Assessing Spatial Relationships between Race, Inequality, Crime, and Gonorrhea and Chlamydia in the United States

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Published online: 22 August 2017
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Abstract Incidence rates of chlamydia and gonorrhea reached unprecedented levels in 2015 and are concentrated in southern counties of the USA. Using incidence data from the Center for Disease Control, Moran's I analyses assessed the data for statistically significant clusters of chlamydia and gonorrhea at the county level in 46 states of the USA. Lagrange multiplier diagnostics justified selection of the spatial Durbin regression model for chlamydia and the spatial error model for gonorrhea. Rates of chlamydia (Moran's $I = .37$, $p < .001$) and gonorrhea (Moran's $I = .38$, $p < .001$) were highly clustered particularly in the southern region of the USA. Logged percent in poverty ($B = .49$, $p < .001$ and $B = .48$, $p < .001$) and racial composition of African-Americans ($B = .16$, $p < .001$ and $B = .40$, $p < .001$); Native Americans ($B = .12$, $p < .001$ and $B = .20$, $p < .001$); and Asians ($B = .14$, $p < .001$ and $B = .09$, $p < .001$) were significantly associated with greater rates of chlamydia and gonorrhea, respectively, after accounting for spatial dependence in the data. Logged rates of rates violent crimes were associated with chlamydia ($B = .053$, $p < .001$) and gonorrhea ($B = .10$, $p < .001$). Logged rates of drug crimes ($.052$, $p < .001$) were only associated with chlamydia. Metropolitan census designation was associated with logged rates of chlamydia ($B = .12$, $p < .001$) and gonorrhea ($B = .24$, $p < .001$). Spatial heterogeneity in the distribution of rates of chlamydia and gonorrhea provide important insights for

strategic public health interventions in the USA and inform the allocation of limited resources for the prevention of chlamydia and gonorrhea.

Keywords Sexually transmitted infection · Crime · Epidemiology

Introduction

Rates of sexually transmitted infections (STIs) in the USA reached unprecedented levels in 2015 imposing an annual economic burden of approximately US\$16 billion [1–3]. The human health consequences of chlamydia and gonorrhea are severe and include infertility, chronic pelvic pain, increased risk of HIV infection, and other medical problems [4]. Chlamydia and gonorrhea are two of the most common STIs with record numbers of more than 1.5 million (1,526,658) and nearly 400,000 (395,216) cases reported, respectively, in 2015 [4]. Rates increased from 2014 to 2015 by 6% for chlamydia (479 per 100,000) and 13% for gonorrhea (124) [4]. Mounting empirical studies suggest rates of STI are distributed unequally across geographic spaces with high rates of infection clustered in states in southern regions of the USA [5–11]. These data underscore the urgency of research that informs public health interventions to attenuate the growth of chlamydia and gonorrhea in the USA. Identifying spatial clusters of high STI prevalence is essential for allocating limited public health resources to interventions that could achieve the

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greatest impact for STI prevention, testing, and treatment interventions in the USA [12, 13].

Extant literature supports several spatial correlates as explanations for geographical clustering in rates of STI in the USA using data county, metropolitan, and state aerial units of analysis [12, 14–19]. Prior studies suggest high rates of STI intersect with areas of concentrated poverty, severe economic inequality, and relative deprivation [16, 17, 20–23]. In addition to economic inequality, a number of spatial studies suggest residential racial composition and segregation, defined as locations with greater proportions of African-American residents are associated with greater rates of STI using areal units at county, metropolitan, and state levels of analysis [19, 24–28]. Counties with the greatest concentrations of African-Americans are in the southern geographic region of the USA intersecting with locations with the highest rates of gonorrhea and chlamydia in the USA [3, 7, 29]. Compared to other census regions, the south region encompasses 8 out of 10 the states in the USA with the greatest incidence rates of HIV, chlamydia, gonorrhea and syphilis [11] and 7 out of the 10 states with the greatest concentrations of African-Americans [29]. Prior literature attributes elevated rates of STI in the South to the disproportionate representation of African-Americans in this region [7, 8].

In addition to the south, geographic regions in the United States may experience higher rates of gonorrhea and chlamydia because of overrepresentation of other racial and ethnic populations including Native American, Alaska Natives, and Hispanic populations [19, 30, 31]. Walker et al. [30], found heightened rates of chlamydia and gonorrhea among American Indians and Alaska Natives within Indian Health Service Areas over the period from 2007 to 2012. Regarding Hispanics, at the county-level, Owusu-Edusei and Chesson [19] found a significant relationship between a unit change in neighborhood percent Hispanic and a percent increase in chlamydia and gonorrhea rates for counties in Texas. These studies emphasize that the geographic distribution of racial and ethnic groups matter greatly in understanding the social epidemiology of chlamydia and gonorrhea in the USA.

At a local level, a number of studies suggest that urban compared to rural environments are correlates of greater rates of STI [11, 17, 32]. As epicenters of economic, cultural, and demographic activity, as well as population movement, cities and adjacent metropolitan communities provide environments for sexual

partnerships and activity that increase rates of chlamydia and gonorrhea compared to rural areas [32, 33]. Conversely, some studies suggest barriers to prevention, testing, and treatment options as well as policies that promote infection in rural environments increase risk of HIV and STI compared to urban communities [6, 7, 10].

