poverty headcount is the percent of the population whose income is below the poverty line (Coudouel 2008), a valid measure of economic deprivation (Krieger 2003). The Gini index and the poverty headcount represent related, but distinct, measures of poverty (Benson, Chamberlin et al. 2005). High Gini and low Gini variables were created by sorting all enumeration areas by Gini coefficient, from low (greater equality) to high (greater inequality). Equal quartiles were created, and each quartile was assigned a rank from 1-4, assigning "1" to the 25% of enumeration areas in the lowest quartile (highest equality); "2" to the lower middle quartile; "3" to the higher middle quartile; and "4" to the highest quartile (highest inequality). In the analysis, group "1", lowest Gini, serves as the reference for middle Gini (groups 2-3) and group "4", high Gini.

The three variables used to measure area-level access, distance to urban areas, road networks, and health facilities, are derived from existing GIS maps of Malawi. Using ArcGIS software the Euclidean distance was measured between each DHS cluster point and the factor of interest. The road network variables were created using GIS road files created for the 1998 census and supported through funding by the Danish International Development Agency. The health facility latitude and longitude coordinates come from a Japanese International Cooperation Agency study from 1997-2002, aided by the World Health Organization. The data for proximity to cities is derived from digital maps produced for the national census and available from the National Statistics Office in Zomba.

Combining Individual- and Area-level Variables

GIS software, ArcGIS (ESRI 2008) enabled the assembly of the comprehensive database for this contextual study. Every cluster in the MDHS has a geographic location allowing the placement of each DHS cluster correctly on the digital map. This DHS cluster information was spatially joined to the poverty and access geographic datasets, allowing for the visualization and utilization of information simultaneously. Each DHS cluster was assigned the poverty and access information in the aggregate EA in which it is located. The distance from each DHS cluster to a major road, health facility, and major urban area was also determined using the distance calculation features in ArcGIS. The complete database of DHS cluster information with area-level attributes was exported into a database file containing 456 observations, the number of rural DHS clusters. The area-level information was imported into STATA 9.2 (STATA 2007) and merged with the individual level data (including HIV) assigning the same area-level variables to every individual within each cluster, but leaving all other individual level information unique. The database was re-exported into ArcGIS, and each individual was randomly scattered approximately 50 meters from the cluster location using the ArcGIS Duplicate Remover, providing a unique location for every observation. Lastly, this final database was divided by gender, and datasets exported in comma separated values files for use in spatial analysis software.

DATA ANALYSIS

Multivariate, logistic, geographically weighted regression (GWR) models are used to test all individual- and area-level factors, taking explicit account of proximity relationships (Fotheringham, Brunsdon et al. 2002). Geographically weighted regression software, GWR3, is used for analysis (Fotheringham 2005), and the logistic model is fitted using iteratively reweighted least squares. GWR3 produces 2 types of results. First, GWR3 calculates an overall model of global associations, similar to traditional population-averaged logistic regression models, with parameter estimates, standard errors, and t-values. Global odds ratios are reported. Second, and more importantly, GWR calculates local parameter estimates at each observation point, determining associations between independent predictors and HIV status for 2,091 women and 1, 827 men. To estimate local models, the influence (weight) of observations within a specific geographic range (bandwidth) are determined using a distance decay weighting system, assigning more weight to observations closer to the local regression point than to those farther away. Selection of the optimal bandwidth is automated using a cross validation (CV) approach in GWR3 software for separate models for men and women. This convergence process determines the bandwidth for all regression points, reducing the CV score until the number of included observations provides stable global and local parameters. In this study, the optimal fixed bandwidth in decimal degrees is 1.55 for women and 2.38 for men. Monte Carlo simulation tests of spatial variation compare the variance of the observed model parameters against 100 random calibrations of the same model, providing t-statistics of significance for local parameters (Fotheringham, Brunsdon et al. 2002). Local t-statistics are mapped to visually represent spatial variations in significant associations. Additional information on geographically weighted regression and GRW3 software may be found in Fotheringham, 2002 (Fotheringham, Brunsdon et al. 2002).

To display the local model results and facilitate interpretation, individual regression points are used to predict parameter values over continuous space through interpolation (Childs 2004). Interpolation is a method to create smooth surface maps and allow for the visualization of relationships between data points. Spline interpolation methods use a mathematical function that takes regression points and minimizes the variation between them, passing through known values to create a smooth surface of variability over space (Childs 2004). For this analysis, the ArcGIS Spatial Analyst spline tool is used to interpolate the surface with cell size of 1000 meters.

RESULTS AND DISCUSSION

Descriptive statistics

Individual-level characteristics are detailed in Table 2. Levels of individual risk behavior differ for men and women. While 7% of women had more than one partner in the last year, 24% of men had multiple sexual partners in the same timeframe ($p<.01$). Among those who have sex, 4% of women and 14% of men used a condom with a recent sex partners ($p<.01$). Also, 10% of women and 6% of men ($p<.01$) had a sexually transmitted infection or its symptoms in the previous 12 months. Among men, 22% had ever paid for sex.

As expected, area-level factors are similar between women and men. Men and women live the same distance from a major city (73km); major road (11km); and MOH clinic (5km). The average poverty percent (percent of residents under the poverty line) is 65%. As defined, almost equal percentages of women and men live in an area within the middle half of income inequality, 51% of women and 50% of men; 24% of men and 28% of women live in areas with the highest level of income inequality.

Global associations between individual- and area-level risk factors and HIV

A key advantage of spatial analysis is the ability to show the distribution and scale of spatial variation. However, global model results for men and women are presented first to frame the discussion of differences at the local level. Global models, presented in Table 3 by gender, are spatially stationary and represent population-averaged results.

Among women, several individual-level behavioral variables are significantly associated with HIV status. As expected, women with STIs are more likely to be infected with HIV than those without (OR 1.84, $p<.01$). Possibly confirming condom use as a proxy for perceived risk of, or susceptibility to, infection from a partner (Chimbiri 2007), use of condoms with a recent sex partner increases the odds of HIV infection by 2.01 ($p<.01$). Surprisingly, multiple partners are not associated with HIV status in the global model. Among area-level factors, and in contrast to hypotheses, the odds of infection decrease with increasing distance to a MOH clinic (OR 0.94, $p<.05$). There are no other significant associations between HIV status and other area-level factors among women at the global level.

For men, only previous sexually transmitted infection is significantly associated with HIV (OR 2.04, $p<.01$) among individual risk factors. Migration and paid sex have no association with HIV at the global level. In contrast to global results for women, recent condom use and multiple partners are also not significantly associated with HIV. Among area-level factors, similar to women, men who live further from MOH clinics are less likely to be infected (OR 0.93, $p<.05$). No other area-level factors are significantly associated with HIV status for men.

From global to local models: mapping spatial variation of relationships

Local spatial regression models provide a specificity of area- and individual-level associations with HIV status based on geographic location. Mapping results allows for visual presentation of the relationships within rural Malawi. Application of the PEH guides interpretation of the results. Although there is risk of committing the individualistic fallacy (applying individual-level findings to draw aggregate conclusions) (Diez-Roux 1998; Diez Roux 2002), local regression models can be cautiously and thoughtfully interpreted as average effects of the independent variable of interest on HIV status among men or women in that specific location, controlling for all other factors.

