Spatial Patterns of HIV Incidence in Mississippi: A Picture of Inequality and Disease

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ABSTRACT. HIV/AIDS is a major disease burden for African Americans in the United States. The CDC reported in 2009 that despite comprising 14% of the general U.S. population, African Americans represent 44% of all new HIV infections. Mississippi, as the poorest state in the union, also ranks 50th for health care and has the highest percentage of African Americans of any state. To investigate patterns of poverty and HIV/AIDS, we analyzed publically available county-level data from the Mississippi Department of Health, to explore the spatial distribution of newly reported infections. Spatial autocorrelation of county-level HIV incidence was undertaken (Moran's I statistic) and GIS-based methods were used to identify HIV "hot spots" that considered incident cases reported in neighboring areas. We then assessed associations of county-level HIV incidence with hypothesized county-level predictors, including population density, proportion of African American residents, income, unemployment rates, property values, number of health facilities, and the Gini coefficient of income inequality. We classified counties according to presence/absence of large urban centers to evaluate whether the social dynamics of transmission in urban areas with a larger MSM community might be different than in rural areas. Counties with and without prisons were compared. Finally, possible determinants of reported incident HIV cases were explored through multi-variable spatial regression models. We found the mean number of new cases in Mississippi counties to be 17.84 per 100,000 in 2009 (range 0 - 86.8 per 100,000 people). Areas of disproportionately high reported HIV incidence were located in rural areas of the Mississippi Delta. High incidence counties were associated with higher proportions of African American residents, higher unemployment, lower median income, fewer health facilities and higher levels of income inequality. Counties with the highest reported numbers of new cases were concentrated around counties that housed larger numbers of prisoners. We conclude that HIV incidence in Mississippi is associated with intense poverty, inequality and a lack of available health services.

Introduction

AIDS is a major public health burden in the state of Mississippi[1]. Despite comprising only 37% of the state population, African Americans account for 78% of HIV cases in the state [2]. In 2000, rural Mississippi had the second highest regional HIV incidence in the U.S., while heterosexual transmission in Mississippi was the highest[3]. HIV transmission in rural Mississippi occurs primarly through heterosexual contact, particularly those involving partnerships between older men and very young women[4]. Furthermore, transmission is disproportionately high for rural AfricanAmericans as compared with urban and rural whites[5]. In urban areas, HIV transmission among men who have sex with men (MSM) is common and well documented. Indeed, HIV incidence among MSM in urban areas of the southern U.S. is increasing more rapidly than that among MSM in all other regions combined[6]. As with heterosexual partnerships that result in HIV transmission among African-Americans in rural Mississippi, age disparities among MSM pairings are highly associated with HIV transmission [7]. Rural African American male HIV cases were more likely than urban cases to report being Injection Drug Users (IDUs), to have had concurrent sexual pairings, and to have exchanged sex for money. Urban HIV cases, however, were less likely to have used condoms than rural HIV-positive men. These results suggest vast differences between urban and rural African American populations in the nature of sexual pairings, hence opportunities for HIV transmission [8].

Mississippi's policies promoting "abstinence only" education, and the realities of poor access to health services with the inability of people to enter the health system until they have full AIDS are exacerbating transmission[9]. Among HIV infected pregnant women, African-American women far outnumber women of other races/ethnicities, are less likely to present to clinics, and more likely to have co-infections with other STIs[10]. Incarceration has been shown to be associated with HIV/Hepatitis C co-infections[11]. Adherence to treatment regimens is affected by lifestyle factors such as drinking and drug use, individual symptoms of depression, and anti-social attitudes with stigmatized HIV infected individuals in rural Southern populations [12].

Mississippi has one of the highest incarceration rates in the U.S., and prison populations tend to be overwhelmingly African American and male[13]. Prisons and crime are known to be associated with HIV transmission[14]. Among formerly incarcerated HIV positive males residing in rural areas, those with more past arrests tend to have more sexual pairings, are less likely to use condoms and more likely to buy or sell sex[15]. Risky sexual behavior among parolees in other contexts has been shown to be common [16]. Changing residence, which might affect spatial data quality, appears unassociated with HIV infection. Although IDUs in one study were more likely than others to change residence following HIV diagnosis, new HIV infections in rural Mississippi and Alabama appear to be occurring locally[17].