There is a wealth of empirical data pointing to the convergence of multiple risk factors including social disorganization, poverty, and other social problems within urban environments and neighborhoods as factors that increase rates of HIV and STI in the USA [17, 22, 33, 34]. Empirical and theoretical studies support a relationship between urban communities higher rates of crime namely drug and property crimes compared to more rural communities [22, 35]. Studies at the ecological level, have found that areas with high rates of incarceration, violent crimes, and drug activity are more likely to have higher rates of gonorrhea and chlamydia [17, 36–40]. Urban environments with high rates of arrest and incarceration are associated with higher rates of chlamydia and gonorrhea infection [17, 39–42]. In addition to criminal justice involvement, studies suggest neighborhoods in cities with drug markets are associated with greater rates of STI [39, 42]. Moreover, mass incarceration of communities erodes protective factors including social cohesion, social control, family stability, and social capital that are shown in prior literature to protect against high rates of gonorrhea, chlamydia, and other infectious diseases [20, 23, 43–47].

Rates of crime reflect the broader structural context within communities and may heighten rates of STI by virtue of increasing social disorganization, undermining social cohesion, and disrupting important social bonds [23, 43, 44, 48]. Dynamic influences of interrelated, environmental, social and structural factors are crucial ecological determinants of how STIs unfold at the population level [49, 50]. The ecological model suggests the convergence of factors in the social environment including poverty, race and ethnicity, and crime work together to increase risk of gonorrhea and chlamydia [18, 51]. The ecological framework presumes the distribution of race, crime, and poverty are spatially patterned thus producing geographic differences in rates of chlamydia and gonorrhea in the USA [49–51].

Despite accumulating evidence in mostly urban environments suggesting crime heightens risk of STI, research is needed at the national level elucidating spatial associations between aggregate county-level rates of crime, poverty, and race on rates of STI at the national

level. To enrich this gap in the literature, the following study aims to (1) assess the data for clusters of spatial dependence in rates of gonorrhea and chlamydia in the USA in 2014; (2) describe the sociodemographic crime and geographic characteristics of statistically significant clusters of rates of gonorrhea and chlamydia in the USA; and (3) assess the data for associations between poverty, racial and ethnic composition, rates of crime (violent and drug), and rates of STI in the USA using regression models that account for spatial dependence. The following study hypothesizes that rates of chlamydia and gonorrhea are significantly clustered (non-random). This study also hypothesizes that after adjusting for spatial dependence, county-level poverty, racial composition of African-Americans and rates of crime will predict higher rates of chlamydia and gonorrhea.

Materials and Methods

Data and Measures

Data for this study were obtained through publically available sources at the county level for the continental USA. Data on annual incidence rates of chlamydia and gonorrhea consist of yearly population-adjusted incidence rates of chlamydia and gonorrhea per 100,000 for every county in the USA and is available for public use by the Centers of Disease Control through the Atlas Plus database [52]. Population-adjusted aggregate county-level counts of part 1 violent crimes (homicide, assault, robbery, and rape), and drug crimes per 100,000 were obtained from the US Department of Justice Federal Bureau of Investigation Uniform Crime Report Program Data: County-Level Detailed Arrest and Offense Data for 2014 and calculated using census population estimates for 2014 [53]. Population percent estimates for race and ethnicity data were provided by the American Community Survey (ACS) for 2015 and included county-level percent composition of Native American, black, Asian, white and Hispanic [54]. Using data from the 2015 American Community Survey, poverty was measured by the proportion of households below 100% of the federal poverty line living in each county [54]. The rural-urban influence codes provide a method for delineating metropolitan regions in the USA [55]. Counties were coded as metropolitan (1 = yes) using the 2013 Urban Influence Codes for residing in an urbanized area of 50,000 or more people. All data

were merged into a single shape file and imported into QGIS and R version 5 to perform spatial statistical analyses (replication data files available upon request).

Statistical Analysis

Descriptive and Exploratory Spatial Analysis An exploratory analysis of spatial patterns in the data visualized the distribution of STIs in the USA with five quintile categories using the analytic software program, QGIS. QGIS is a free publically available geographic statistical processing, data management, and visualization tool that provided an expedient method of describing and visualizing the data [56]. Moran's I computations with 99,999 randomizations scrutinized the data for statistically significant clusters of chlamydia and gonorrhea infection using the spatial analytic software, GeoDa and exported into QGIS for visualization of significant clusters of counties (Aim 1) [57]. The Moran's I is a measure of spatial autocorrelation based on a feature's value and location and assesses if the distribution of the feature is random or non-random in either clustered or dispersed form [58, 59]. A score that is closer to +1 indicates clustering in the data. A z score test statistic tests the hypothesis that the data provides sufficient evidence to reject the null hypothesis that the data is distributed geographically at random [58–60]. A significant p value indicates that the data is non-randomly distributed in either clustered or dispersed form. The following study uses global Moran's I statistic to test the hypothesis that the data is distributed non-randomly and are clustered geographically. GeoDa is a powerful spatial analytic software program specializing in calculating weight matrices for assessing data to inform spatial regression models [61]. The predetermined weight matrix used for Moran's I computations included a queens contiguity matrix that assessed if spatial patterns in rates of chlamydia and gonorrhea were clustered across counties in the United States at a level of significance of $p < .001$ [62].