All variables from the global multivariate model are tested in local multivariate models stratified by gender. Decreased AIC (corrected) from the global to the local model suggests the local model fits the data better (Charlton, Fotheringham et al. 2006), and a decrease of more than 3 points is considered significant (Fotheringham, Brunsdon et al. 2002). Among women, the 15 point drop in the AIC (corrected) suggests that the local models are a better fit and demonstrates that the global model may mask considerable variation in the drivers of HIV in rural Malawi. However, the 5 point drop in the AIC (corrected) from the global to the local model for men suggests only a small increase in fit from the global to the local model, signifying less spatial variation overall.

Local regression model results are presented Tables 4 and 5. Factors that are significant in local models for more than 10% of the study population, by gender, are illustrated in Figures 2-5 for women and Figures 6-8 for men. These figures display relationships with significant spatial variation. In each map pairing, maps on the left side depict significance, illustrating where local t-statistics denote significant associations between the variable of interest and individual HIV status. Student t-values of ±1.96 indicate significance at the .05 level. Darker shades represent geographic areas where the variable is significantly associated with odds of HIV infection. Lighter areas indicate a non significant relationship with the variable of interest. Paired maps on the right show the distribution of the variable of interest within the study population.

Local spatial variation in associations between area- and individual-level factors and HIV among women

Local regression models indicate significant spatial variation in the associations between individual- and area-level factors and HIV status for women in rural Malawi. Although individual risk factors are significant, the significance of area-level factors above the contribution of individual-level influences provides evidence for the importance of place-based effects, confirming relationships proposed by the PEH.

Among hypothesized area-level drivers of HIV, three access factors exhibit significant spatial variation. First, distance to a major road is negatively and significantly associated with HIV status for 25% of women located in the Central Region near transportation arteries connecting Lilongwe and areas along the Mozambique border (Figure 2). In other parts of the country, the association varies in sign and is not significant. It appears that women in more remote or isolated locations, further from major roads, are less likely to be infected than women who live closer to major thoroughfares. This finding supports a recent study in South Africa using GIS to map HIV prevalence among pregnant women, concluding that women living in a homestead closer to a road were more likely to be infected than women who lived further from main transportation arteries (Tanser, Lesueur et al. 2000). Less access to roads may reduce risk behaviors through decreased access to markets and broader social networks, resulting in fewer additional sex partners (Tawfik 2007).

Second, distance to a major city is also significant and negative for 27% of the sample clustered in the middle of the country between Lilongwe and Mzuzu (Figure 3). Women in this area are less likely to be infected if they live further from a major city. The relationship between distance to a major city and HIV status is not static, and the association is positive in parts of the country including near Blantyre. In more isolated locations, especially in the Northern Region, distance or cost of travel may be prohibitive (Porter 2002), offering partial explanation for lower odds of HIV in areas further from cities or major roads. This finding affirms possible links between remoteness and reduced risk of infection.

Third, similar to the global model, distance to a MOH clinic is negatively associated with HIV status: women who live further from MOH clinics are less likely to be infected than female peers who live closer to a MOH clinic. As illustrated in Figure 4, this relationship is significant for 29% of women clustered in the Central and Southern Regions. The direction of this association is unexpected and puzzling, conflicting with both expectations and previous research showing proximity to health centers as protective against HIV for women after adjusting for some individual-level behaviors (Gabrysch, Edwards et al. 2008). It is unlikely that access to these services increases a woman’s likelihood of infection. Rather, it is possible that clinics are purposefully placed in areas of higher risk, thereby causing endogeneity and confounding the results, or that people who are sick or HIV-infected may select to live near clinics. Lastly, clinics are likely located in smaller commercial centers, making this variable a proxy for distance to market center.

Individual-level risk factors also exemplify significant spatial variation. Previous sexually transmitted infection is significantly and positively associated with HIV status for 93% of women (Figure 5), covering the entire Central and Southern Regions of the country. The strength and geographic breadth of this relationship reaffirms the results of the global model, demonstrating the importance of this risk factor. Condom use is significant in fewer than 10% of local models, and multiple partners is not significant in any location, perhaps attributable to low reporting (Tawfik 2007).

Socio-cultural factors may influence these relationships. Consideration of these factors merits attention in future research. In both global and local models, Chewa women are less likely to be infected, and this relationship is significant for more than half of the sample. Chewa society is matrilineal (Benson, Chamberlin et al. 2005), and it is possible that women from this ethnic group hold more power over their sexual and social relationships, decreasing their risks. Other traditions such as polygamous marriage are associated with increased odds of infection for 30% of rural women, demonstrating the possible strength, but differential effect, of cultural practice on HIV risk.

Overall, the local model adds detail to the importance and distribution of these key relationships among women. The significance of the area-level variables in local models suggests that global associations dilute important drivers of HIV in specific geographic areas. In particular, and as supported by the PEH, the significance of distance to roads, cities, and clinics suggests that women are less likely to be infected in more isolated areas. Contrary to the conceptual model, income inequality and absolute poverty are not associated with HIV status in global or local models. This lack of association may be due to the pervasive nature of poverty in rural Malawi, masking relationships that might be evident in more economically diverse areas.

Spatial variation in associations between area- and individual-level factors and HIV among men

As expected from the global model, and in contrast to the female sample, there is little spatial variation and few significant factors associated with HIV at the local level among men. Among men, three risk factors show significant spatial variation at the local level, providing only a marginal improvement over the global model.

At the area-level, distance to a MOH clinic is significantly associated with HIV status for 10% of men clustered near the southern shores of Lake Malawi in Machinga and Mangochi Districts on the border with Mozambique, setting this location apart from other rural regions (Figure 6). Although the relationship between distance to MOH clinic and HIV remains negative throughout the country, only men who live further from a MOH clinic in this area are significantly less likely to be infected. Similar to the women, the direction of this relationship is unexpected and contradicts previous research noting the association between community-level health worker activity and decreased extramarital sex among men in Zambia (Benefo 2008). As suggested previously, it is unlikely that health clinic proximity increases the odds of HIV infection for men. Rather, it is more likely that MOH clinics serve as a proxy for smaller commercial centers and that commercial hubs in these lakefront districts may be dissimilar to other locations in Malawi. Further research into the specific characteristics of men in this distinct area warrants investigation. No other area-level factors are significant for men in local models.

Demonstrating the value of the local model to reveal relationships watered down at the global level, migration is significant and positive for 47% of men in local models (Figure 7). Men who live in the center of the country, mostly between the districts of Mangochi and central

Mazimba (including areas around Lilongwe and Mzuzu), who migrate are more likely to be infected with HIV than men who do not. In areas of significance, men may follow distinct migration patterns, working or traveling in particular areas of neighboring countries that increase their risk, especially through additional sex partners (Chirwa 1997).

Among individual-level risk behaviors, only STI is associated with HIV status for men in the global and local models, demonstrating the importance of this factor across much of rural Malawi. Previous STI is positively associated with HIV status for the entire area and significant for 75% of men (Figure 8). This relationship is not significant in the Northern Region, an area of lower STI prevalence.

Individual-level demographic factors further explain patterns of infection among men. Increasing age and socio-economic status are associated with increased odds of infection for almost all rural men. Similar to women, socio-cultural factors may also influence individual risk (Morah 2007). Among men, as with women, Chewa ethnicity is significantly associated with decreased HIV risk. As noted previously, Chewa are traditionally matrilineal, and men frequently move into the homestead of the wife's family at marriage (Benson, Chamberlin et al. 2005; Chimbiri 2007), potentially increasing gender equality and reducing risk behaviors. Additionally, Chewa show preference for marriage within their ethnicity (Posner 2004), suggesting a level of protection among closed social networks.

