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*Sex Transm Dis*. Author manuscript; available in PMC 2023 May 23.

Published in final edited form as:
*Sex Transm Dis*. 2014 November ; 41(11): 649–655. doi:10.1097/OLQ.0000000000000195.

# Neighborhoods at Risk: Estimating Risk of Higher *Neisseria gonorrhoeae* Incidence Among Women at the Census Tract Level

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## Abstract

**Background:** The association between area-based social factors and sexually transmitted diseases has been demonstrated in numerous studies. Such associations have not previously been explored for their potential to quantify likelihood of higher transmission of gonorrhea in small geographic areas.

**Methods:** Aggregate census tract-level sociodemographic factors in 4 domains (demographics, educational attainment, household income, and housing characteristics) were merged with female gonorrhea incidence data from 113 counties in 10 US states. Multivariate models were constructed, and a tract-level composite gonorrhea risk index was calculated. This composite risk index was validated against gonorrhea incidence among women from 2 independent states.

**Results:** Seven tract-level factors were found to be most strongly correlated with female gonorrhea incidence: educational attainment, proportion of female headed households, annual household income below US $20,000, proportion of population non-Hispanic black, proportion

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Conflict of interest: None declared.

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of housing units currently vacant, proportion of population reporting moving in last year, and proportion of households that are nonfamily units. Composite index was highly correlated with female gonorrhea in the study area and validated with independent data.

**Conclusions:** Social factors predict gonorrhea incidence at the census tract level and identify small areas at risk for higher morbidity. These data may be used by health departments and health care practices to develop geographically based disease prevention and control efforts. This is especially useful because gonorrhea incidence data are not routinely available below the county level in many states.

## BACKGROUND

Gonorrhea is the second most commonly reported sexually transmitted disease (STD) in the United States and a significant cause of serious reproductive health consequences.[1] Although the association of economic, social, and racial factors with the incidence of STDs, including gonorrhea, has been demonstrated in a variety of settings and at various levels of geographic resolution, most prior investigations have been limited in geographic scope to either a single or several adjoining states or jurisdictions, which limits the generalizability of findings.[2–8] Where studies have been conducted using multistate data, determinants have been modeled at higher levels of geography, such as at the county or regional level, limiting application of findings for local programs. Given the observed spatial heterogeneity and clustering of gonorrhea,[9–11] this STD provides a particularly robust candidate for modeling characteristics of place associated with incidence, especially when compared with STDs with considerably more generalized incidence patterns such as *Chlamydia trachomatis*.[12] Such models can provide an invaluable tool for geographic targeting of prevention services.

The demographic characteristics of populations with the highest incidence of gonorrhea in the United States are well known through descriptive analysis of national case data. Disparities in the burden of disease by race, age, and sex persist, and these have been widely analyzed and reported at the national level.[13,14] Issues of population health equity have also been highlighted in national summaries published by the Centers for Disease Control and Prevention (CDC),[1,15] and inequalities are particularly striking for non-Hispanic blacks. In 2012, non-Hispanic blacks bore a markedly disproportionate burden of disease with a case incidence rate of 462 per 100,000 versus 31 per 100,000 for non-Hispanic whites, a 15-fold difference in case incidence.[1] However, these observations are likely too broad to be appropriate for targeting local disease control efforts because there are non-Hispanic black communities with gonorrhea incidence rates no higher than adjoining white communities. Sexually transmitted disease prevention interventions based solely on racial composition may also unintentionally contribute to stereotyping and stigmatization of population groups and neighborhoods.

Where people live matters for highly clustered STDs such as gonorrhea; neighborhood-level factors, and the existence of geographically constrained partner networks, have been found to be important in sustaining high levels of disease and contribute to sustaining “core” transmission groups.[16–18] Prevention priorities specifically crafted to neighborhood-sized areas should provide significant efficiencies in the use of resources and assure

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that interventions are of sufficient scope and coverage to impact incidence. Although such targeted prevention efforts are perhaps best informed by mapping local case data, limited resources, disparate public health authority, and capacity gaps may prevent health departments from using disease incidence data at the census tract level to prioritize local interventions.[19]

In 2005, The Division of STD Prevention at the US CDC established the STD Surveillance Network (SSuN), a collaboration of geographically diverse state and local health departments with enhanced STD surveillance capacity, in part, to address important gaps in knowledge about gonorrhea incidence.[20,21] In this study, we analyzed data reported from 10 SSuN sites for correlations between gonorrhea incidence and sociodemographic factors at the census tract level. Our primary objective was to test the hypothesis that area-based sociodemographic factors are strongly associated with incidence of disease and that these findings can be used to develop a tool to target gonorrhea prevention efforts at the neighborhood level.