Inequalities and HIV. In comparisons among countries, national poverty, instability and poor governance have long been associated with HIV prevalence. Recent evidence indicates that the macro-social conditions contribute to HIV risk in ways more complex than originally assumed [18, 19]. This is especially evident in underdeveloped countries of Africa. Botswana, long viewed as an example of good governance and a rising economic star in Sub-Saharan Africa (SSA), ironically has one of the highest HIV prevalences in the world. On the other hand, more corrupt and less affluent countries such as Côte

D'Ivoire have so far been spared of the worst of the epidemic's effects[18]. In a recent multi-national comparison, within-country income inequality, as measured by the Gini coefficient, was found to be more closely related to HIV prevalence than was average poverty[20]. In a related pattern, a link has been recognized between HIV prevalence and decreased levels of social cohesion, functioning through community inequalities and stigmatization that prevent individuals from being tested [21]. Similarly, gender inequalities that encourage women to barter sex to satisfy household economic needs and reduce their ability to demand that sexual partners use condoms have been shown to contribute to the spread of HIV[22, 23]. Impoverished women, seeking to help meet the needs of their children, offer sex to men who now possess cash resources to buy it[24]. Wealthier men have greater freedom to move between sexual partners, thereby creating more opportunities for transmission[25]. In this manner, poverty *per se* is not spreading AIDS, rather male-centered economic advantage and low economic empowerment of women or other socially marginalized people is contributing to increased HIV transmission. Analyses which center not on overall deprivation, but on within-country economic differences, may be essential to better understanding what conditions favor transmission.

Mississippi is the poorest state in the U.S., and one of the most economically unequal with an income Gini coefficient of 47. Gaps between blacks and whites in Mississippi which is the most racially segregated state in the U.S. Overall life expectancy for the poorest residents of Mississippi is comparable to that of some of the poorest countries of Sub-Saharan Africa. A long history of slavery, segregation, marginalization and unequal economic development suggest that Mississippi shares many traits that have historically developed with larger, worldwide economic disparities. Accordingly, we took the approach used in global disparities analysis to analyze Mississippi's within-state HIV patterns. Starting from the perspective that HIV prevalence may not be easily reduced to simple ethnic or racial divisions, we analyzed the role of more complex economic phenomena including income inequality, property ownership, gender inequities and family composition. In particular, we determined the spatial distributions of county-level HIV prevalence and economic inequality (Gini index) in Mississippi by exploring associations using spatial statistical methodologies. We then evaluated the level and statistical significance of county-level social, demographic and economic variables with HIV prevalence using spatial regression techniques.

Methods

Data Sources. Data on the number of people living with an HIV positive diagnosis for 82 Mississippi counties in 2009 were obtained from the Mississippi Department of Health (MDoH) website[2]. No data were available on individual characteristics of people, although summary information on age distribution and ethnicity were obtained by health management district. However, districts were too coarse for this analysis, therefore only county-level data were used.

GIS layers on county-level population attributes such as the percentage African American, percentage living in poverty, median income per capita, ratio of female to male earnings, and owner-occupied to all housing ratio were downloaded from the Mississippi Automated Resource Information System (MARIS) website[26]. Census tract-level information was aggregated spatially to county.

Geographic locations and total numbers of hospitals and community health clinics (CHC), prisons and churches were also added to the spatial data base.

The Gini coefficient, an index of statistical dispersion, characterizes inequality among values of a frequency distribution. The Lorenz curve of a plotted ranked frequency distribution is compared to the diagonal straight line of perfect equality. The Gini coefficient ranges from 0 (perfect equality) to 1 (perfect inequality). We used publicly available data on county income inequality as characterized by the Gini coefficient [27]. Because this Gini coefficient application measures inequality in income but not wealth, counties that are on average poor may have the same level of inequality as counties that are very wealthy. However, the distribution of resources and opportunities between such counties may be quite different. For this reason, the Gini coefficient may not be an optimal measure for comparisons between urban and rural counties, for example. Regardless, the simplicity and frequent use of the Gini coefficient as a measure of economic disparities make it a useful measure for our investigation.

Analytical approach. Descriptive methods were used to examine the statewide spatial distribution of HIV, both through graphical displays of raw and population adjusted (per 100,000) counts. To explore spatial trends of HIV, we employ an Empirical Bayes smoothing technique[28]. As counts of HIV infected individuals are small compared with the population denominator, prevalence estimates varied widely. Empirical Bayes smoothing shrinks such estimates closer to local and global means, helping to unveiling more stable spatial trends and potential clusters of disease.