After identifying statistically significant clusters of high and low rates of chlamydia and gonorrhea, analyses elucidated crime (drug, violent); sociodemographic (racial and ethnic composition, poverty, metropolitan census designation); and geographic characteristics of high and low-rate clusters of chlamydia and gonorrhea (AIM 2). The geographic classification system set forth by the Census Bureau for the USA includes four regions subcategorized into divisions including (1) the northeast

region with New England and Middle Atlantic divisions; (2) midwest region with east north central and west north central divisions; (3) south region with South Atlantic, east south central, and west south central divisions; and (4) west region with mountain and Pacific divisions [63]. Descriptive results were stratified by type of clusters in Moran's I analyses using GeoDa of gonorrhea and chlamydia (high rate [high], high-high [HH], high-low [HL], low-high [LH], and low rate [low] clusters). Proportions and counts of counties were provided for each geographic region and division stratified by clusters of chlamydia and gonorrhea.

Spatial Regression Analyses The presence of spatial heterogeneity in Moran's I analyses would suggest that the effects of independent variables on rates of STIs are a function of geographic location in the USA and must be modeled accordingly in regression analyses (Aim 3). The following study employs a log-log spatial regression approach to assess the data for relationships between poverty, race, ethnicity, and crime after accounting for spatial dependence in the data [64, 65]. Two major advantages of modeling the natural log of dependent and independent variables include (1) linearization of regression parameters from nonlinear variables and (2) straightforward interpretation of regression coefficients [66]. The log-log spatial regression approach places rate and percentage variables on a normal distribution and provides a standardized scalar method of interpretation based on percentage in which a 1% increase in each independent variable (rates of violent and drug crimes, racial and ethnic composition, and poverty) results in a 1% increase in the dependent variables (chlamydia and gonorrhea) [64]. The regression coefficient (B) measures the responsiveness of logged incidence rates of chlamydia and gonorrhea to a percent change in logged independent variables of rates of crime (drug, violent); racial composition (black, Hispanic, Asian, Native American); and poverty. The regression coefficients (B) for gonorrhea and chlamydia is interpreted as the expected percentage change when rates of drug, property, or violent crime, percent in poverty, percent racial composition of black, white, Hispanic, Asian, and Native American either increase or decrease by a given percentage. Interpretation of the dichotomous metropolitan variable is the

percent difference in mean rates of chlamydia and gonorrhea between metropolitan (1) and non-metropolitan (0) regions in the USA. Logarithmic transformations of variables with zero values produce undefined logged values and are thus excluded from analysis [66]. Excluding counties with zero values on any of the variables of interest produced a sample size of 2721 for chlamydia and 2458 for gonorrhea for inclusion in multivariable spatial regression analyses.

Goodness of fit Statistics for Spatial Regression Models Three model-fit statistics are provided by LaGrange spatial diagnostics that are used to select between error term, spatial lag and spatial Durbin models [67–69]. When only error or lag model-fit statistics are significant then the most appropriate selection is either the error term or spatial lag models, respectively [70]. When both the error and lag, or the SARMA fit statistics are significant, the appropriate model selection is the spatial Durbin model [70]. The spatial Durbin model combines adjustments provided by the error term (constraints to the error term) and the lag models (spatially lagged independent variables) to account for spatial dependence in the data [70–72]. All estimations of model parameters and fit statistics were performed using the statistical computing software R version 5 [69]. In the spatial regression model for chlamydia, all three LaGrange multiplier diagnostics were significant indicating that the spatial Durbin model was a significant improvement over the OLS, spatial lag and error term models. In the model for gonorrhea, the LaGrange spatial diagnostic fit statistics supported selection of the spatial error term model because the spatial lag diagnostic statistic was insignificant and the spatial error term statistic was significant at $p < .001$.

Results

Descriptive and Exploratory Spatial Analysis

Independent Variables

Rates of crime for the USA in 2014 were 100.76 (0–1162.79) for part 1 violent crimes, and 453.06 (0–164,608.70) for drug crimes. On average, 16.1% (0–47.40) of households reported incomes below the poverty line. In terms of racial

composition, 9.32% (0–85.12) of people residing in the counties were black, 2.03% (0–86.46) were Native American alone, and 85.39% (10.72, 99.15) were white alone. Summary statistics including means, percentages and standard errors are provided for each of the variables for 2935 counties in the USA in Table 1.

Dependent Variables

Chlamydia

Rates of Chlamydia ranged from 0.00–2776.50 per 100,000 of the population with a mean of 342.91. Overall rates of chlamydia by county are presented in Fig. 1.

Assessing Spatial Heterogeneity in Rates of Chlamydia (aim 1) Figure 2 presents statistically significant spatial clusters of chlamydia in the USA using empirical Bayes Moran's I analysis. Findings identified significant evidence of spatial clustering in the data with a statistically significant coefficient estimate of local spatial dependence of .38 ($p < .001$). More than 10% (10.32%, $n = 303$) of counties with high rates of chlamydia

bordering other counties with high rates (high-high), and 14.55% (427) of counties with low rates adjacent to other counties with low rates (low-low). There were 54 (1.84%) counties with high rates adjacent to counties with low rates (high-low) and 62 counties (2.11%) with low rates were adjacent to counties with high rates (low-high). Overall, 12.18% (357) of counties were located in clusters of counties with high rates ("high rate clusters") and 16.66% (489) in clusters of counties with low rates of chlamydia ("low rate clusters").