## METHODS

### Description of the Data

Female gonorrhea case counts at the census tract level were obtained from health departments in 10 participating SSuN jurisdictions (Table 1). We limited our analysis to female cases because a relatively large proportion (>40%) of male cases reported in SSuN jurisdictions were identified, through follow-up of a random sample of cases, as men who have sex with men (MSM).[22] Estimates of the MSM population at the census tract level, needed to calculate incidence rates, are not currently available so we excluded male cases from our analysis. Evidence also suggests that population-level socioeconomic factors may be different for MSM versus heterosexual men.[23] For the purposes of this analysis, we assumed that gonorrhea incidence among women reflects overall heterosexual incidence patterns.

Gonorrhea case data for 2009 to 2011 were collected by state and local health departments as part of routine STD surveillance. Census tract of residence for individual cases was not routinely included in surveillance data sent to CDC by all sites participating in the SSuN project, but the overall frequency of cases by sex and by census tract was available for this study. Sociodemographic factors were obtained from the American Community Survey (ACS) 2007–2010 5-year summary files and from the 2010 Census Summary files.[24,25]

Census tracts generally contain around 4000 persons, and although not specifically designed to reflect neighborhoods, census tracts are nevertheless a reasonable proxy.[26] Twenty-two tract-level factors were explored in the initial phase of our analysis that had been previously associated with poor health outcomes. These factors were grouped into 4 sociodemographic domains: educational attainment, income, housing characteristics, and population demographics (Table 2). All factors were either calculated values or obtained directly from US Census source data as continuous proportions of the total population, the female population, or the universe of all households within tracts. Where multiple candidate factors were available that measured very similar or the same characteristic, these were

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assessed separately for association with female gonorrhea incidence; only the most strongly correlated factors, based on $R^2$ from initial regression models, were retained for subsequent modeling.

Data from 11,975 census tracts in participating SSuN sites were available for our study. We excluded 143 tracts because the 2010 US Census reported no female residents in those tracts. The remaining 11,832 tracts represented 113 full or partial counties in 10 US states. Three-year average female incidence rates per 100,000 were calculated for each census tract using population data from the 2010 Census, and these were used in modeling rather than individual year rates to provide for greater rate stability. Female incidence rates were log transformed and merged with area-based sociodemographic data at the census tract level.

The SSuN received a determination of non-research from the CDC, National Center for HIV, Viral Hepatitis, STD and TB Prevention for these activities; data collection in SSuN sites was conducted with approval from the Office of Management and Budget (OMB Control Number 0920–0842). No personally identifiable information was available to the analysts or used for this study.

## Statistical Analyses

Analyses were performed using SAS 9.2 (SAS Institute, Cary, NC). The simplest model predicting female gonorrhea incidence was developed using the GLM SELECT procedure with the least absolute shrinkage and selection operator (LASSO) option for model selection.[27] We selected options for this procedure which used half of the census tract records for covariate selection, 25% to validate the resulting model, and the remaining records to test the model for goodness of fit. Factors with the smallest effect estimates (i.e., $\beta < 0.001$) were dropped from the model. A significant portion of the variation observed in log-transformed female gonorrhea rates at the census tract level was explained by county-level effects, so we used a hierarchical model (PROC MIXED) to control for nesting of census tracts within counties.

The regression coefficients from this final model were used to calculate a weight for each factor reflecting the relative contribution of each to the observed variation in female incidence rates. These weights were standardized and used to compute a composite risk index (gonorrhea risk index) for the census tracts in SSuN sites by multiplying factors obtained from the ACS and census data by these weights and calculating the tract-level mean value across all factors.

