Unraveling US National COVID-19 Racial/Ethnic Disparities using County Level Data Among 328 Million Americans

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Abstract

Racial and ethnic disparities in COVID-19 outcomes reflect the unequal burden experienced by vulnerable communities in the United States (US). Proposed explanations include socioeconomic factors that influence how people live, work, and play, and pre-existing comorbidities. It is important to assess the extent to which observed US COVID-19 racial and ethnic disparities can be explained by these factors. We study 9.8 million confirmed cases and 234,000 confirmed deaths from 2,990 US counties (3,142 total) that make up 99.8% of the total US population (327.6 out of 328.2 million people) through 11/8/20. We found national COVID-19 racial health disparities in US are partially explained by various social determinants of health and pre-existing comorbidities that have been previously proposed. However, significant unexplained racial and ethnic health disparities still persist at the US county level after adjusting for these variables. There is a pressing need to develop strategies to address not only the social determinants but also other factors, such as testing access, personal protection equipment access and exposures, as well as tailored intervention and resource allocation for vulnerable groups, in order to combat COVID-19 and reduce racial health disparities.

Introduction

Mounting evidence suggests that the COVID-19 pandemic has had a disproportionate racial and ethnic impact across communities in the US. For example, Black/African Americans and Hispanic/Latinos have been observed to have more COVID-19 cases, hospitalizations, and deaths than non-Hispanic Whites[1–4]. Proposed explanations draw on a social determinants of health framework, considering how structural patterns of privilege and disadvantage affect how communities live (e.g. in high density housing), work (e.g. in “essential” jobs), travel (e.g. on public transportation), and access healthcare, as well as people’s underlying susceptibility to serious illness or death (e.g. prevalence of comorbidities such as hypertension or diabetes)[5–8]. However, little work has been done to systematically investigate the extent of racial health disparities in COVID-19 using large representative national samples.

There is a pressing need to examine how demographic (particularly racial and ethnic composition), socioeconomic, and health factors jointly contribute to disparities in COVID-19 outcomes. Several US studies have investigated racial and ethnic disparities. However these studies either looked at only a single health care institution or system[9,10], used national voluntary surveys that are subject to selection bias[11], or small scale ethnicity specific opinion surveys.[12] In the absence of large scale nationally representative individual-level data in the US to investigate this matter, analysis of ecologically aggregated county-level data across the US can provide valuable insights.

In this study, we investigated COVID-19-related health disparities using county-level data on demographic, socioeconomic, and health factors. We assessed the extent to which observed health disparities by race/ethnicity and by racial segregation in county-level COVID-19 case and death rates persist after adjusting for county-level socioeconomic and health factors and additional unexplained state-to-state

variation. We then calculated model-based county cumulative case and death rates to identify vulnerable US counties with the greatest total COVID-19 burden to date.

Brief Materials And Methods

We obtained demographic, socioeconomic and comorbidity data from a COVID-19 GitHub repository that drew from the US Department of Agriculture, Area Health Resources Files, County Health Rankings and Roadmaps, Centers for Disease Control and Prevention, and Kaiser News Health[13]. We obtained COVID-19 county cases and deaths from 1/22/20-11/8/20 from USA Facts[14] and additional demographic data from the US Census Bureau[15]. Numbers of COVID-19 tests by state were obtained from The COVID Tracking Project[16]. Daily percentage time home mobility metrics from 3/8/20-9/30/20 were obtained from SafeGraph[17]. Additional details about data sources are available in the supplement materials.

We used a Poisson mixed model to model county cumulative case and death counts. We included fixed effects for each state to account for state-to-state variation not explained by variables in the model (such as state testing rates), a random effect for each county to account for overdispersion, and an offset term for log county population (2019 US Census estimates). Univariate and multivariate regression with county-level race/ethnicity percentages were performed. We used the fitted models to calculate estimated county cumulative case and death rates to identify counties with elevated rates across the study period. **Table S2** lists the covariates used in modeling.