Analysis of High- and Low-Rate Clusters of Chlamydia (Aim 2) Table 2 stratified data by high- and low-rate clusters of gonorrhea and chlamydia. The mean rate of chlamydia in high-rate clusters was 663.73 (SD = 325.54) compared to 174.42 (SD = 85.81) in low-rate clusters. Violent (133.13 SD = 97.53 vs. 77.36 SD = 71.98) and drug (453.06, SD = 380.92 vs. 356.05, SD = 381.69) rates of crime were higher in high-rate clusters compared to low-rate clusters. On average, counties in high-rate clusters of chlamydia were composed of 31.29% (SD = 21.48) black compared to 2.86% (SD = 6.58) in low-rate clusters. Counties in high-rate clusters of chlamydia were composed of more than twice as many Native Americans (3.84%, SD = 3.57) than low-rate clusters (1.22% SD = 4.89). Counties in high-rate clusters of chlamydia were composed of fewer whites (62.05% SD = 20.30) compared to low-rate clusters (93.69%, SD = 7.57). Nearly a quarter of persons (23.01%, SD = 7.75) in high-rate clusters earned incomes below the poverty line compared to 15.85% (SD = .02) in low-rate clusters. Over a third (36.41%, $n = 130$) of the counties in high-rate clusters were in metropolitan census regions compared to approximately 15% ($n = 75$) of counties in clusters of low rates of chlamydia.

More than three quarters (79.80%, $n = 285$) of high-rate clusters of chlamydia were located in the south region of the USA compared to 27.40% (117) of counties in low-rate clusters. The geographic division accounting for the greatest proportion of counties in high-rate clusters was the South Atlantic Division (32.77%, $n = 117$). The fewest number of counties in high-rate clusters were in the northeast with 1.96% (7) compared to 5.78% (28) of low-rate clusters. The mid-west region accounted for 13.73% (49) of counties in high-rate clusters compared to 45.81% (224) of counties in low-rate clusters. Nearly 5% of counties in high-rate clusters were in the west region (4.48%, $n = 16$)

Table 1 Overall descriptive characteristics ($n = 2935$)

	Overall	Range
Overall % (n)		
Dependent variables		
STI ^a		
Chlamydia mean (SD)	342.91	(0–2776.50)
Gonorrhea mean (SD)	66.25	(0–857.80)
Independent variables		
Crime rates ^b		
Violent mean (SD)	100.76	(0–1162.79)
Drug mean (SD)	453.06	(0–164,608.70)
Race		
Black % (SD)	9.32	(0–85.12)
N. American % (SD)	2.04	(0–86.46)
White % (SD)	85.39	(10.72–99.15)
Asian % (SD)	1.32	(0–34.97)
Hispanic % (SD)	9.11	(.20–95.78)
Poverty % (SD)	16.91	(3.20–47.40)
Metropolitan % (n) ^c	36.66	(1076)

^a Per 100,000

^b Per 10,000

^c Small or large metropolitan county designation >50,000 persons

Fig. 1 Spatial distribution of rates of chlamydia in the USA, 2014

compared to 15.13% (74) of counties in clusters of low rates of chlamydia.

Gonorrhea

Figure 3 visualizes the spatial distribution of rates of gonorrhea in counties in the USA. Rates of gonorrhea ranged between 0 and 857.80 (per 100,000) with a mean of 66.25 (per 100,000).

Assessing Spatial Heterogeneity in Rates of Chlamydia (Aim 1) Findings from Moran's I analyses revealed spatial clustering in the data through a statistically significant coefficient value of .38 ($p < .001$) and is visualized in Fig. 4. Exploratory data analysis identified 10.36% of

counties (304) were in high-high clusters and 23.07% (677) in low-low clusters. Approximately 1% (1.06%, $n = 31$) of counties were in high-low clusters and a small proportion of counties (2.59%, $n = 76$) were in low-high clusters of gonorrhea.

Analyses of High- and Low-Rate Clusters of Gonorrhea (Aim 2) Average incidence rates of gonorrhea for counties in high-rate clusters were 185.05 (111.71) compared to 16.97 (17.31) for counties in low-rate clusters of gonorrhea. Violent (133.28, SD = 90.87 vs. 77.87, SD = 65.53) and drug (425.66, SD = 309.93 vs. 343.63, SD = 284.24) crime rates were higher in high-rate clusters of gonorrhea compared to low-rate clusters. Low-rate clusters of gonorrhea were composed of nearly 95% whites (94.71%,

Fig. 2 Empirical Bayes adjusted spatial clusters of chlamydia in the USA, 2014

Table 2 Sociodemographic and crime characteristics of spatial clusters of chlamydia and gonorrhea in 2014; $n = 2935$