## Validation

We assessed the resulting index for strength of association with female gonorrhea rates by single factor regression in SSuN sites. We also calculated this risk index value for all census tracts in the contiguous United States (N = 73,057), allowing us to test our index against other states. The Ohio and Florida Departments of Health graciously provided assistance in validating our calculated index by providing female gonorrhea cases geocoded to the census tract level for 2952 tracts in Ohio and 4245 tracts in Florida. Single factor regression results were obtained for our risk index versus log-transformed female gonorrhea rates in both of these independent jurisdictions.

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County-level index values were also calculated for all counties in the contiguous United States (N = 3144) by computing the mean of all tracts within each county. The resulting county-level risk index was assessed for strength of association with county-level female gonorrhea rates obtained nationwide from National Electronic Telecommunications Surveillance System for 2011.

## RESULTS

From 2009 to 2011, 78,792 female cases were reported from SSuN sites. Geographic information was complete for 65,318 (82.9%) of these cases, including the census tract assignment. The number of tracts included in our analysis, number of female cases reported for 2009 to 2011, and 3-year average female gonorrhea rates at the census tract level are shown in Table 1. The mean female gonorrhea rate across all 11,832 census tracts included in our analysis was 94.1 per 100,000, just slightly below the overall national incidence rate for women of 108.9 per 100,000 in 2011.[15]

The gonorrhea risk index values for census tracts ranged from 0 to 30.01, with a median value of 5.79 and first and third quartile values of 4.33 and 8.33, respectively. These values represent a continuum of the social factors, with the highest values indicating social, environmental, and demographic conditions that correspond to higher rates of female gonorrhea incidence. Within SSuN sites, almost 70% of female gonorrhea cases for the study period were reported from just 14% of census tracts. These high morbidity census tracts had a mean gonorrhea risk index value from our model of 15.2, versus a mean value of 5.9 for the remaining 86 % of tracts. At the national level, information on all 7 factors needed to calculate our gonorrhea risk index was complete in the ACS for 98.8% (72,211) of census tracts in the lower 48 states. Resulting index values ranged from 0 to 32.2, with a median value of 5.9.

Scatter plots (Fig. 1) demonstrate the association of the factors in our final model and female gonorrhea incidence. These plots show the relationship between the factors on the *x*-axis and log-transformed female incidence rates on the *y*-axis. Some factors such as proportion of households with less than US $20,000 annual income (panel D), proportion headed by females (panel E), and proportion of the population that is non-Hispanic black (panel A) show strong linear correlation across the entire distribution of rates at the tract level, whereas others such as proportion of adult women with less than high school education (panel C) and residential vacancy rates (panel G) are most strongly correlated at the lower end of the distribution of log-transformed rates and display nonlinear characteristics. For all of the factors, a small number of tracts were identified where ACS data indicated a value of zero (shown as clusters along the *y*-axis in the panels in Fig. 1). These potential outliers were examined and determined to have nonzero values for other relevant factors and were retained in our analysis. Effect estimates for the selected factors from the final hierarchical model (Table 3) were used to calculate the gonorrhea risk index value for all tracts in SSuN sites.

Similarly, scatter plots and regression lines of our calculated gonorrhea risk index at the census tract level versus log-transformed female gonorrhea rate and versus female gonorrhea rate per 100,000 show a strong correlation between the gonorrhea risk index and female

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gonorrhea incidence rates (Fig. 2A and B, respectively) for census tracts included in our analysis. The $R^2$ for a 1-factor model of female incidence per 100,000 versus the gonorrhea risk index is 0.64, which indicates that a significant proportion of observed variation in female gonorrhea rates in these census tracts can be explained by our risk index.

Data for census tracts in the states of Ohio and Florida were assessed against our index values, and $R^2$ values of 0.71 and 0.52 were observed for Ohio and Florida data, respectively, providing independent evidence supporting the validity of our findings. We also calculated gonorrhea risk index values at the county level (N = 3143) for all counties in the lower 48 states. Values for the county-level index ranged from 2.0 to 20.9 with a median of 6.3. The county-level gonorrhea risk index versus reported 2011 female incidence at the county level was found to have an $R^2$ value of 0.452 in single factor regression, indicating that our index explains approximately 45% of variation in female incidence rates at the county level as well.