We performed several additional analyses to gain further insight into the findings and investigate sensitivity of the findings to model assumptions. We examined correlations between county race percentage and socioeconomic and health variables to understand differences in univariate and multiple regression results. We performed a sensitivity analysis investigating potential non-linear associations between county race/ethnicity percentage and cases and deaths by categorizing county race/ethnicity percentage into quartiles. We assessed adding county-level diabetes and kidney disease rates to improve modeling. To gain additional insight into our results, we investigated how the mobility measure using SafeGraph county resident percentage time at home[17] was associated with demographic, socioeconomic, and health factors. We studied the effects of monthly average percentage time at home between March and August on cumulative case and death rates. Lastly, we performed exploratory Case Fatality Rate (CFR) and Infection Fatality Rate (IFR) analyses to characterize associations among infected cases. Additional details about statistical analyses are in the supplement.

Results

As of 11/8/20, there were 9,827,966 total confirmed COVID-19 cases and 234,538 total COVID-19 deaths among all US counties. The primary analyses included 2,990 US counties (of 3,142 total US counties) which had complete information for all covariates (**Fig. S1**). Per 2019 US Census estimates, these counties comprised 327,553,510 Americans (99.8% of 328,239,523 total). There were 9,808,959 confirmed COVID-19 cases and 234,357 deaths among these 2,990 counties. Case and death rates in the

subsequent discussions refer to cumulative case and death rates. **Fig. 1** shows the case (**A**) and death (**B**) rates per 100,000 people for all counties. **Fig.1** shows heatmaps for race/ethnicity percentage (**C**) and residential racial segregation (0 complete integration to 100 complete segregation, **D**). Counties in the Southeast tended to have a larger proportion of Black/African American individuals, and counties in the Southwest tended to have a larger proportion of Hispanic/Latino individuals. Counties with a large percentage of American Indian individuals, such as the Navajo Nation in Arizona, New Mexico, and Utah, also tended to have a greater degree of residential racial White/non-White segregation. **Fig. S2** shows heatmaps for all other covariates.

Relative risks (RRs) for the multiplicative increase in county COVID-19 cumulative case and death rates were calculated for a one standard deviation increase of a county-level variable. Our univariate regressions showed county-level Black/African American, Hispanic/Latino, Native American percentages, Asian percentages, and Native Hawaiian/Pacific Islander percentages were highly significantly and strongly associated with higher case and/or death rates (**Table 1**). These univariate results are consistent with the literature.[18–22]

Table 1. Comparison of univariate regression (unadjusted) and multiple regression (adjusted) race/ethnicity analyses. Univariate/unadjusted includes log population offset, state fixed effects, and county random effects. Fully adjusted also includes all other variables in the primary models. The coefficients in the fully adjusted models are the same as those in Figure 2A. Bold indicates confidence interval does not include 1.

	Cumulative Case Rate		Cumulative Death Rate	
Variable	Unadjusted	Fully Adjusted	Unadjusted	Fully Adjusted
Black (%)	**1.21 (1.18, 1.24)**	**1.05 (1.02, 1.08)**	**1.24 (1.19, 1.30)**	**1.13 (1.07, 1.19)**
Hispanic (%)	**1.30 (1.27, 1.33)**	**1.09 (1.06, 1.12)**	**1.23 (1.18, 1.28)**	**1.08 (1.02, 1.14)**
American Indian (%)	**1.05 (1.03, 1.07)**	1.01 (0.99, 1.04)	**1.12 (1.07, 1.17)**	**1.10 (1.05, 1.15)**
Asian (%)	**1.09 (1.07, 1.11)**	0.99 (0.96, 1.01)	1.01 (0.98, 1.05)	1.01 (0.97, 1.06)
Native Hawaiian (%)	**1.11 (1.09, 1.13)**	**1.03 (1.01, 1.05)**	**1.04 (1.00, 1.09)**	1.02 (0.98, 1.05)