Contrary to theoretically-informed hypotheses, most area-level factors are not associated with HIV for men. In part, the lack of significant associations may reflect the heightened status of men in comparison to women. In Malawi, men have more access to income and hold more social power than women (Schatz 2005). Social norms of masculinity and marriage include controlling women (Chirwa 1997), largely providing men with decision-making power over partner selection and use of condoms (Kaler 2003). This status may allow men to buffer negative influences of area-level socio-economic factors such as poverty or inequality (Craddock 2000). Also, improvements in rural infrastructure may enable men's mobility, smoothing underlying differences in access.

CONCLUSION

This study demonstrates that *place* matters in the context of HIV in rural Malawi, and the strength of area- and individual-level drivers of HIV vary in space. This spatial analysis calls attention to two important conclusions. First, gender plays a role in the spatial determinants of HIV: the influence of area-level factors and HIV status are exacerbated for women. The PEH clarifies these findings. The socio-economic environment in Malawi may reinforce gender inequality and reduce women's rights to govern their sexual health (Kathewera-Banda 2005). As a result, women literally *embody* the discrimination, economic disadvantage, and inequality they face (Krieger 1999; Krieger 2005). Within couples, *embodiment* translates to compromised gender-based power, diminishing a woman's ability reduce HIV risk through refusal of sex or insistence on condoms (Blanc 2001; Luke and Kurz 2002; Dunkle, Jewkes et al. 2004; Pettifor, Measham et al. 2004; Schatz 2005).

Second, spatial analysis affirms that area-level socio-economic and access factors play a significant role in increasing HIV risk above and beyond individual-level contributions. Drawing on the PEH for interpretation, ecological factors such as economic underdevelopment, mobility, and power differentials create social and economic "risk environments" that limit individual choice, constrain behavior, and restrict ability to make positive health decisions (Minkler, Wallace et al. 1994; Minkler 1999), increasing vulnerability to HIV infection (Parker, Easton et al. 2000; Rhodes, Singer et al. 2005). In response, reducing poor health outcomes such as HIV infection requires moving from an emphasis on individual behavior to consideration of macro-level factors that reduce an individual's power to effect change (Doyal 1995; Farmer 1999; Farmer 2003).

Using spatial methods to explore place-based effects on HIV in Malawi presents several challenges. First, people are likely to self select into neighborhoods, making area-level effects less randomly distributed among the populations (Sampson, Morenoff et al. 2002; Oakes 2004). Also, geographic information from developing countries is sparse, and combining multiple geographic layers from various sources with different scales may add small errors in location information, potentially allocating individuals to incorrect geographic areas. The inclusion of only Ministry of Health clinics attempts to reflect reach of government health facilities, but the effects of excluding private health care and other clinic options have unknown effects on measuring access to health services. Lastly, although the global regression models showed no significant multicollinearity among variables, multicollinearity is still possible in local models (Wheeler and Tiefelsdorf 2005). The magnitude and direction of biases cannot be determined with the available data.

Overall, the results contribute to the growing body of evidence connecting health and place, expanding application of spatial methods to the context of HIV in sub-Saharan Africa. To successfully address the complexity of the epidemic, solutions will need to account for differences between both individuals and the areas in which people live. Although this study reveals *where* area- and individual-level factors drive HIV in rural Malawi, *why* and *how* HIV is affected remains unanswered. Additional studies at finer spatial scales and complementary qualitative research would elucidate these relationships in rural Malawi.

Table 1: Variables included in spatial regression model

Variable	Definition	Type of variable
Individual-Level		
HIV Status	Infection with HIV-1 or HIV-2 on 2 tests of HIV status, including rapid and confirmation with Western Blot or ELIZA	Dependent
Gender	Male or female	Moderator
Condom	Condom use with any of previous 3 sexual partners	Independent
Multipart	2 or more sexual partners in last year	Independent
STI	Diagnosis/symptoms of sexually transmitted infection within past year	Independent
Migration	Travel for more than one month in last 12 months	Independent for men
Paid Sex	Ever paid for sex	Independent for men
SES	The socio-economic status of each household (see elaboration below)	Control
Age	Continuous age in years	Control
Marital Status	Dummy variables for never married; married; and previously married	Control
Polygyny	Multiple marital union	Control
Education	No education, primary education, secondary education; > secondary	Control
Religion	Dummy variables of Christian; Muslim; other	Control
Ethnicity	Dummy variables for Chewa; Lomwe; Yao; Other	Control
Circumcision	Circumcised or not	Control for men only
Area-Level		
High Gini	Gini coefficient in the 75th percentile or higher	Independent
Middle Gini	Gini coefficient in the 26th – 74th percentile	Independent
Poverty Headcount	% of population below the poverty line (Foster, Greer, Thorbecke)	Independent
Distance to major road	Km from DHS cluster point to closest major road	Independent
Healthcare availability	KM from DHS cluster to closest Ministry of Health clinic	Independent
Distance to Regional Capital city	Km from DHS cluster to the closest regional capital, Mzuzu, Lilongwe, or Blantyre	Independent

Table 2 – Descriptive proportions of key variables among men and women

		% Women, n=2091	% Men, n=1827
Age**	15-19	12	12
	20-24	26	21
	25-29	19	20
	30-34	16	16
	35-39	11	11
	40-44	10	10
	45-49	7	6
	50-54	n/a	3
Religion	Christian	37	38
	Muslim**	12	10
	Catholic	24	22
Region**	North	13	13
	Central	39	43
	South	48	45
Ethnicity	Chewa	34	35
	Yao	13	12
	Lomwe	18	18
Education***	None	27	14
	Primary 0-4	64	65
	Grade 5 or higher	9	21
Marital status***	Never married	5	22
	Married/Union	77	74
	Previously married	18	4
Wealth quintile (SES)***	Lowest	19	14
	Second	24	23
	Middle	25	27
	Fourth	23	25
	Highest	10	11
Circumcised		n/a	22
Migrate		n/a	12
Multiple partners in last year***		7	24
Recent condom use***		4	14
Previous STI in last 12 months***		10	6
Ever had paid sex		n/a	22
Risk score***	0	83	57
	1	14	27
	2	2	12
	3	1	4
HIV+ status***		13.8	9.6