We tested for clusters of inequality using the Moran's I statistic[29]. To find correlated clusters of the number of HIV cases with high or low income inequality as measured by the Gini coefficient, we employed a bivariate Moran's I technique. High concordance or discordance of both variables beyond that which is expected by chance was evaluated. To explore associations of potentially predictive covariates and HIV prevalences, we used spatial lag regression[30], thus including values of surrounding spatial units to account for "neighborhood" effects. This technique was intended to address spatial autocorrelation of county-level HIV prevalence. Statistical significance of covariates and a "neighborhood" variable were included in the results. First, we produced estimates and standard errors for all variables on HIV prevalences individually to determine whether statistically significant relationships existed. Next, we examined how all variables together were associated with HIV prevalence by finding the subset of variables which best predicted the outcome. Models were compared and the one model with the lowest AIC value was chosen as the "best" model.

All analyses were performed using SpaceStat version 3.0.5[31].

Results

A total of 610 Mississippi residents, representing .0002% of the population, were living with HIV infection during 2009. The mean number of people with HIV per county was 7.34 people (82 counties), ranging from zero (12 counties) to 136 (Hinds County) (Table 1). The statewide period prevalence of HIV cases was 17.84 cases per 100,000 people, with a county-specific high of 86.8 cases per 100,000 (again, Hinds county). Both county-specific counts and prevalences were spatially heterogeneous (Figure 1).

Empirical Bayes smoothing of local mean predicted county prevalences indicated that HIV cases were highest in the more populated areas in and around Hinds county and the Jackson metropolitan area, as well as the Gulf coast region, and northern counties south of Memphis, TN (Figure 2). Estimates of local prevalences, however, indicated that counties surrounding heavily populated areas did not have uniformly high counts of HIV cases and that some rural counties, such as those within the Mississippi Delta, had HIV rates are high as those in heavily populated regions. When adjusting for population, Forrest County also had rates of HIV comparable to that of the Mississippi Gulf Coast.

The Gini coefficient for income inequality ranged from 38 to 57 with a mean value of 46.7 (Figure 3). The distribution of values was normal, and also geographically heterogeneous. In general, counties of the western part of the state ("Mississippi Delta") had higher inequality than those in the east. The spatial pattern analysis using Moran's I statistic to determine clusters of inequality indicated a significant cluster of counties with high inequality the western area (Figure 3c). Significant clusters of low inequality counties were found in the northern part of the state. Bivariate Moran's I indicated that these same counties were both highly unequal and had high prevalence of HIV cases (Figure 3d).

Multivariate Associations. Pearson correlation coefficients for combinations of all variables are presented in Table 2. We log-transformed HIV prevalence to induce normality. Among statistically significant associations, county-level HIV prevalence was positively correlated with: income inequality Gini values (r=.37), average family size (r=.35), percent African American (r=.39), percent in poverty (r=.24) and the urban to rural ratio (r=.29). The ratio of owner occupied to all housing units was negatively associated with HIV prevalence (r=-.31). The categorical measure of presence of a private prison was positively associated with HIV rates (r=.23). Table 2 also shows that there are high levels of multicollinearity in the data. Average family size, for example, is highly correlated with both the percent of county population living in poverty and the percent of county population which is African American. The percentage of county population which is African American is highly correlated with poverty levels, average family size, home ownership, the ratio of female to male earnings, the number of hospital beds per capita and the mean county household income. Such collinearity complicates analysis and inference.

To further evaluate apparent trends graphically, we plotted HIV prevalence with the Gini inequality coefficient. Results confirmed that county-level HIV prevalence increased with increasing county-level income inequality (Figure 5). This is visually shown by depicting the size of circles as a measure of the percentage of African Americans in the county, and shading circles to vary with the percentage that lives in poverty. We again note that all of these variables are positively correlated with one another.

Univariate estimates from a spatial lag model of all covariates with HIV prevalence were calculated (Table 3). The percentage African American, average family size, ratio of owner occupied to all housing units, urban to rural ratio, and the presence of the private prison were all significantly associated with log transformed HIV prevalence. These regression estimates have been back transformed. Interestingly, the association between HIV and the percentage living in poverty was only weakly significant (p=.05). There was no evidence for a relationship of HIV rates with per capita income (p=.87), ratio of female to male earnings (p=.15) and the health care variables.

Since many of the available variables are highly correlated with one another, we chose an optimal subset of variables through Akaike's Information Criterion (AIC) which best predicted HIV prevalence using spatial lag models. An optimal subset of predictive covariates included the percent African American, percent living in poverty, average family size, the Gini income inequality coefficient and the presence of private or joint county prisons. However, only income inequality and presence of a private state prison were significant at the p=.05 level. The resulting optimal model is not entirely satisfactory as it only accounted for ~40% of the variation in the data (Table 3).