Adjusting for all non-race demographic, socioeconomic, and county-level disease rates, higher county Black/African American percentage was still associated with higher county COVID-19 case (RR: 1.05, 95% CI: 1.02-1.08) and death rates (RR: 1.13, 95% CI: 1.07-1.19); higher Hispanic/Latino percentage with higher county case rates (RR: 1.09, 95% CI: 1.06-1.12) and death rates (RR: 1.08, 95% CI: 1.02-1.14); higher American Indian/Native Alaskan percentage with higher county death rates (RR: 1.10, 95% CI: 1.05-1.15); and higher Native Hawaiian/Pacific Islander percentage with higher county case rates (RR: 1.03, 95% CI: 1.01-1.05); (**Fig. 2a**). The associations of county American Indian, Asian, and Native Hawaiian percentage and case/death rates that became insignificant did so after controlling for other race/ethnicity percentages or percentage with no health insurance (**Table S3-S5**). Greater White/non-White segregation was associated with higher county case (RR: 1.05, 95% CI: 1.03-1.07) and death rates (RR: 1.07, 95% CI: 1.03-1.10).

After adjusting for demographic variables and prevalence of comorbid conditions, county average household size, percentage in poverty, and percentage of individuals with no high school diploma were associated with higher county case and/or death rates. Adjusting for demographic and socioeconomic variables, the percentages of individuals with heart failure, hypertension, and stroke were associated with higher county case and/or death rates, and county-level asthma and chronic obstructive pulmonary disease (COPD) rate were associated with lower county case and/or death rates.

After adjusting for demographic and socioeconomic variables and county-level comorbidity disease rates, there was a stronger association between American Indian/Native Alaskan percentage death rates among counties in the top quartile of White/non-White segregation (RR: 1.13, 95% CI: 1.07-1.20) compared to counties with less White/non-White segregation (RR: 1.06, 95% CI: 1.00-1.12). The difference in death rate associations was statistically significant (effect modification: 1.07, 95% CI: 1.00-1.14) (**Fig. 2B**).

Estimated cumulative case and death rates for each US county were calculated from Poisson mixed models (**Figs. 3A and 3B**). Of the counties presented in **Figs. 3C and 3D**, during the study period, those comprising the Navajo Nation, Miami, and New York City had the highest estimated case rates. Counties comprising New York City, the Navajo Nation, and Detroit had the largest estimated death rates. Observed and model-based rates had good agreement, suggesting adequacy of model fit (**Fig. S3**). Results for every US county with full covariates are provided online.

We calculated the correlation of demographic, socio-economic and existing medical conditions to better understand the racial disparity findings and differences between multiple regression and univariate regression results. We found different county race/ethnicity percentages were correlated with different socioeconomic variables and disease rates (**Fig. S4**). County Black/African American percentage was positively associated with county poverty (R^2 = 0.39; 95% CI: 0.36, 0.42), no high school diploma (R^2 = 0.33; 95% CI: 0.29, 0.36), and hypertension (R^2 = 0.56; 95% CI: 0.54, 0.58). County Hispanic/Latino percentage was positively associated with county average household size (R^2 = 0.42; 95% CI: 0.39, 0.42) and county percentage of individuals with no health insurance (R^2 = 0.45; 95% CI: 0.42, 0.48). County American Indian/Native Alaskan percentage was positively associated with county percentage of individuals with no health insurance (R^2 = 0.31; 95% CI: 0.28, 0.34). County Asian percentage was negatively associated with county smoking (R^2 = 0-0.40; 95% CI: -0.43, 0.37) and COPD (R^2 = -0.36; 95% CI: -0.39, -0.33).

We investigated potential non-linear associations between county race/ethnicity percentage and cases/deaths. Controlling for demographic and socioeconomic variables and county disease rates, we found counties with Black/African American percentages in the top quartile had greater case and death rates than those in the bottom quartile (**Table S6**). Similarly, counties with Hispanic/Latino percentages in the top quartile had greater case and death rates than those in the bottom quartile.