Chi square results of difference in proportions, * p<.1; **p<.05, ***p<.01

Table 3: Global model parameters for women and men

	Women			Men		
Parameter	Estimate	t-value	Odds Ratio	Estimate	t-value	Odds Ratio
Intercept	-4.081 (0.681)	-5.99***	0.02	-4.298 (0.632)	-6.79***	0.014
Individual-level demographic						
Age	0.021 (0.008)	2.63***	1.02	0.027 (0.010)	2.77***	1.03
Education	-0.024 (0.127)	-0.19	0.98	0.047 (0.151)	0.30	1.05
Current marriage	1.204 (0.464)	2.59***	3.33	2.119 (0.469)	4.51***	8.31
Previous Marriage	2.046 (0.460)	4.44***	7.73	1.566 (0.587)	2.66***	4.78
polygyny	0.219 (0.187)	1.17	1.24	-0.087 (0.343)	-0.25	0.91
SES	0.249 (0.055)	4.48***	1.28	0.250 (0.076)	3.27***	1.28
Chewa	-0.653 (0.200)	-3.26***	0.52	-0.727 (0.247)	-2.94***	0.48
Lomwe	0.271 (0.192)	1.41	1.31	0.248 (0.232)	1.06	1.28
Yao	0.251 (0.272)	0.92	1.28	-0.188 (0.373)	-0.50	0.82
Christian	0.026 (0.149)	0.17	1.02	0.035 (0.184)	0.18	1.03
Muslim	0.080 (0.267)	0.30	1.08	0.114 (0.395)	0.28	1.12
Circumcised				0.013 (0.243)	0.05	1.01
Individual-level risk factor						
Multpart	0.402 (0.279)	1.44	1.49	0.048 (0.284)	0.16	1.05
STI	0.612 (0.202)	3.02***	1.84	0.714 (0.306)	2.33***	2.04
Condom use	0.697 (0.307)	2.27***	2.01	0.438 (0.274)	1.59	1.54
Paidsex				0.058 (0.197)	0.29	1.06
Migrate				0.421 (0.245)	1.72	1.52
Area-level factor						
Gini high	0.193 (0.192)	1.00	1.21	-0.241 (0.245)	-0.98	0.78
Gini middle	-0.010 (0.173)	-0.056	0.99	0.036 (0.205)	0.17	1.03
MOH clinic	-0.060 (0.026)	-2.34***	0.94	-0.071 (0.033)	-2.12**	0.93
District road	0.006 (0.008)	0.74	1.01	0.000 (0.012)	0.02	1.00
Major road	-0.013 (0.007)	-1.90	0.99	-0.013 (0.009)	-1.49	0.98
Medium city	-0.004 (0.003)	-1.27	0.99	-0.001 (0.005)	-0.23	0.99
Major city	0.001 (0.002)	0.36	1.00	0.001 (0.002)	0.23	1.00
Poverty%	0.001 (0.004)	0.15	1.00	0.003 (0.005)	0.56	1.00
Log-likelihood:	-797.350			-512.785		
Akaike Information Criterion:	1640.700			1079.570		
Corrected AIC (AICc)	1641.234			1080.410		

Standard errors in parentheses. *** p<.05; **p<.01, ***p<.001**

Table 4: Comparison of Local Parameter summaries to global parameter for women

Label	From Local Parameter Model						Global model parameter
	Minimum	Lwr Quartile	Median	Upr Quartile	Maximum	% with significan t local t value	
Intrcept	-7.449	-5.328	-4.309	-3.959	-3.589	100	-4.081
Demographic factors							
Age	0.018	0.018	0.020	0.022	0.040	83	0.021
Education	-0.364	-0.031	0.005	0.015	0.028	0	-0.024
Chewa	-0.795	-0.725	-0.580	-0.410	0.149	65	-0.653
Lomwe	-0.950	0.073	0.109	0.341	0.525	0	0.271
Yao	0.029	0.062	0.106	0.354	0.838	0	0.251
Christian	-0.054	-0.004	0.023	0.034	0.853	0	0.026
Muslim	-0.317	-0.161	0.015	0.093	0.167	0	0.080
Previous marriage	1.263	2.174	2.355	2.416	2.477	91	2.046
Current marriage	-0.165	1.286	1.507	1.620	1.674	80	1.204
Polygyny	-0.617	0.164	0.314	0.421	0.512	30	0.219
SES	0.209	0.238	0.257	0.269	0.702	100	0.249
Individual-level risk factors							
STI	0.497	0.546	0.573	0.653	1.139	93	0.612
Multiple partner	0.249	0.307	0.339	0.392	1.546	0	0.402
Condom	0.466	0.542	0.603	0.711	0.851	6	0.697
Area-level factors							
Gini high	0.046	0.209	0.227	0.244	0.259	0	0.193
Gini medium	-0.519	0.035	0.041	0.045	0.104	0	-0.010
Km to MOH	-0.064	-0.057	-0.050	-0.045	-0.007	29	-0.060
Km major road	-0.025	-0.016	-0.012	-0.011	0.011	25	-0.013
Km to major city	0.000	0.001	0.002	0.005	0.008	27	0.001
Poverty %	-0.007	-0.004	0.000	0.008	0.015	2	0.001
	Local Logistic Model Diagnostics						
	Log Likelihood:						-767.07
	Akaike Information Criterion						1623.78
	Corrected AIC						1625.79

Table 5: Comparison of Local Parameter values to global model for men

Label	From Local Parameter Model						Global model parameter
	Minimum	Lwr Quartile	Median	Upr Quartile	Maximum	% with significant local t value	
Intercept	-6.4597	-4.7847	-4.2412	-3.9487	-3.7850	100	-5.441
Demographic factors							
Age	0.0414	0.0422	0.0442	0.0481	0.0613	100	0.027
Educ	-0.2266	-0.1149	0.0170	0.1856	0.6866	5	0.047
Chewa	-0.8238	-0.8114	-0.7913	-0.6902	-0.2466	90	-0.727
Lomwe	0.0553	0.1144	0.2101	0.3428	0.6380	0	0.228
Yao	-0.5939	-0.2826	-0.2644	-0.2482	-0.2038	0	-0.188
Christ	-0.1181	-0.0367	0.0596	0.1909	0.3135	0	0.035
Muslim	-0.3338	-0.1934	-0.0167	0.2343	1.4324	0	0.114
Married	2.0686	2.1064	2.1459	2.1864	2.5262	100	2.119
Previously married	1.1702	1.2052	1.2594	1.3220	2.9428	46	1.566
Polygyny	-0.4715	0.1625	0.3358	0.4296	0.4689	0	-.087
SES	0.0701	0.1865	0.2306	0.2749	0.3137	87	0.250
Circum	-0.5643	-0.0370	0.0410	0.0714	0.0860	0	0.013
Individual-level risk factors							
STI	0.4819	0.6691	0.7192	0.7806	0.8612	75	0.714
Multiple partners	-0.5606	-0.5463	-0.5273	-0.5116	-0.4428	0	0.048
Condom	0.3721	0.4436	0.4940	0.5418	0.8477	0	0.438
Paidsex	-0.2062	0.1195	0.1727	0.1902	0.2184	0	0.058
Migrate	0.3491	0.4320	0.5126	0.5852	0.6776	47	0.421
Area-level factors							
Gini high	-0.4634	-0.3864	-0.3167	-0.2467	-0.1782	0	-0.241
Gini mid	-0.6623	-0.0794	0.0415	0.1097	0.1435	0	0.036
MOH	-0.0687	-0.0663	-0.0645	-0.0589	-0.0528	**10**	-0.071
Km to major road	-0.0190	-0.0175	-0.0159	-0.0152	-0.0110	0	-0.013
Km to major city	0.0015	0.0027	0.0031	0.0034	0.0038	0	0.001
Poverty %	-0.0002	0.0006	0.0027	0.0066	0.0186	0	0.003
	Local Logistic Model Diagnostics						
	Log Likelihood						-497.811
	Akaike Information Criterion						1073.530
	Corrected AIC						1075.272