Discussion

The distribution of HIV cases in Mississippi counties was found to be geographically heterogeneous in a manner that corresponded to various social and economic factors which were hypothesized as possible determinants of risk. In particular, the spatial pattern of HIV was associated with that of racial/ethnic distribution and of income inequality. The Gini coefficient of household income inequality, however, is only one socio-economic metric that might be affecting HIV transmission patterns. Therefore, other variables were considered that also might reflect economic inequality associations with HIV. We found that the ratio of owner occupied to all housing units was negatively associated with HIV prevalence, while other factors such as the ratio of female to male earnings was not. Similarly, no association between HIV prevalence and median household income was identified. Furthermore, we found no correlation between HIV prevalence and health-care related variables (e.g. number of hospital beds per capita and presence of community health clinics that offer STI and HIV services), suggesting the low access to health care may not contribute to HIV risk. Though issues of health care access and utilization are likely better assessed through individual level surveys, our findings are interesting.

The Gini income inequality index, limited though it may be, was the best predictor of HIV prevalence, both in the bivariate models and the optimal multivariate model. What this suggests is that proximal factors such as county-level median income and access to care are not nearly as important in creating conditions favoring HIV transmission as are economic disparities among county residents. This is a result that agrees with worldwide and Sub-Saharan African trends, as discussed in the introduction. Thus, it appears that rather than differences between aggregate units, the economic differences and disparities among people within those units may be exacerbating HIV transmission.

Income inequality does not occur at random. We note that many of the variables are correlated with each other, and that the percent of county residents who were African American was significant in a bivariate test of association with HIV. Mississippi's history of institutionalized racism and exclusion has probably contributed to the incredible inequalities which exist there today. We attempted to account for economic gender inequalities by including a variable for the ratio of female to male earnings, but the association, as measured and tested here, proved insignificant. We also attempted to measure differences in family structure that might negatively impact female wage earning by accounting for family size, yet this variables was significant in bivariate tests and in the optimal model. Untangling this complicated relationship is difficult and requires a deeper level of analysis than this paper can provide. Income inequality could merely be an efficiently measured intermediary in the "web of causation" that creates HIV outcomes. The relationships of historical factors to present day social inequities and the processes that produce them are essential to inferring what conditions determine population health.

Some studies have indicated that individual behaviors contribute to the spread of HIV and cultural values and practices put some groups at higher risk than others. We agree that relationships between "culture" and disease exist for a variety of human diseases. Pathogens opportunistically respond to the nature with which humans interact with one another. Differences in social groups and in sexual practices related to STIs may exist between black and white sectors of Mississippi society. Unfortunately, we cannot account for these factors using the data at hand. Differences in cultural practices and their impacts on pathogen transmission patterns are easier to account for when comparing highly disparate groups across countries and/or continents. Striking patterns appeared in our study of HIV in Mississippi, however, even though it is a small geographic region under a single administrative body.

We recognize the inherent difficulties in ecological analyses, namely that of the "ecological fallacy." However, when examining upstream and macro-social determinants of disease given sparse information on diseased and non-diseased populations, there are few tractable options[32, 33]. Given the known associations between the population at risk (African Americans in Mississippi) and the deep history of economic, social and genetic marginalization in the Deep South, the associations that we have identified represent scientifically reasonable causal hypotheses, even if they are difficult to fully confirm. As with any ecological study, our findings provide no definitive evidence of causation. Indeed, proper classification of an "exposure" to economic inequality as part of a causal pathway to eventual disease would be nearly impossible to obtain. Furthermore, the long term historical processes by which development creates conditions for disease generally do not permit data collection that facilitates analyses of causation. Our results, however, which correspond to worldwide studies of HIV, provide valuable insights into possible causal mechanisms, and could potentially inform novel interventions beyond the individual centered strategies which represent the dominant prevention paradigm. It may be possible to strategically target population-level intervention in areas identified as "risky" for known ecological attributes.

Conclusions

There is evidence for an association between county level income inequality and HIV prevalence. Evidence for a weak association between poverty and HIV exist independently of that of inequality and HIV. County-level racial composition also was associated with HIV prevalence, but race alone is only one of many risk factors, and not determinant of disease. Analyses should not ignore macro-social and economic determinants when examining HIV transmission and prevalence. New insights are likely to come from more careful examination of upstream factors that can be used in designing public health interventions to mitigate HIV transmission.

Competing Interests

None

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Table 1: Means and Standard Deviations of all variables used in the analyses.