## DISCUSSION

The health departments collaborating in this study reported more than 20% of the 933,432 gonorrhea cases reported to the CDC for the 3-year study period. Using these data, 7 sociodemographic factors were identified that, in combination, are strongly correlated with gonorrhea incidence rates among females. Furthermore, we demonstrate that the resulting gonorrhea risk index at the census tract level correlates with the observed gradient of incidence rates for 2 geographically disparate jurisdictions that did not contribute data to our initial modeling effort. The wide range of rural, urban, and suburban geographies represented by SSuN sites likely contributes to the robustness of our findings.

This risk index is readily calculated for census tracts in the United States—independent of local case data, which are often not available below the county level for STDs despite the increasing capacity of many health departments to geocode case data. In many jurisdictions, heightened concerns about patient confidentiality preclude the public release of case counts and characteristics at the census tract level. We propose that this index could be used to prioritize limited public health resources for gonorrhea control in specific geographic areas, and by health care facilities and large provider networks to inform gonorrhea screening policies based on location of care facilities in areas with higher risk values, thereby strengthening efforts to screen all sexually active women at higher population-level risk of gonorrhea exposure. These index values could also be used by public health agencies to identify neighborhoods where partnerships and outreach for promoting screening, diagnosis, and treatment might be especially productive. Moreover, resource intensive partner services could be prioritized to patients reported with disease from these higher risk neighborhoods.

Although discussion of the specific pathways by which the factors we modeled influence female gonorrhea rates is beyond the scope of this investigation, our findings are consistent with previous studies showing race, household income, characteristics of housing, the built environment, and educational attainment associated with gonorrhea rates.[28,29] The multiple factors in our model are likely operating as a complex system of effects, with each proportionately contributing to the overall incidence at the tract level. As a system of

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effects, our index also provides the more nuanced context needed to address the inequalities in disease burden by non-Hispanic black race, which are profound and have persisted despite overall declines in gonorrhea nationally.

The proportion of the population that is non-Hispanic black was the second strongest factor associated with female incidence in our model, and with many of the factors exhibiting a high degree of colinearity, it could be argued that race alone might be a simpler, equally useful measure to use for this purpose. However, we found that more than 10% of census tracts with predominantly non-Hispanic Black populations had female gonorrhea rates lower than or equal to the national rate. Our composite index retained discriminating power in this subgroup of census tracts for detecting higher versus lower rates. This leads us to conclude that inclusion of non–race-based social factors contributes to a more robust model, and use of our index for geographic targeting would allow public health agencies to respond to racial disparities in a more socially informed manner. Using this index will also result in prioritizing census tracts with predominantly white populations, where poverty, education, and housing measures are likely the most salient factors associated with higher female gonorrhea incidence. Thus, our index may provide a more equitable measure to address disparities in gonorrhea incidence associated with poverty or other deleterious social conditions.

Although not appropriate for assigning individual risk or to inform care decisions at the individual patient level, health care facilities using or adopting electronic medical records might incorporate neighborhood risk indices such as ours into automated prompts to remind clinicians in their facilities to review the patient's sexual risk history. This could be easily accomplished if vendors of electronic medical record applications incorporated one of the many available geocoding services into their systems. We are making our risk index available for download (see Supplemental Digital Content, available at http://links.lww.com/OLQ/A91) so that results of our model are readily available for this and other purposes. Similarly, public and private health care partnerships informed by neighborhood risk profiling may be ideal for planning colocation of a broad range of health and social services where they are readily accessible to those at risk.

## Limitations

Our analysis is subject to a number of important limitations inherent in all ecological studies as well as limitations of the data we had available for the analysis. With respect to the former, our unit of analysis was the census tract and we analyzed aggregate characteristics of populations and households within tracts; no inference of disease risk for specific individuals is appropriate or implied. Rather, gonorrhea risk was modeled as an attribute of census tracts, and our resulting risk index is an attribute of place rather than of person. It is also possible that had we selected different geographic units of analysis, such as zip code tabulation areas or counties, our methods might have resulted in a different set of sociodemographic factors best fitting our model.