Figure 1: Conceptual model

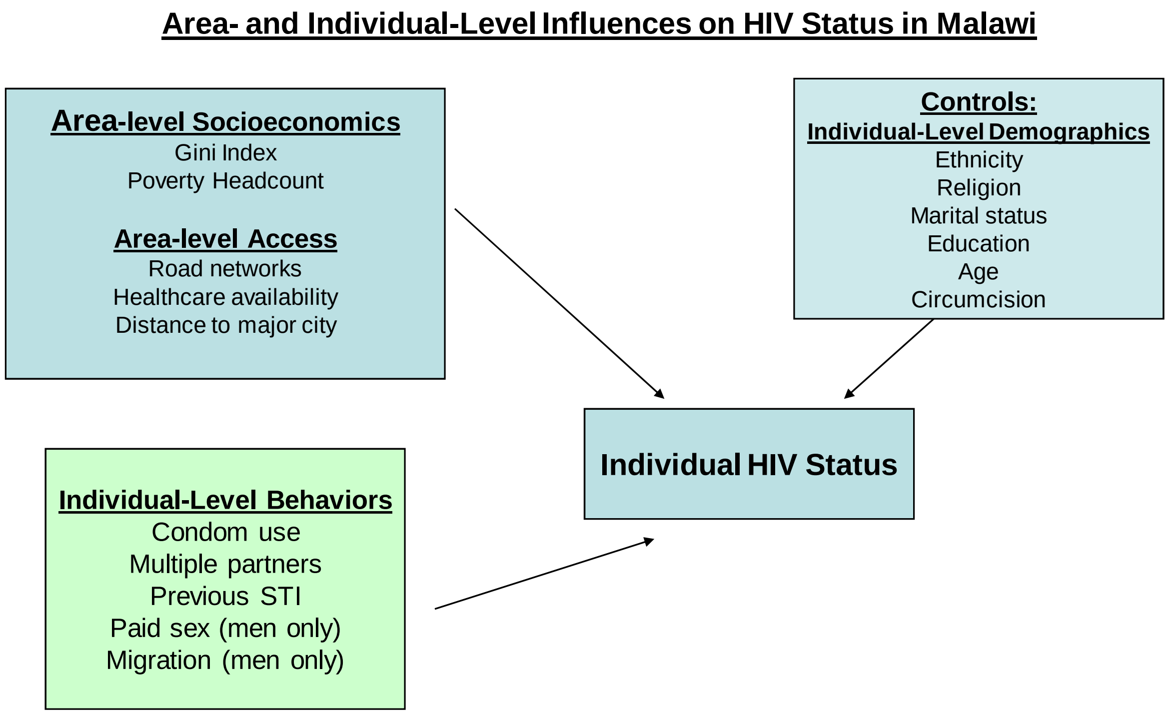


Figure 2: Distance to major road t values and distribution for women

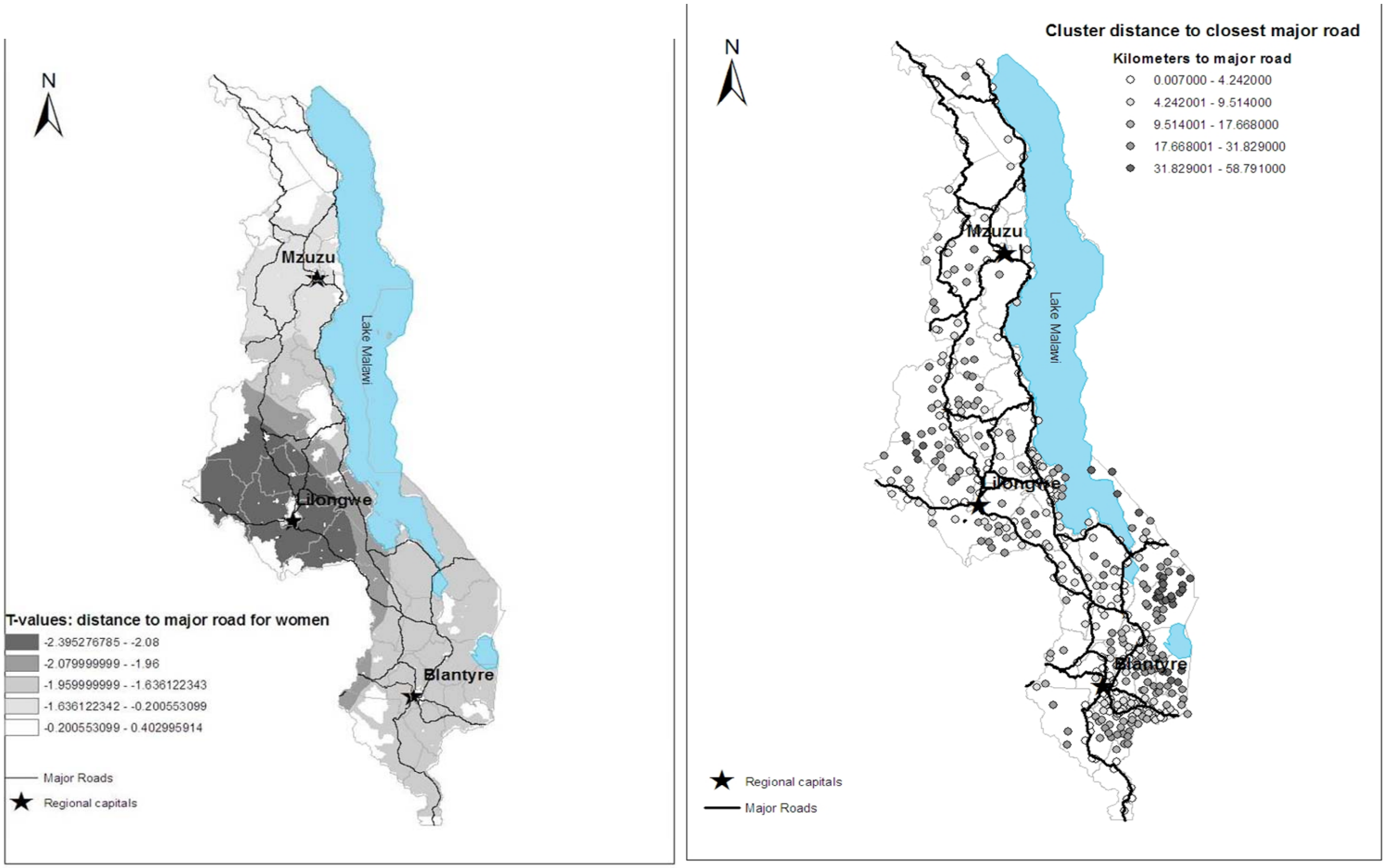


Figure 3: Distance to major city t values and distribution for women