To gain additional insight into observed health disparities, we used mobility data to study whether time spent at home due to stay-at-home orders and social distancing were associated with demographic and socioeconomic variables. Controlling for all other county level variables, adjusted effects for the change in county percentage time spent at home were calculated for a one standard deviation increase in a county-level variable (**Fig. S5**). Counties with greater percentage of residents ages 20-29 years (-1.39; 95% CI: -1.68, -1.10) and greater no health insurance (-0.63, 95% CI: -1.11, -0.15) were associated with spending less time at home. Higher county population density, metro > 1 million people, metro/near metro 20,000 to 1 million people (relative to nonmetro <20,000 people), and higher average household size were associated with county residents spending more time at home. Including average percentage time at home as a covariate also did not change adjusted cumulative case and death relative risks (**Fig. S6**).

We performed exploratory Case Fatality Rate (CFR) analyses and Infection Fatality Rate (IFR) analyses (**Fig. S7**). Assuming the ascertainment rates of reported cases vary by state and counties modeled using fixed and random effects respectively, the CFR and IFR regression analyses produced identical results (see **Methods** for further discussion). These results had similar directions to the primary death rate results but there were fewer significant associations. These analyses are likely subject to bias due to several factors, such as differential underestimation of the total number of cases (including asymptomatic and mildly symptomatic cases) by race and ethnicity[23,24], selection bias of subjects who have been tested (e.g. symptomatic subjects and vulnerable subjects were more likely to be tested), insufficient testing capacity in many areas, and variable testing rates between and within states (**Methods**).

Discussion

Our ecological study used US county-level data to investigate US health disparities by studying the joint effects of demographic, socioeconomic, and health variables on COVID-19 cumulative case and death rates as of 11/8/20 using representative national data. We found racial and ethnic health disparities among Black/African American, Hispanic/Latino, American Indian/Native Alaskan, and Native Hawaiian/Pacific Islander communities persisted after adjusting for county-level socioeconomic and prevalence of comorbid conditions. We also observed that increased racial residential segregation increased COVID-19 case and death rates, with different impacts across racial and ethnic communities. Lastly, our estimated COVID-19 case and death rates account for potential instability in observed rates from counties with small populations or few confirmed cases/deaths and can assist in identifying counties with the greatest total COVID-19 burden.

Univariate associations between race/ethnic composition and COVID-19 outcomes were considerably stronger prior to adjustment for socioeconomic factors and comorbidities, indicating socioeconomic factors and comorbidities may partially explain observed racial and ethnic disparities. Several unstudied factors may additionally contribute residual racial and ethnic disparities, including differences in neighborhood testing rates, percentage of healthcare workers, percentage of essential workers, exposure to infected individuals within households and in communities, Personal Protection Equipment (PPE) access, use of public transportation, access, quality, and utilization rates of available healthcare

facilities/resources, access to living resources (such as a lack of access to clean water in many households of American Indian/Alaskan Native communities), and health literacy. Since many of these measures were either not available or quantifiable at the county-level, we were unable to control for them in analyses.

Counties with increased racial residential segregation experienced increased COVID-19 case and death rates. While Black and American Indian communities have historically been segregated into counties, Hispanics communities are more prone to micro-segregation within counties[25–27]. Counties and states may appear to be less segregated on a larger level, but Hispanic/non-Hispanic communities may still remain racially segregated at the neighborhood level[28,29]. In addition, after adjusting for socioeconomic variables and comorbidities, counties with more racial segregation had stronger associations between Native American percentage and COVID-19 case and death rates. This suggests stronger COVID-19 disparities were experienced on Native American territories and reservations, which have more racial segregation, compared to Native American living in other communities.

Our county-level results on racial and ethnic disparities also reinforce and expand findings reported from existing individual-level studies. Single institution studies in the US have also found that Black COVID-19 patients were more likely to be hospitalized, enter the intensive care unit, and die[9,30]. United Kingdom Biobank and electronic health record studies looking at individual-level data have also found that Black and Asian individuals have an increased risk of COVID-19 hospitalization and deaths after adjusting for covariates[31–33].