Chlamydia							
	High clusters			Low cluster			High
	High	HL		Low	LH	LL	
		HH	HL				
Overall % (n)	11.41 (335)	10.32 (303)	1.84 (54)	16.66 (489)	2.11 (62)	14.55 (427)	11.41 (335)
Dependent variables							
STI							
Chlamydia mean (SD)	663.73 (325.54)	696.61 (333.09)	479.24 (196.95)	174.42 (85.81)	224.54 (97.21)	167.15 (81.63)	185.05 (111.71)
Gonorrhea mean (SD)							
Independent variables							
Crime rates ^a							
Violent mean (SD)	133.13 (97.53)	137.39 (99.91)	109.21 (79.59)	77.36 (71.98)	80.27 (65.86)	76.93 (72.88)	133.28 (90.87)
Drug mean (SD)	453.058 (380.92)	448.94 (396.57)	476.11 (287.11)	356.05 (381.69)	414.49 (585.72)	347.57 (342.34)	425.66 (309.93)
Race							
Black % (SD)	31.29 (21.48)	36.31 (19.35)	3.14 (3.65)	2.86 (6.58)	12.75 (14.31)	1.43 (2.02)	32.40 (20.43)
N. American % (SD)	3.84 (3.57)	3.48 (15.51)	5.88 (14.16)	1.22 (4.89)	1.50 (2.55)	1.19 (2.92)	3.11 (11.48)
White % (SD)	62.05 (20.30)	57.60 (17.93)	87.02 (13.73)	93.69 (7.57)	82.77 (13.88)	95.27 (4.26)	61.52 (19.47)
Asian % (SD)	1.09 (1.84)	.99 (1.84)	1.72 (1.74)	.69 (1.01)	1.19 (2.23)	.62 (.65)	1.16 (1.99)
Hispanic % (SD)	6.01 (8.77)	5.20 (7.60)	10.56 (12.75)	6.38 (9.99)	9.49 (18.40)	5.93 (8.01)	5.35 (6.42)
Poverty % (SD)	23.01 (7.75)	24.22 (7.62)	16.25 (4.28)	15.85 (.02)	16.60 (7.28)	15.74 (5.81)	22.97 (7.63)
Metropolitan % (n)	36.41 (130)	37.29 (113)	31.48 (17)	15.34 (75)	41.94 (26)	11.48 (49)	41.19 (138)
Gonorrhea							
High cluster							
HH	HL	Low		Low cluster			LL
				LH			
10.36 (304)	1.06 (31)	25.66 (753)		2.59 (76)	23.07 (677)		
Dependent variables							
STI							
192.38 (114.06)	113.21 (40.82)	16.97 (17.31)		37.64 (22.42)	14.65 (14.97)		
Independent variables							
Crime rates ^a							
136.31 (96.84)	133.28 (90.87)	77.87 (65.53)		82.68 (89.31)	77.33 (62.36)		

Table 2 (continued)

Gonorrhea				
High cluster		Low cluster		
HH	HL	Low	LH	LL
428.98 (315.88)	393.08 (245.81)	343.63 (284.24)	357.61 (340.89)	342.07 (277.41)
Race				
35.12 (19.42)	5.89 (6.01)	2.67 (6.30)	1.37 (76)	1.48 (1.91)
3.02 (11.43)	4.07 (12.13)	1.33 (4.33)	1.72 (2.76)	1.41 (4.48)
59.09 (18.39)	85.37 (15.88)	93.39 (7.94)	81.60 (14.71)	94.71 (5.35)
1.07 (1.98)	2.11 (1.84)	.90 (1.55)	1.43 (3.66)	.84 (1.07)
7.15 (5.97)	5.17 (6.44)	5.12 (7.24)	6.10 (9.90)	5.01 (6.88)
23.56 (7.58)	17.11 (5.44)	15.61 (6.85)	15.94 (7.61)	15.57 (5.72)
39.47 (120)	58.06 (18)	19.65 (148)	47.37 (36)	16.54 (112)

^a Per 100,000

SD = 5.35) compared to approximately 60% in clusters of high rates of gonorrhea (61.52%, SD = 19.47). Counties in high-rate clusters were composed of nearly a third blacks (32.40% SD = 20.4) compared to approximately two and a half percent for counties (2.67%, SD = 6.30) in low-rate clusters. Counties in high-rate clusters were composed of more than twice as many Native Americans (3.11% SD = 11.48) compared to counties low-rate clusters (1.41%, SD = 4.48). Counties in high-rate clusters were composed of slightly more Hispanics (5.35%, SD = 6.42) compared to low-rate clusters (5.01%, SD = 6.88). Counties in high-rate clusters were composed of more Asians (1.16% SD = 1.99) than counties in low-rate clusters (.84% SD = 1.07). The prevalence of poverty for high-rate clusters was 22.97% (SD = 7.63) compared to 15.57% (SD = 5.72) in low-rate clusters. Over a third (36.41%, $n = 130$) of counties in high-rate clusters of gonorrhea were in metropolitan census regions compared to approximately 15% of counties low-rate clusters (15.34%, $n = 75$).

A majority of counties in high-rate clusters of gonorrhea were located in the south (85.97%, $n = 288$) compared to a little more than a fifth of counties in low-rate clusters (21.91%, $n = 165$). Over a quarter of counties in high-rate clusters were in the West South Central Division (26.57%, $n = 89$) compared to slightly more than 3% of counties in low-rate clusters (3.19%, $n = 24$). Only 1.49% counties in clusters of high rates were in the northeast ($n = 5$) compared to 2.48% (94) of low-rate clusters. The midwest accounted for nearly 10% (9.55%, $n = 32$) of counties in high-rate clusters compared to 48.74% (367) of counties in low-rate clusters. Out of all the counties in high-rate clusters, 2.99% were in the west compared to 16.87% of counties in low-rate clusters of gonorrhea.

Spatial Regression Results

Heterogeneity in spatial distribution of rates of gonorrhea and chlamydia identified by local Moran's I analyses justified selection and specification of spatial regression models. With the exception of metro census designation, all multivariable spatial and linear regressions were performed on logged rates of STIs, logged rates of crime, as well as logged percent estimates of race, ethnicity and poverty.