Variable	Mean	Standard Deviation
HIV Cases per county	7.43	16.2
HIV Cases per 100,000 People	17.84	17.13
Income inequality (Gini coefficient) by county	46.74	3.17
Percent African American	40	20
Percent in Poverty	252.44	78.4
Per Capita Income	14538.05	2045.3
Average Family Size	3.16	0.13
Owner Occupied to all Housing Ratio	0.69	0.06
Female to Male Earnings Ratio	0.62	0.06
Urban to Rural Ratio	0.47	0.7
Number of Hospital Beds Per Capita	<.01	<.01
Number of Community Health Clinics per County	0.26	0.44
Number of Churches per County	97.74	48.31
Number of Counties With State Prison	3	
Number of Counties With Private Prison	6	
Percent of Counties With Joint County Prison	18	

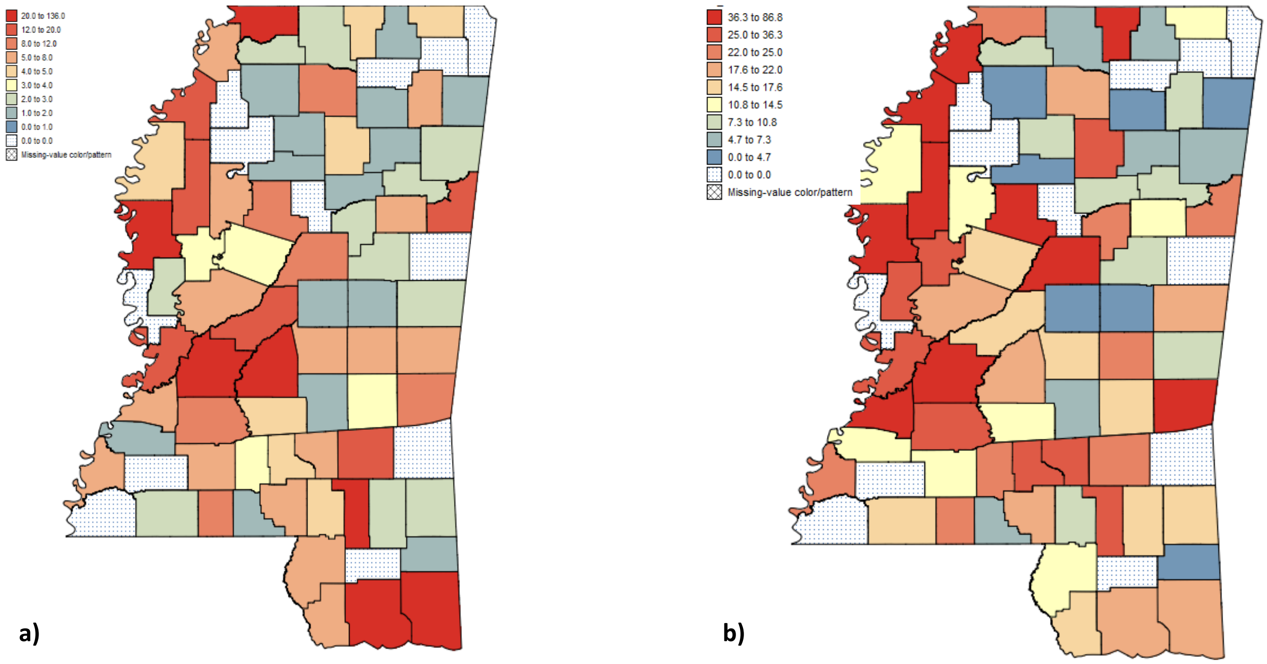
Table 2: Correlation matrix of all variables

Variable	log(HIV Prevalence)	Average Family Size	Ratio of Owned to All HH Units	Gini	Ratio of Female to Male Earnings	Number of Hospital Beds Per Capita	State Prison	Ratio of Women to Men	Private Prison	Joint County Prison	Number of Churches	Percent African American	Percent in Poverty	Per Capita Income	Urban to Rural Ratio
LogHIV2009	1.00	**0.35**	**-0.31**	**0.37**	**0.18**	0.05	0.11	-0.04	-0.23	-0.13	0.09	**0.39**	**0.24**	-0.04	**0.29**
Average Family Size		1.00	**-0.40**	**0.36**	**0.37**	0.06	0.10	-0.26	0.05	**0.18**	0.08	**0.77**	**0.75**	-0.45	**0.16**
Ratio of Owned to All HH Units			1.00	**-0.62**	**-0.48**	**-0.43**	0.01	-0.03	-0.10	0.13	**-0.35**	**-0.45**	**-0.47**	-0.06	**-0.64**
Gini				1.00	**0.25**	**0.34**	-0.05	-0.01	0.04	0.10	**0.20**	**0.56**	**0.57**	**-0.28**	**0.27**
Ratio of Female to Male Earnings					1.00	0.13	0.02	-0.10	0.13	-0.08	**0.38**	**0.46**	**0.43**	-0.05	**0.28**
Number of Hospital Beds Per Capita						1.00	-0.13	**0.23**	0.13	**-0.16**	**0.42**	0.16	**0.20**	0.01	**0.38**
Statepriso							1.00	**-0.69**	-0.05	0.07	0.07	-0.02	-0.01	0.07	0.04
Ratio of Women to Men								1.00	-0.06	**-0.40**	0.08	-0.07	**-0.22**	**0.21**	0.07
Private									1.00	0.03	**0.20**	0.12	0.14	-0.08	0.03
Joint										1.00	**-0.20**	0.16	**0.25**	**-0.31**	**-0.21**
Count_3											1.00	0.13	-0.02	**0.26**	**0.66**
Percent African American												1.00	**0.83**	**-0.49**	0.15
Percent in Poverty													1.00	**-0.66**	0.00
Per Capita Income														1.00	**0.46**
Urban to Rural Ratio															1.00