STD Surveillance Network sites were also not designed to be representative of all states and counties in the United States, and most census tracts in our study came from just 2 of the collaborating SSuN sites. Mindful of this limitation, we obtained data from Ohio and Florida

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to help validate our model. We found good agreement between our calculated index value and female incidence in these states, providing evidence that our gonorrhea risk index may indeed have broader applicability.

With respect to missing data, incomplete ascertainment of information, including underreporting of gonorrhea cases and underdiagnosing due to asymptomatic infections, may also affect our findings. For the purposes of our study, there was no attempt to estimate the magnitude of underreporting or the proportion of asymptomatic cases potentially missed by the collaborating state's surveillance systems. A significant proportion of cases (17%) could not be assigned to the census tract level by collaborating health departments and were excluded from analysis; this may also have introduced bias in our models. Additional case-level clinical or demographic information was not available to fully assess the direction and magnitude of any resulting bias. However, it is reasonable to assume that similar biases affect reporting of cases across the spectrum of state and local health jurisdictions. In light of these almost universal surveillance system limitations, similar biases would be encountered in using gonorrhea case incidence alone to prioritize disease control efforts. We believe that our approach has the added advantage of allowing health departments to address the social and environmental determinants of gonorrhea in a meaningful way.

## CONCLUSIONS

We have developed an additional tool that the public health community can use to geographically prioritize prevention efforts in areas at high risk for gonorrhea incidence among women. We have also demonstrated that specific area-based social and economic factors are strongly correlated with higher female gonorrhea incidence at the census tract level, contributing to the growing literature on the social determinants of STDs. We have used these correlations to calculate a geographically specific risk index that provides a viable framework for using social determinants of health for identifying populations and places at risk for higher gonorrhea incidence. These same methods might be applied to other highly clustered STDs such as syphilis where data on incidence at the census tract are available. These methods may also assist in developing models for more widely prevalent STDs such as chlamydial infection. However, more research is critically needed to better understand the determinants of gonorrhea and other STDs among MSM and how these may differ from heterosexuals. Including males in our modeling efforts would have productively expanded our analysis, and this would have only been possible if robust, small area estimates of the population of MSM were available.

Moreover, sentinel surveillance projects such as SSuN should continue to be supported to collect more comprehensive case surveillance information and provide a sustainable platform for monitoring the relationship between social factors and STD-related health outcomes. This may be especially critical as health care delivery systems evolve to provide greater access to preventive care and as disease surveillance systems confront significant challenges in resources and impending technological innovation. Using social determinants of disease to geographically prioritize limited public health resources, inform prevention partnerships, and target populations at highest risk of disease represents an achievable step toward more strategic STD prevention frameworks.

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## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

## Acknowledgments:

The authors gratefully acknowledge the contribution of collaborating health departments including Jefferson County Health Department, Birmingham, AL; Baltimore City Health Department; California Department of Public Health; Chicago Department of Public Health; Colorado Department of Health and Environment; Connecticut Department of Public Health; New York City Department of Health and Mental Hygiene; Philadelphia Department of Public Health; Virginia Department of Health; and Washington State Department of Health. The authors thank Tyler Weant, MPH, with the STD Surveillance Unit at the Ohio Department of Health and the STD Program, Bureau of Communicable Disease, Florida Department of Health. The authors also wish to express their gratitude to Lisa Llata, Jim Braxton, and Darlene Davis with the Surveillance and Data Management Branch, Division of STD Prevention, US Centers for Disease Control and Prevention.

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the CDC.