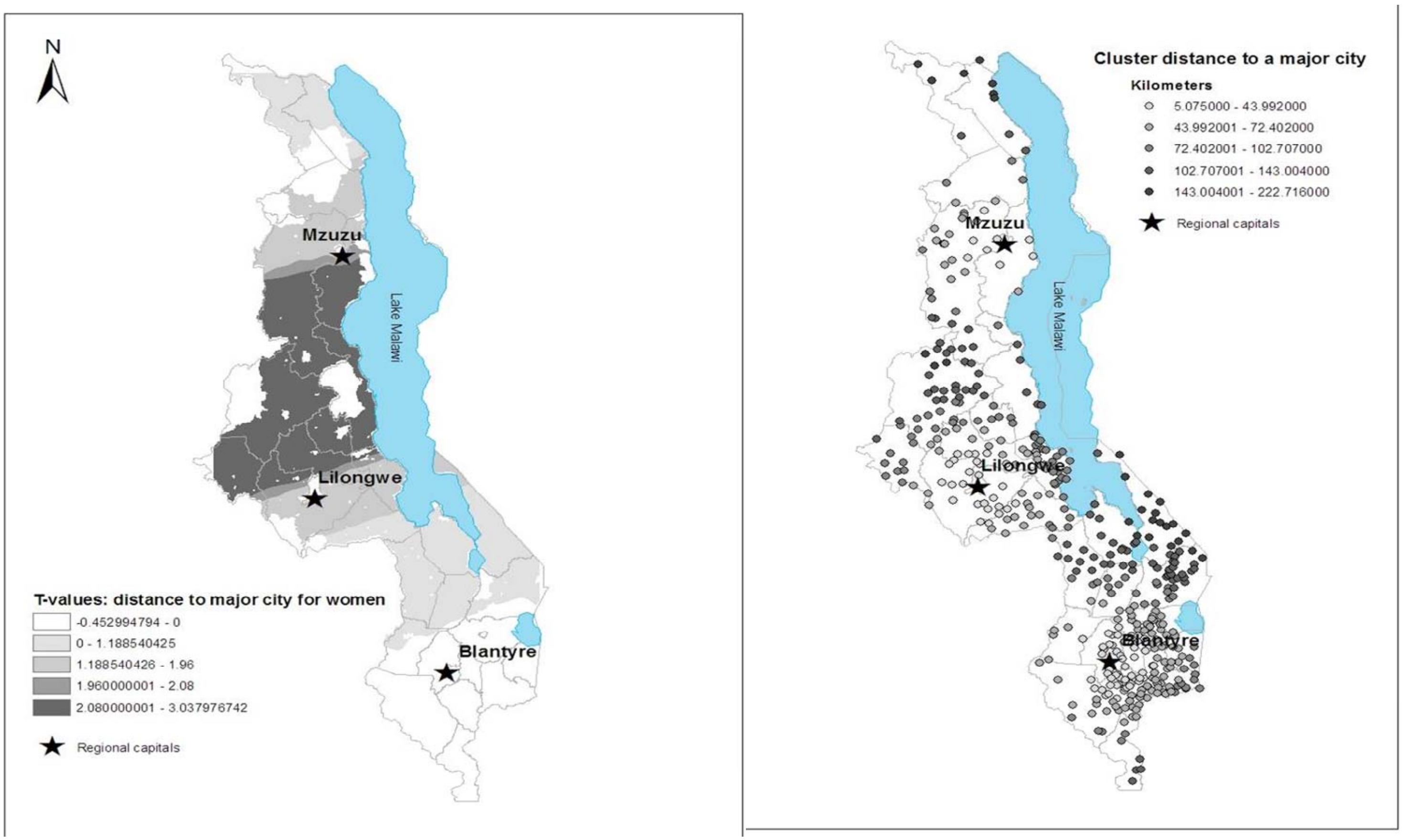


Figure 4: Distance to MOH t values and distribution for women

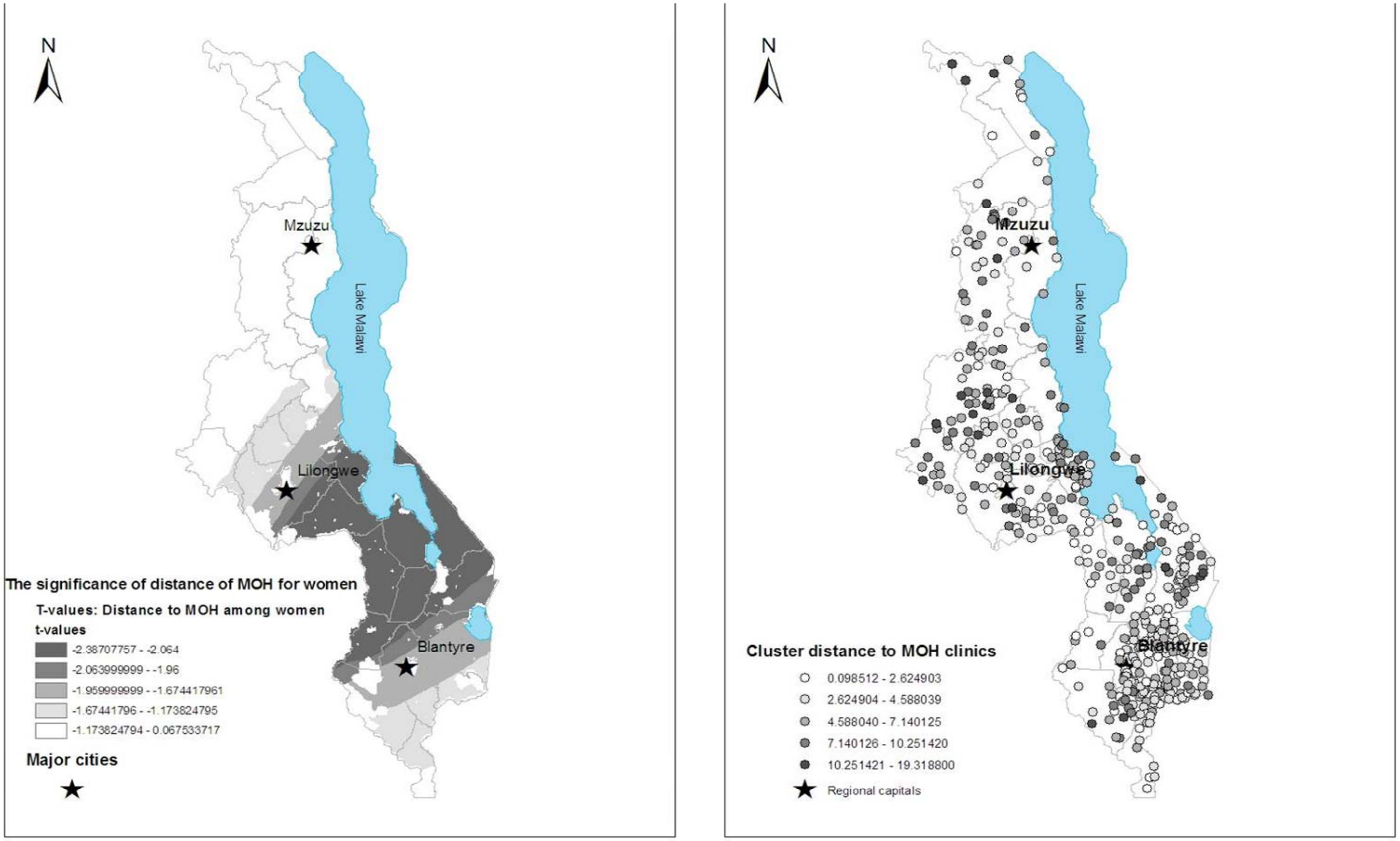


Figure 5: STI t values and prevalence for women