Our county-level results in the other domains are consistent with those from several smaller scale individual-level studies. We found counties with a greater proportion of individuals with ages 60+ years tended to have increased death rates. Individual-level studies also reported that older patients were more likely to develop severe COVID-19 symptoms and have greater mortality rates[34]. We found county average household size was associated with increased case and death rates. Household size is known to affect COVID-19 contact and transmission rates[35]. We found county level rates of heart failure, hypertension, and stroke were associated with case and/or death rates. These pre-existing health conditions are important biological and clinical risk factors for COVID-19 disease severity and mortality[34,36]. We found county COPD percentage was negatively associated with COVID-19 case and death rates. Some studies have observed a lower than expected prevalence of COPD in COVID-19 patients, but this association is still being investigated as other studies have reported COPD is a significant risk factor for COVID-19 infection at the individual level[37–39]. Lastly, we found counties with more individuals ages 20-29 tended to have residents spend less time at home. As early as early February 2020, there have been discussions about young adults being more likely to go out and socialize despite social distancing guidelines[40]; this issue received more media attention in June and July.

Our SafeGraph mobility metric analyses suggested residents of counties with a higher percentage of people with no high school diplomas or health insurance tended to spend less time at home. These

communities may have a higher percentage of essential workers who are unable to work from home, may be more likely to take public transportation, and may be more susceptible to contracting COVID-19[41]. Such areas may require additional attention and interventions.

We observed different county-level socioeconomic associations across various races/ethnicities. This emphasizes that demographic, socioeconomic and immigration complexities faced by various populations are likely to differ substantially between vulnerable communities, especially those with high proportions of under-represented minorities[42]. To address this challenge, public health interventions, medical care services, and outreach efforts need to be tailored to the unique challenges and needs of each community.

Because we control for fixed state effects, adjusted race/ethnicity composition associations adjust for unmeasured state-specific factors (e.g. differences in testing capacity or response procedures). Within states, counties with larger non-white populations may tend to be more socioeconomically underserved, and the numbers of reported cases are likely to underestimate the total number of infected cases[23,24]. If under-reporting is driven by race/ethnicity, our reported adjusted associations likely understate the true extent of racial/ethnic disparities. To address racial health disparity on COVID-19 in US, county-level race/ethnicity specific case and death count data are needed for research purposes.

Our findings are based on ecological associations at the county level, and analysis at this level is subject to several limitations (**Methods**). Associations observed at an aggregated level may be in the same direction, different direction, or not exist at the individual level[43]. As with all observational studies, associational findings do not imply causality. It is of interest to in the future conduct studies on COVID-19 disparities using individual-level data with additional information on household and community exposures to COVID-19 cases, occupation and work conditions, housing conditions, public transportation usage, basic living resources, and COVID-19 treatments. Despite these limitations, our US county-level ecological study identified elevated risks of COVID-19 cases and deaths in areas with substantial non-White populations after adjusting for socioeconomic and disease prevalences.

Multi-faceted efforts are needed to combat the pandemic by addressing these COVID-19 health disparity issues. Increased resources, such as testing priority and accessible points of care, should be allocated to counties with more racial/ethnic minority populations or residential racial segregation, as well as those counties with more crowded housing, more elderly residents, less education infrastructure, greater prevalences of hypertension, and less living resources, such as a lack of clean water. Intervention measures can include policies requiring face coverings, guaranteeing workers can take paid sick leave, providing personal protective equipment to essential workers, and ensuring prioritized and robust testing, tracing, and isolation infrastructure. Outreach efforts can include transportation assistance, social and community support, and increased accessibility and affordability of health care.

Declarations

Data and code availability

All materials and code for analysis are available on https://github.com/lin-lab.