Table 3: Regression results of bivariate associations of covariates with county-level HIV prevalence and results of the optimal multivariate model.

	Bivariate Associations				Multivariate Model			
Variable	**Exp(Est)**	**SD**	**p**	**sig**	**Exp(Est)**	**SD**	**p**	**sig**
Gini	1.09	0.03	0	*	1.08	0.03	0.01	*
Percent African American	5.03	0.47	0	*	4.22	0.81	0.08	
Percent in Poverty	1	0	0.05		1	0	0.07	
Per Capita Income	1	0	0.87					
Average Family Size	10.85	0.75	0	*	7.22	1.08	0.07	
Ratio of Owner Occupied to all Housing Units	0.03	1.4	0.01	*				
Ratio of Female to Male Earnings	11.47	1.71	0.15					
Urban to Rural Ratio	1.35	0.12	0.02	*				
Number of Hospital Beds Per Capita	331041.8	53.1	0.81					
Number of Community Health Clinics	1.3	0.2	0.2					
Number of Churches	1	0	0.49					
Presence of State Prison	1.56	0.46	0.34					
Presence of Private Prison	0.44	0.39	0.04	*	0.44	0.34	0.02	*
Presence of Joint County Prison	0.75	0.23	0.22		0.71	0.2	0.1	
Rho					0.91	0.15	0.54	
Intercept					0	3.59	0.08	

Figure 1: a) Number of people living with HIV **b) Prevalence per 100,000 residents with HIV**



a) **b)**

Figure 2: Empirical Bayes Smoothing patterns of county-specific a) counts of HIV cases, and b) prevalence of HIV cases per 100,000 residents.