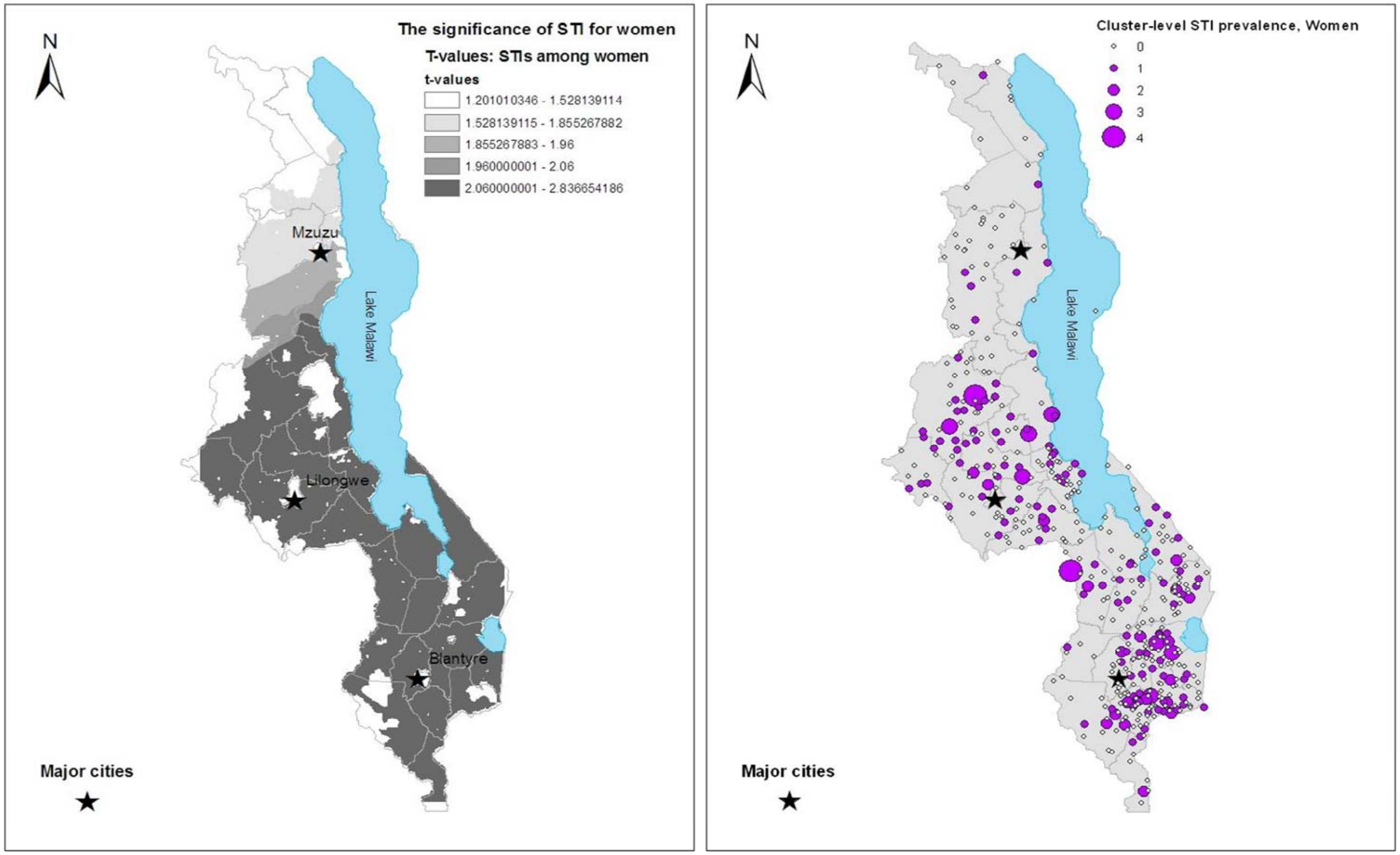


Figure 6: Distance to MOH clinic t values and distribution for men

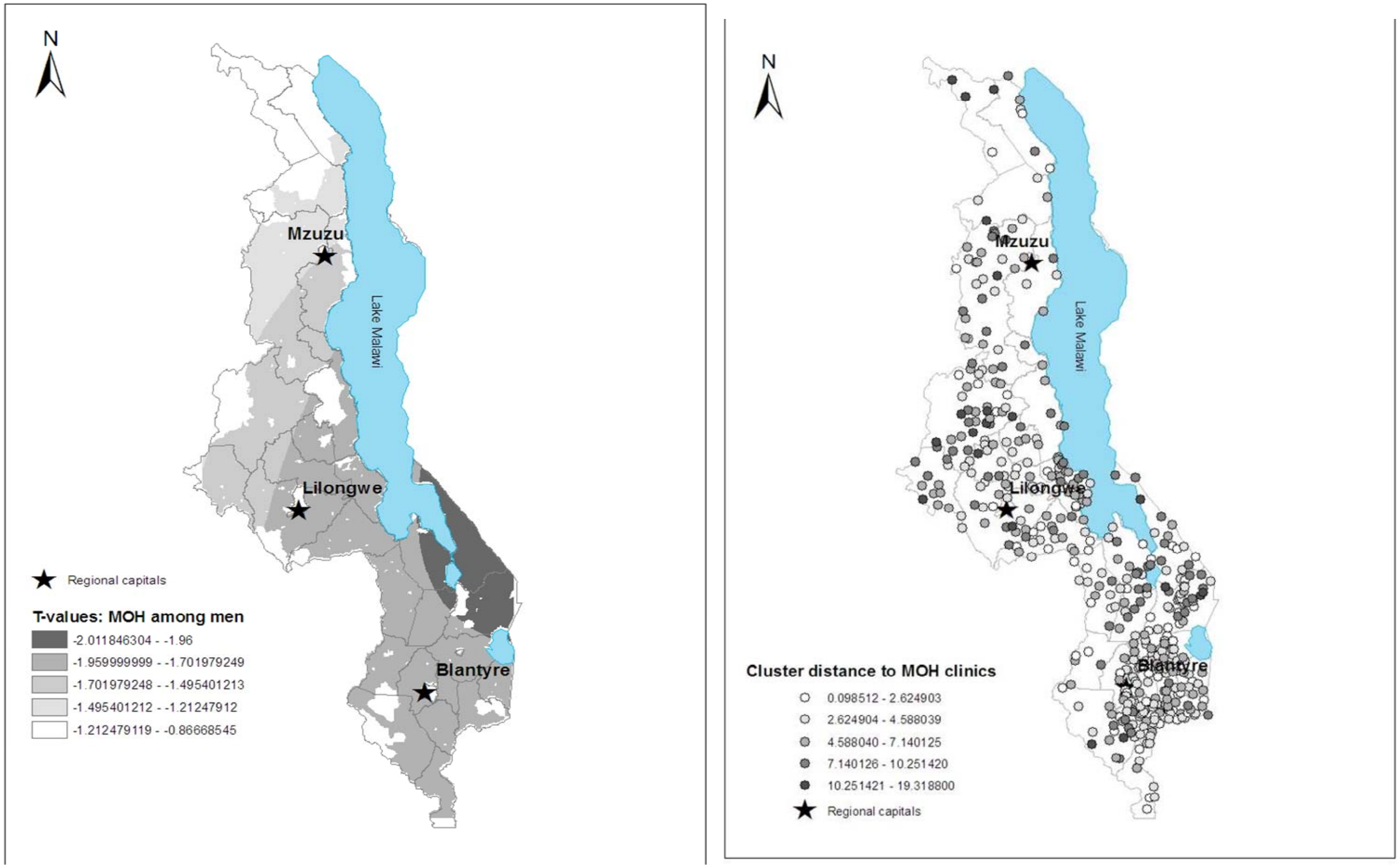


Figure 7: Male migration t values and distribution