Chlamydia

Assessing Correlates of Chlamydia after Accounting for Spatial Dependence (Aim 3) Table 2 presents linear and

Fig. 3 Spatial distribution of rates of gonorrhea in the USA, 2014

spatial regression models estimating relationships between logged drug, violent, and property crimes and race ethnicity, poverty and metropolitan census designation on rates of chlamydia for 2721 counties in the USA. The significant lambda statistic of .45 ($p < .001$) indicates the regression model significantly accounted for spatial dependence in the distribution of chlamydia in the data. In the spatial Durbin model, after adjusting for spatial dependence, an increase in logged rates of drug and violent crimes of one unit was significantly associated with small increase in logged rates of chlamydia of .057 (SD = .01; $p < .001$) and .052 (SD = .16, $p < .001$), respectively, after adjusting

for rates of drug and property crimes and potential confounders. In terms of racial and ethnic composition, a 1% increase in percent black was associated with a percent increase in rates of chlamydia of .16 (SD = .01; $p < .001$). Counties with greater percentages of residents with income below the poverty line was significantly associated with increased rates of chlamydia of .49 (SD = .04, $p < .001$). An increase in logged percent Native American was associated with an increase in rates of chlamydia of .12 (SD = .02; $p < .001$). Metropolitan census designation was associated with an increase in chlamydia of .08 (SD = .02, $p < .001$).

Fig. 4 Empirical Bayes adjusted spatial clusters of gonorrhea in the USA, 2014

Gonorrhea

Assessing Correlates of Gonorrhea after Accounting for Spatial Dependence (Aim 3) Results from linear and spatial regression models estimating the effects of logged rates of crime, demographic factors, and logged rates of gonorrhea for 2458 counties in the USA are presented in Table 3. The significant rho statistic of .47 ($p < .001$) indicated the spatial error regression model significantly accounted for spatial dependence in the distribution of gonorrhea in the data. A one unit increase in logged rates of violent crimes resulted in a small albeit significant increase in logged rates of gonorrhea of .10 ($SD = .02$; $p < .001$) after adjusting for spatial dependence in the data and potential confounders. Regarding racial and ethnic composition, an increase in logged percent black was associated with an increase in logged rates of gonorrhea by .42 ($SD = .02$; $p < .001$). An increase in percent Native American and Asian was associated with an increase in logged rates of Gonorrhea of .20 ($SD = .02$; $p < .001$) and .09 ($SD = .02$; $p < .001$). An increase in percent living below the poverty line was associated with an increase in rates of gonorrhea of .48 ($SD = .05$; $p < .001$). Metropolitan census designation was associated with an increase in rates of gonorrhea by .24 ($SD = .03$; $p < .001$).

Discussion

Findings from this study rejected the hypothesis that rates of chlamydia and gonorrhea in the USA are randomly distributed and instead found significant evidence of clustering. Moran's I analyses identified statistically significant spatial clusters of high rates of gonorrhea and chlamydia that occurred predominantly in the southeastern region of the USA. Nearly three quarters of counties in high-rate clusters of chlamydia and more than 85% of counties in high-rate clusters of gonorrhea were located in the south. Specifically, one division, the South Atlantic accounted for approximately a third of the high-rate clusters of chlamydia and gonorrhea. Metropolitan counties were disproportionately represented in high-rate clusters of gonorrhea and chlamydia. On average nearly a quarter of counties in high-rate clusters were in poverty. The mean percentage of counties that were African-Americans in high-rate clusters was more than 30 times the mean percentage in low-rate

clusters of chlamydia and gonorrhea. The mean percent white of counties in low-rate clusters was more than 50% greater than the mean percent white of counties in high-rate clusters. These findings reveal wide racial disparities in the characteristics of counties in high- and low-rate clusters in the USA. Disparities were also found in the mean percent of Native American/Native Alaskan with a proportion in high-rate clusters more than three times the mean percentage in the low-rate clusters. These relationships were statistically significant in spatial regression analyses in which poverty followed by percent African-American were the strongest correlates of rates of gonorrhea and chlamydia after controlling for spatial dependence and other factors. Average rates of violent crime in high-rate clusters was more than 40% and more than 20% greater for drug crimes compared to rates in low-rate clusters. In spatial regression analyses, logged rates of drug and violent crimes were associated with higher logged rates of chlamydia. Logged rates of drug crimes predicted greater logged rates of only chlamydia and not gonorrhea (Tables 4 and 5).

Limitations

Despite a number of significant findings from this study, there are limitations that warrant explication. A limitation of this study involves missing data from Florida and Illinois. Missing data from Florida and Illinois created a study space that did not provide a complete representation of all the counties in the USA. Additional research is warranted that investigates if similar relationships between crime, sociodemographic factors and STI in Florida mirror the same relationships that were observed in this study. Similarly, a cost of conducting a log-log spatial regression analysis involves loss of cases that report zero counts on any of the variables. The log of zero is undefined resulting in some missing cases that were excluded from the study. Given that this is an ecological study it is important that causality is not inferred from findings from analysis of data. Finally, the data on crime did not differentiate between crime and incarceration, which is a nuanced but important distinction in criminal justice research. Prior research has found that the legal environment particularly the criminalization of drug use heightens STI and sexual risk behaviors [73]. Future research must account for spatial heterogeneity and parse out criminal behaviors

Table 3 Geographic characteristics of spatial clusters of chlamydia and gonorrhea in 2014 $n = 2935$