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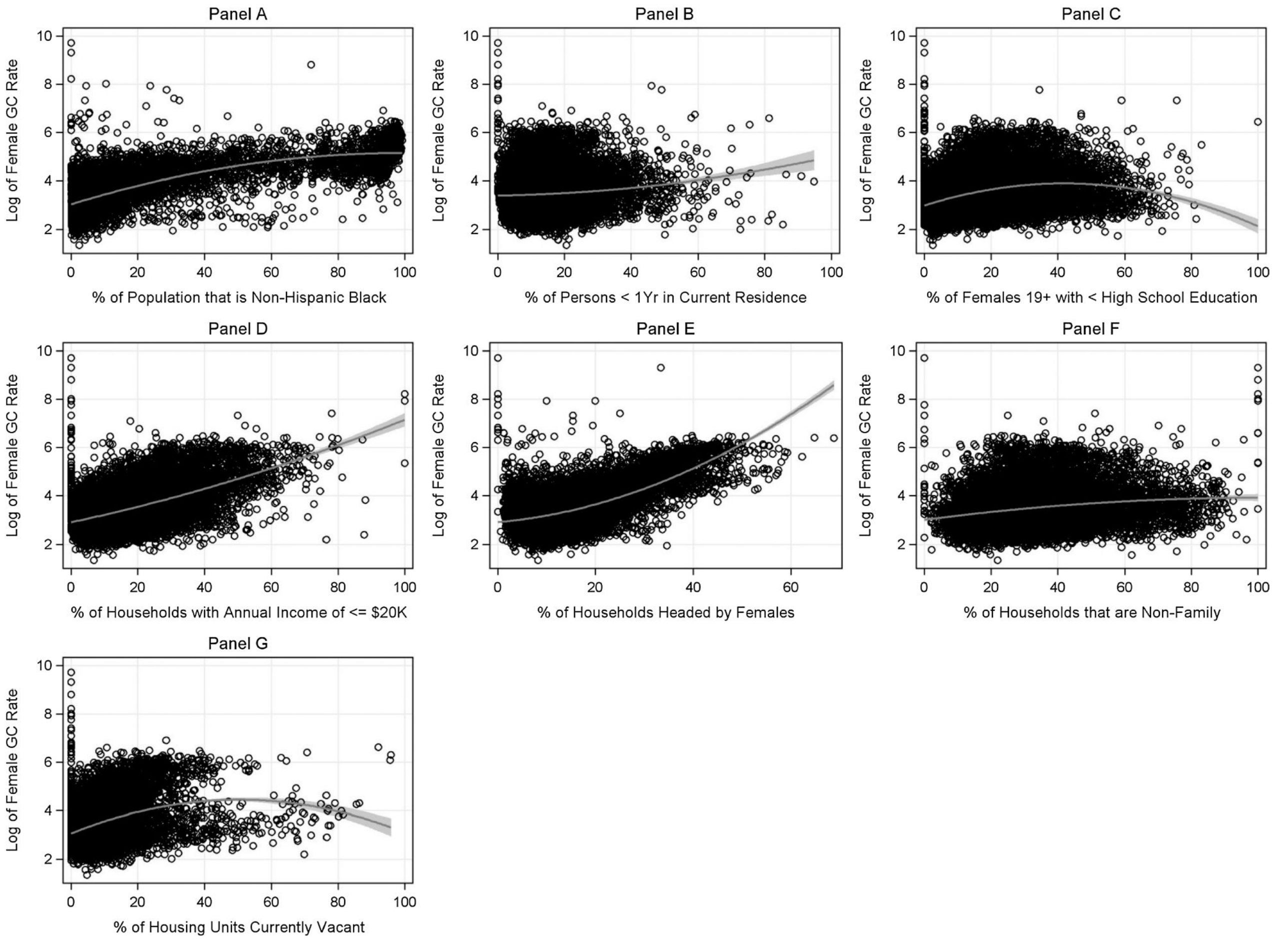


**Figure 1.**

Scatter plots with regression lines of log-transformed female gonorrhea rates versus social determinants included in final model.

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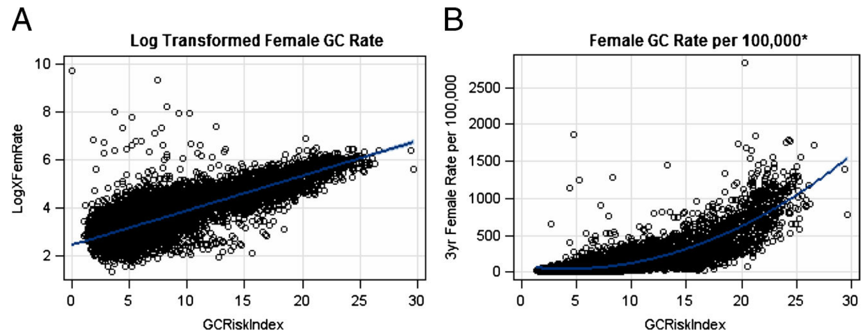


**Figure 2.**

Scatter plots with regression lines, female gonorrhea rates (log-transformed rate [A] and rate per 100,000 [B]) versus gonorrhea risk index.