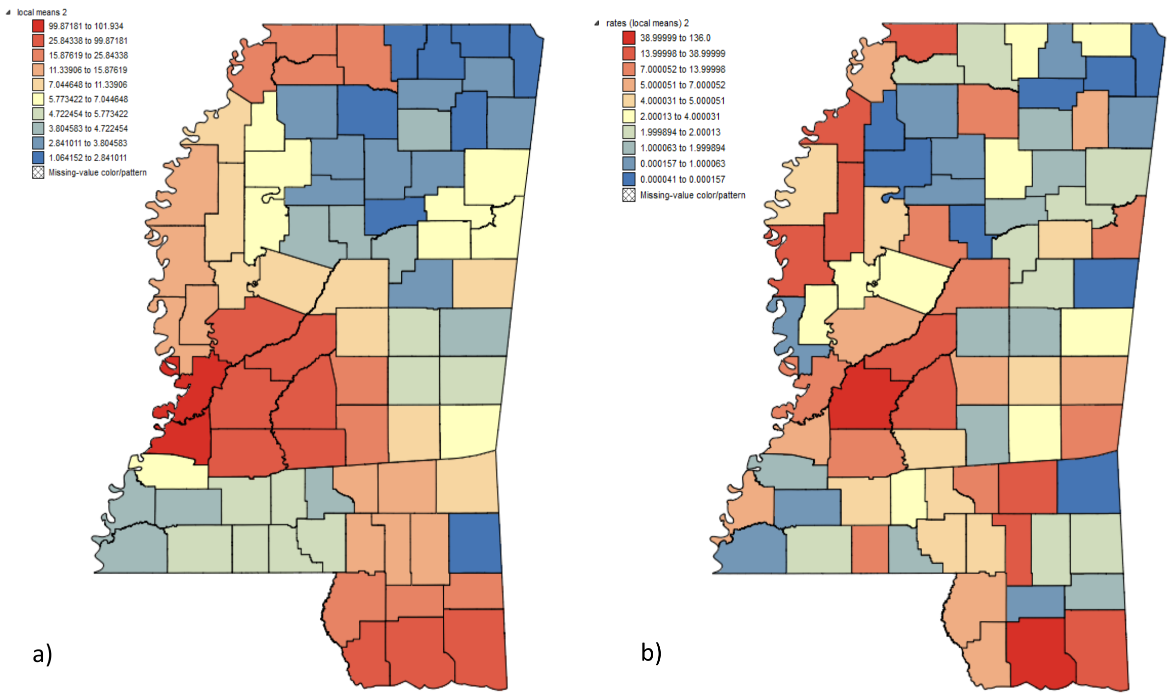


Figure 3: a) Spatial pattern of Gini coefficients of county-level income inequality, b) Histogram of these Gini coefficients, c) “Hot spots” of income inequality detected by Moran’s I analysis, and d) “Hot spots” of coincident HIV prevalence and income inequality values through bivariate Moran’s I analysis.

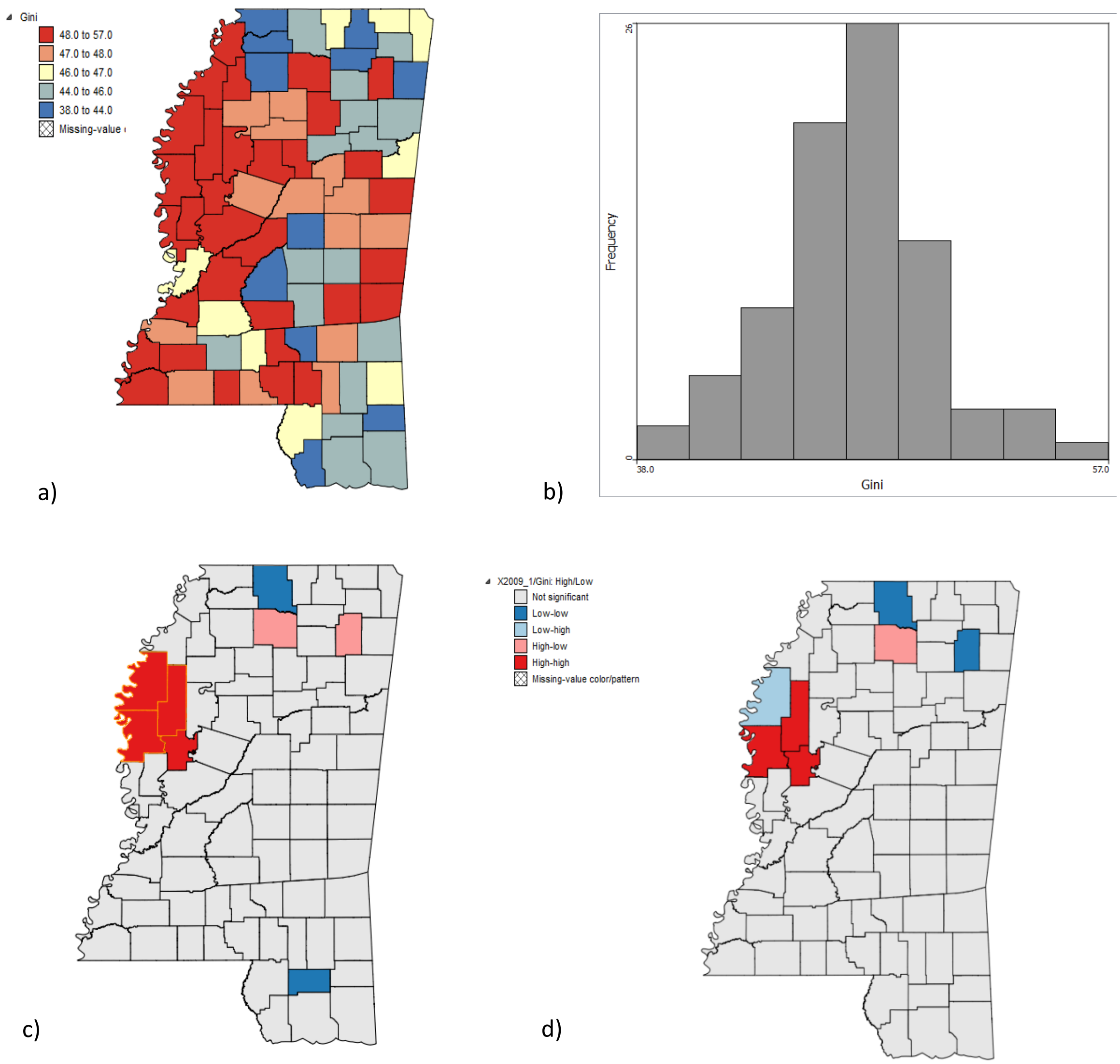


Figure 4: County-specific a) population, b) Percentage African American, c) Percentage in poverty, and d) ratio of owner occupied to all housing units