	Chlamydia						Gonorrhea						
	Overall	High	High Clusters			Low Cluster			High Cluster	Low Cluster			
			HH	HL	Low	LH	LL	High		HH	HL	Low	LH
Overall % (n)		12.16 (357)	10.32 (303)	1.84 (54)	16.66 (489)	2.11 (62)	14.55 (427)	11.41 (335)	10.36 (304)	1.06 (31)	25.66 (753)	2.59 (76)	23.07 (677)
Northeast % (n)	7.33 (215)	1.96 (7)	.99 (3)	7.41 (4)	5.73 (28)	3.23 (2)	6.09 (26)	1.49 (5)	0.99 (3)	6.45 (2)	2.48 (94)	1.32 (1)	13.74 (93)
New England % (n)	2.21 (65)	.56 (2)	0	3.75 (2)	0	0	0	0	0	0	5.05 (38)	0	5.61 (38)
Middle Atlantic % (n)	5.11 (150)	1.40 (5)	.99 (3)	3.70 (2)	5.73 (28)	3.23 (2)	6.09 (26)	1.49 (5)	.99 (3)	6.45 (2)	7.44 (56)	1.32 (1)	8.12 (55)
Midwest % (n)	32.44 (952)	13.73 (49)	5.28 (16)	61.11 (33)	45.81 (224)	22.58 (14)	49.18 (210)	9.55 (32)	5.59 (17)	48.39 (15)	48.74 (367)	22.37 (17)	51.70 (350)
E. North Central % (n)	11.43 (335)	.84 (3)	0	5.56 (3)	7.36 (36)	1.61 (1)	8.20 (35)	1.49 (5)	0	16.13 (5)	15.54 (117)	1.32 (1)	17.13 (116)
W. North Central % (n)	21.02 (617)	12.89 (46)	5.28 (16)	55.56 (30)	38.45 (188)	20.97 (13)	40.98 (175)	8.06 (27)	5.59 (17)	32.26 (10)	33.20 (250)	21.05 (16)	34.56 (234)
South % (n)	46.17 (1355)	79.8 (285)	91.42 (277)	14.81 (8)	27.40 (117)	69.35 (43)	27.40 (117)	85.97 (288)	92.76 (282)	19.35 (6)	21.91 (165)	68.42 (52)	16.69 (113)
South Atlantic % (n)	17.75 (521)	32.77 (117)	37.29 (113)	7.41 (4)	17.18 (84)	32.26 (20)	14.99 (64)	32.54 (109)	34.54 (105)	12.90 (4)	9.83 (74)	27.63 (21)	7.83 (53)
E. South Central % (n)	12.40 (364)	27.45 (98)	32.01 (97)	1.85 (1)	7.36 (36)	12.90 (8)	6.56 (28)	7.36 (36)	28.95 (88)	6.45 (2)	8.90 (67)	15.79 (12)	8.12 (55)
W. South Central % (n)	16.01 (470)	19.61 (70)	22.11 (67)	5.56 (3)	8.18 (40)	24.19 (15)	5.85 (25)	26.57 (89)	29.28 (89)	0	3.19 (24)	25.00 (19)	.74 (5)
West % (n)	14.07 (413)	4.48 (16)	2.31 (7)	16.67 (9)	15.75 (77)	15.75 (77)	4.84 (3)	2.99 (10)	.66 (2)	25.81 (8)	16.87 (127)	7.89 (6)	17.87 (121)
Mountain % (n)	9.57 (281)	4.48 (16)	2.31 (7)	16.67 (9)	15.13 (74)	4.84 (3)	16.63 (71)	1.79 (6)	.33 (1)	16.13 (5)	15.94 (120)	6.58 (5)	16.99 (115)
Pacific % (n)	4.50 (132)	0	0	0	.61 (3)	0	.70 (3)	1.19 (335)	.33 (1)	9.68 (3)	.93 (7)	1.32 (1)	.89 (6)

Census regions

Table 4 Linear and spatial relationships between logged rates of crime and logged rates of chlamydia in counties (2721) in the USA, 2014

	Linear β (SD)	Spatial lag β (SD)	Spatial error β (SD)	Durbin β (SD)
Crime				
Violent ^a	.031 (.01)***	.029*** (.01)	.041** (.01)	.052*** (.16)
Drug ^a	.026 (.01)*	.033** (.01)	.056*** (.01)	.057*** (.01)
Race				
Black ^b	.20 (.01)***	.16*** (.008)	.19*** (.009)	.16*** (.01)
Hispanic ^b	-.02 (.01)*	-.03 (.01)**	-.02 (.01)	.02 (.02)
Asian	.11 (.01)*	.13 (.01)***	.14 (.01)	.14*** (.01)
Native American ^b	.12 (.01)*	.11 (.009)***	.12***	.12*** (.02)
Metropolitan ^c	.07** (.02)	.05*	.06** (.02)	.08*** (.02)
Poverty ^b	.42*** (.03)	.41 (.03)	.47*** (.03)	.49*** (.04)
Model Fit				
Adjusted- r^2	.48***			
Rho/Lambda		.21***	.41***	.37***
AIC	3512.5	3415.90	3265.70	NA
Robust Lagrange multiplier diagnostics				
Spatial lag	11.32***			
Error term	158.98***			
SARMA	277.85***			
Local Moran's I	.38***			

* $p < .05$; ** $p < .01$; *** $p < .001$

^a Logged rates per 100,000

^b Logged percent

^c Small or large metropolitan county designation >50,000 persons

from structural factors including arrest practices and drug laws.

Implications for Public Health Practice

Limitations notwithstanding, there are several notable implications for public health practice that arise from this research. The USA is immersed in a period of unprecedented growth of incidence rates of chlamydia and gonorrhea with record numbers cases reported in 2015. The apportioning of resources strategically to geographic areas where the need for intervention is greatest could yield promising gains in attenuating rates of chlamydia and gonorrhea. Findings from this study could inform policy and advocacy decisions regarding the allocation of additional STI prevention services for counties that are disproportionately impacted by the rapid expansion of rates of chlamydia and gonorrhea in the USA. Structural interventions that address extreme concentrations of poverty particularly in urban

centers and in the southern region of the USA that prioritize STI prevention interventions at national and local levels could result in reductions in aggregate rates. Poverty is noted in prior literature as a driver of engaging in commercial sex work and thus may heighten rates of STI in impoverished communities by virtue of increasing rates of sex work [74]. Survival sex may also drive aggregate rates of arrest particularly among women thereby heightening rates of STI. A fruitful avenue of future research includes investigating if rates of commercial sex work at the county level increases rates of chlamydia and gonorrhea using arrest data or other measures.