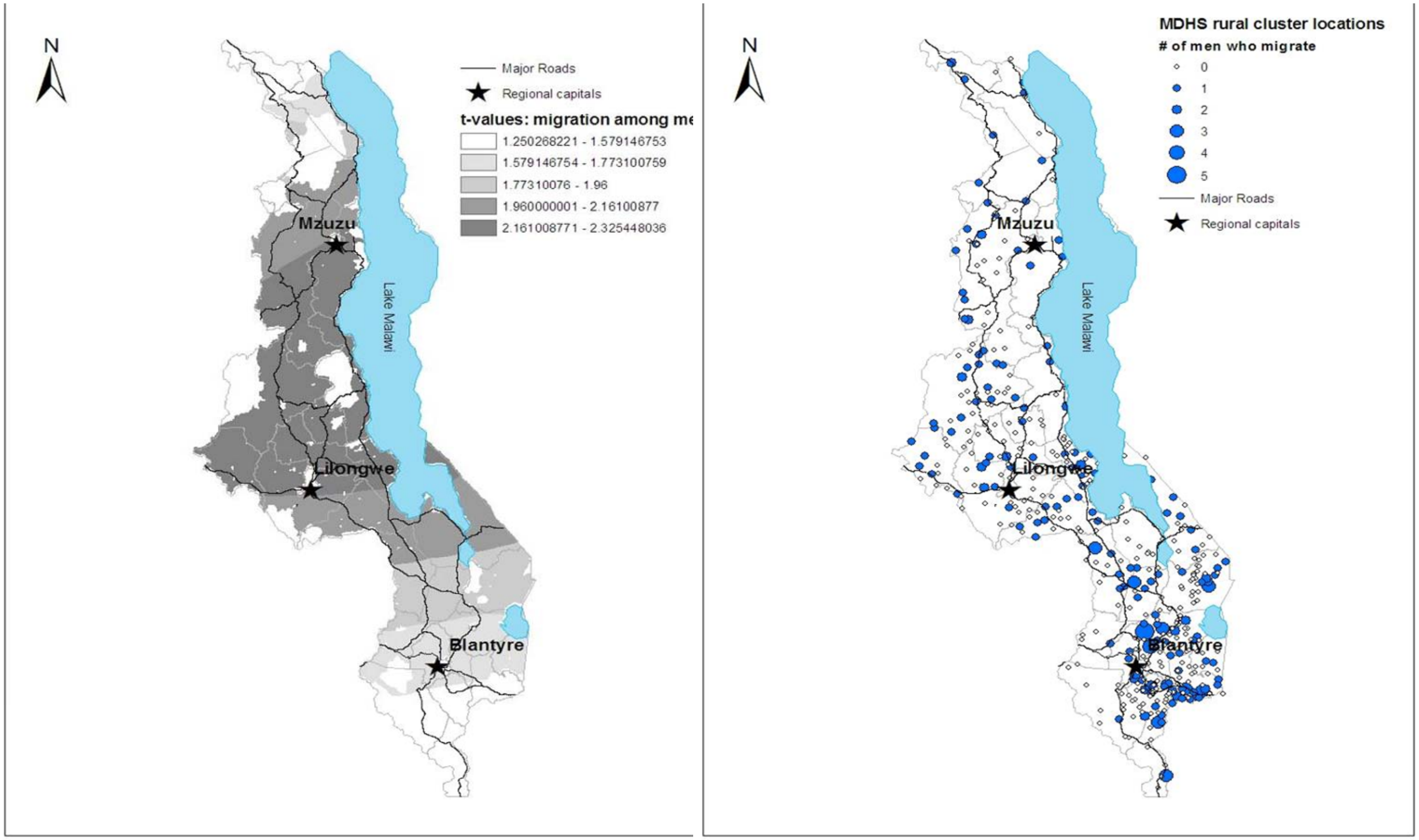
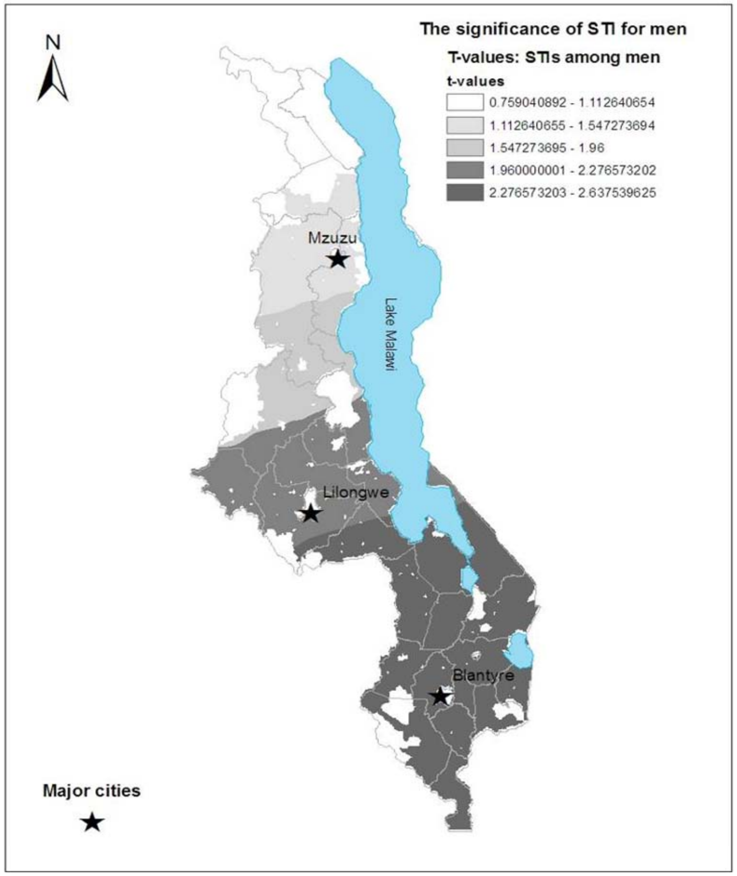
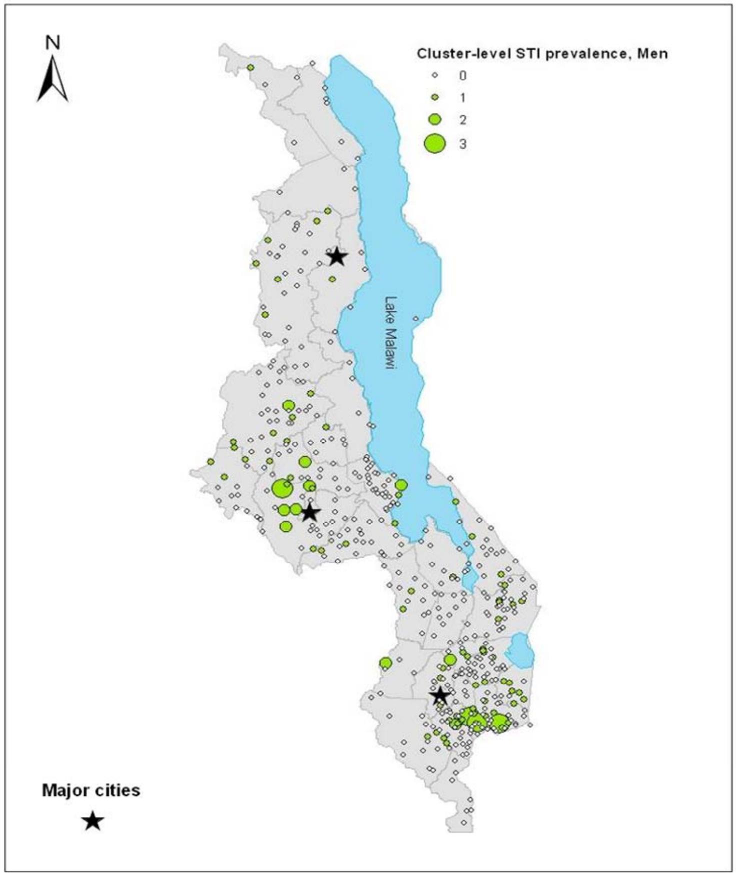


Figure 8: STI t values and distribution for men





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