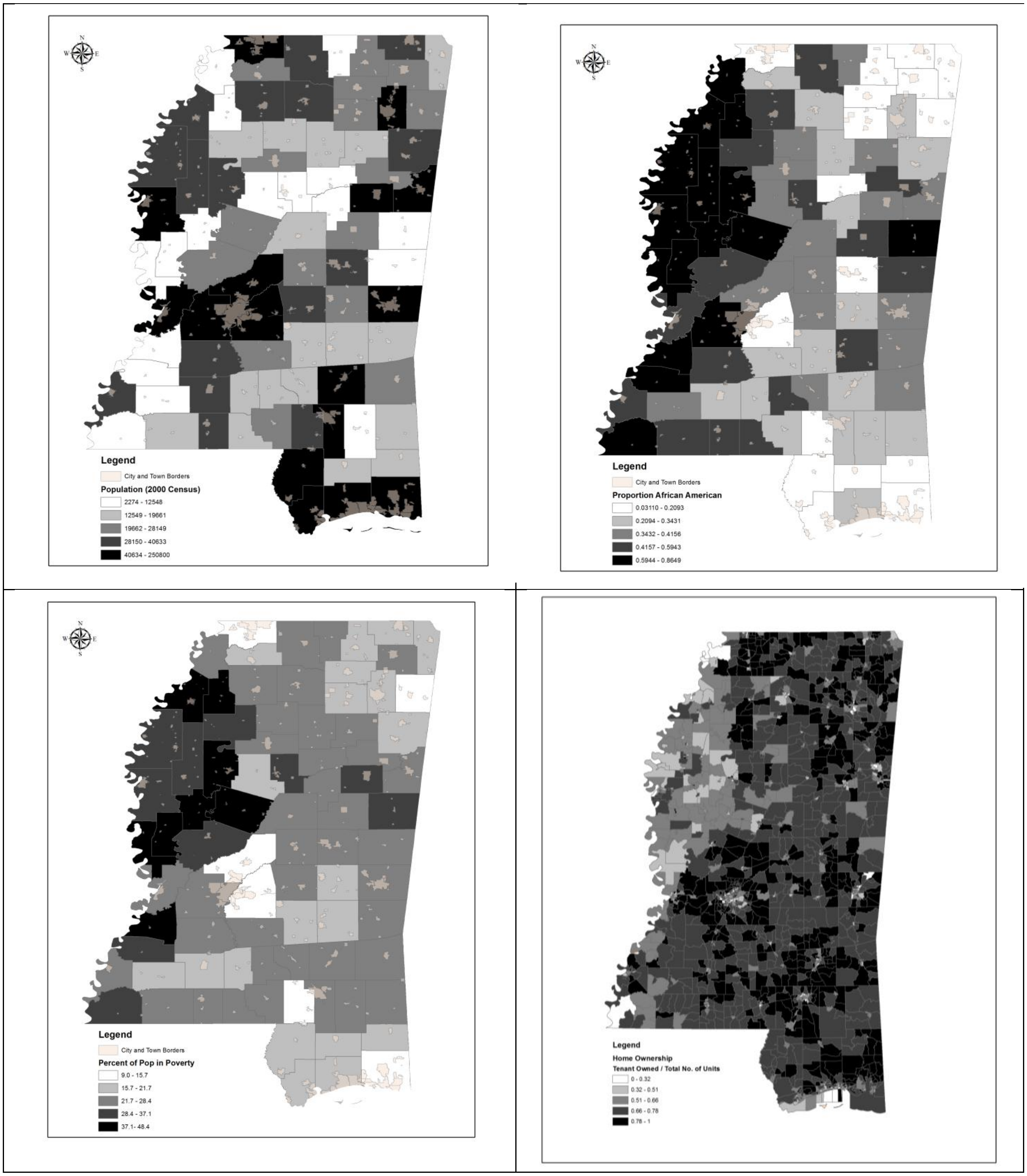


Figure 5: HIV case prevalence (per 100,000 residents) plotted against the Gini coefficient for 82 Mississippi counties. Size of dots represents the percentage of the county population that is African American. Color of points is graded from blue to red representing low to high percentage of county residents in poverty. Line represents a linear interpolation of the Gini coefficient with HIV cases per 100,000 residents.