In addition to poverty, this study raises important social justice issues embedded within population-level STI prevention interventions in which specific racial and ethnic subpopulations are disproportionately impacted by rates of STI. In this study, counties with greater concentrations of African-Americans were disproportionately represented in high-rate clusters of both

Table 5 Linear and spatial relationships between crime and rates of gonorrhea in the USA, 2014 (2458).

	Linear regression β	Spatial lag β	Error term β	Durbin β
Crime				
Violent ^a	.084*** (.02)	.077** (.02)	.10*** (.02)	.11*** (.02)
Drug ^a	.006 (.02)	.01 (.02)	.006 (.02)	.007 (.02)
Race ^b				
Black ^b	.45*** (.01)	.33*** (.01)	.42*** (.02)	.40*** (.02)
Hispanic ^b	.03* (.02)	-.001 (.02)	.0006 (.02)	-.04 (.03)
Asian ^b	.01 (.02)	.08*** (.02)	.09*** (.02)	.12*** (.02)
Native American ^b	.23*** (.02)	.19*** (.02)	.20*** (.02)	.18*** (.03)
Metro ^c	.26*** (.03)	.21*** (.03)	.24*** (.03)	.26*** (.04)
Poverty ^b	.44*** (.05)	.46*** (.04)	.48*** (.05)	.51 (.05)***
Model fit				
R-squared	.56***			
Rho		.31***	.47***	.45***
AIC	5356.80	5121.40	4992	NA
Robust Lefrange multiplier model diagnostics				
Spatial lag	1.13			
Error term	271.17***			
SARMA	467.43***			
Local Moran's I				
Gonorrhea	.37***			

* $p < .05$; ** $p < .01$; *** $p < .001$ ^aLogged rates per 100,000^bLogged percent^cSmall or large metropolitan county designation >50,000 persons

gonorrhea and chlamydia. A potential explanation for these findings is the systematic disadvantage of African-Americans in counties throughout the USA stemming from institutionalized racism and other sources of structural oppression resulted in exposure to risk factors for STI including economic insecurity, community violence and mass incarceration that increase aggregate rates of STI at the county level [45, 75–77]. African-Americans in the USA face numerous barriers to testing, treatment, and care for STIs resulting from systemic and structural inequality. These inequalities are reflected at the aggregate county level in widespread racial disparities in rates of STI of gonorrhea and chlamydia. Findings from this study support prior literature pointing to relationships between communities with high rates of exposure to violence and rates of STI at the county level [34, 36].

Findings from this study underscore the critical importance of county- and state-level policies and structural-level interventions that involve the criminal justice system

specifically involving drug-related offenses. There is a call for additional research into improving linkage to care and testing for chlamydia and gonorrhea in the USA [78, 79]. Findings from this study are consistent with prior literature at the individual and aggregate level pointing to relationships between criminal justice system involvement and gonorrhea and chlamydia infection. Legal environments consisting of excessive policing and patrol heighten risk of HIV and STI [74, 80, 81]. Counties with high rates of incarceration concentrates risk factors of infectious diseases resulting in high rates of chlamydia and gonorrhea [82, 83]. Additional research is necessary that investigates if criminal justice reform particularly changing drug laws and policing practices to reduce excessive rates of arrests for drug crimes may reverberate in reductions in rates of STI at the county level. Finally, criminal justice settings in counties with high rates of crime including probation and other services may be opportune venues to situate STI prevention interventions [84] Additional, intervention and

epidemiological research is necessary that further investigates these relationships.

Rates of STI are not distributed homogeneously in the USA suggesting public health practitioners must consider not only important subpopulations but also where concentrations of high rates of STI are located in the USA when strategically allocating resources for STI prevention. Research into STI testing and treatment services must be expanded to take into account the influence of geographic context in conditioning how infectious diseases unfold in urban environments. In this study, one geographic division accounted for more than a third while one region accounted for more than three quarters of high-rate counties in the study. Additional research is necessary that focuses on the impact of directing services to counties in the south region and the South Atlantic division on rates of chlamydia and gonorrhea in the USA. The analysis and mapping of STI in this study could inform the design of ecological STI prevention interventions that take into account the role of spatial dependence in structuring racial and ethnic differences in the distribution of STI rates in the USA.

Conclusion

Given record numbers of chlamydia and gonorrhea were reported in 2015, research must inform the allocation of STI prevention interventions that address the influence of geography in reinforcing persistent health inequities in the USA. A coordinated, multi-sectoral approach at local and national levels is essential to confronting the growth of STI in the USA. Collaboration between federal and state governments in the south are essential to promote the expansion of STI prevention and treatment programs for populations residing in counties with high rates of STI. This study provides valuable information for policy makers and public health practitioners who are responsible for identifying locations for public health campaigns, health communication and free testing services.

Acknowledgements The author gratefully acknowledges methodological and statistical support provided by Jeremy Porter, PhD at the Graduate Center, City University of New York (CUNY). Funding provided by the National Institute on Drug Abuse (1T32DA037801) supported the writing of this manuscript.

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