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## TABLE 1.

Cases Reported, Included Census Tracts and 3-Year Average Female Gonorrhea Rate

| SSuN Site* | No. Census Tracts† | No. Female Cases 2009–2011‡ | 3-y Average Female Gonorrhea Rate Per 100,000 (Range) |
|---|---|---|---|
| Alabama | 163 | 1572 | 182.1 (0–1176.5) |
| Baltimore | 199 | 4242 | 453.2 (0–1370.4) |
| California | 5466 | 14,932 | 38.2 (0–1442.7) |
| Chicago | 797 | 12,795 | 350.5 (0–2836.9) |
| Colorado | 386 | 2290 | 95.1 (0–1689.7) |
| Connecticut | 411 | 2885 | 124.3 (0–1207.7) |
| New York City | 2390 | 13,429 | 90.5 (0–1866.3) |
| Philadelphia | 375 | 8683 | 351.0 (0–1445.3) |
| Virginia | 200 | 1586 | 137.5 (0–1109.2) |
| Washington | 1445 | 2904 | 29.5 (0–546.1) |
| Total | 11,832 | 65,318 | 94.1 (29.5 – 453.2) |

* SSuN sites included 113 counties in 10 states participating in the SSuN; 4 sites (Alabama, Baltimore, Chicago, and Philadelphia) contributed data only for a single county or city. California data include all counties except Los Angeles and San Francisco.

† Excludes 143 census tracts where no female residents were counted in the 2010 Census.

‡ Includes only cases with sufficient information to geocode to the census tract level (82.9%).

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## TABLE 2.

Social Determinants Considered in Initial Models

| Domain | Factor |
|---|---|
| Demographics | Proportion of population that is Hispanic<br>Proportion of population that is nonwhite<br>Proportion of population that is non-Hispanic black<br>Proportion of persons reporting having moved within the last year<br>Ratio of females to males in the population<br>Median income<br>Gini coefficient (a measure of income inequality)<br>Proportions of persons living in poverty<br>Population density in persons/mile$^2$<br>Rural/urban commuting area |
| Education | Proportion of the adult female population (19+ y) with less than a high school diploma<br>Proportion of the adult population (19+ y) with less than a high school diploma |
| Household characteristics | Proportion of households with annual income of US $20,000 or less<br>Proportion of households receiving any public assistance<br>Proportion of households headed by females<br>Proportion of households that are nonfamily households<br>Median household income |
| Housing unit characteristics | Proportion of housing units that are vacant<br>Proportion of housing units that are rental properties<br>Proportion of housing units that are family occupied<br>Proportion of housing units with single occupant<br>Density of housing units in units/mile$^2$ |

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## TABLE 3.

Factors Retained in the Final Model and Contributing to Gonorrhea Risk Index

| Domain | Factor | Adjusted Estimate (β)* | *P* |
|---|---|---|---|
| Demographics | Proportion of population that is non-Hispanic black | 0.01337 | <0.0001 |
| | Proportion of persons reporting having moved within the last year | 0.00383 | <0.0001 |
| Education | Proportion of the adult female population (19+ y) with less than a high school diploma | 0.002494 | <0.0001 |
| Household characteristics | Proportion of households with annual income of US $20,000 or less | 0.007175 | <0.0001 |
| | Proportion of households headed by females | 0.01824 | <0.0001 |
| | Proportion of households that are nonfamily households | 0.003357 | <0.0001 |
| Housing unit characteristics | Proportion of housing units that are vacant | 0.01182 | <0.0001 |

*Parameter estimate from hierarchical-level model controlling for county-level effects.