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Figures

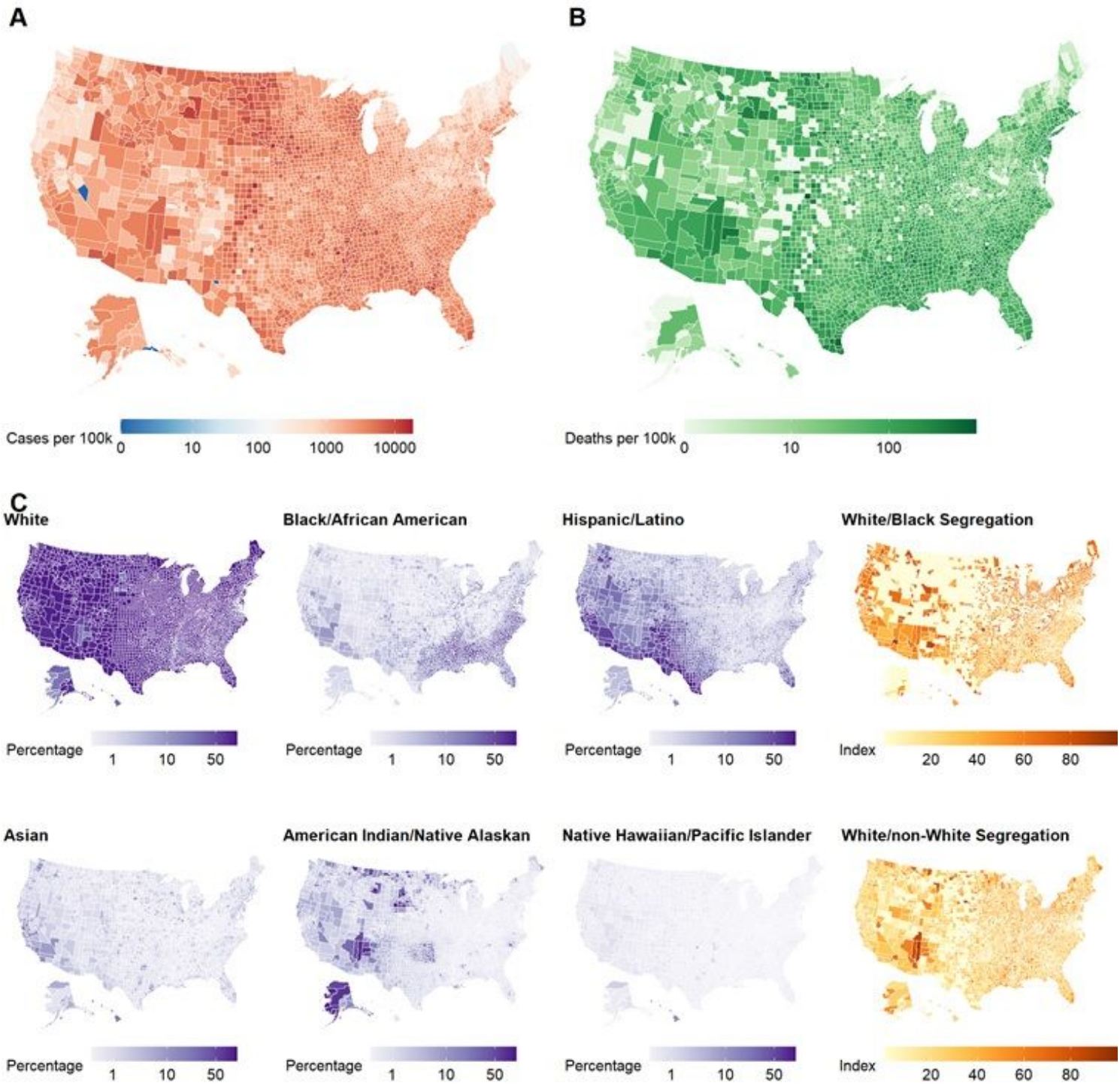

Figure 1

Case rate, death rate, racial variable heatmaps. (A) Observed case rates and (B) observed death rates from 1/22/20-11/8/20, and (C) race and ethnicity percentage and residential racial segregation index of dissimilarity (from 0 complete integration to 100 complete segregation) heatmaps.

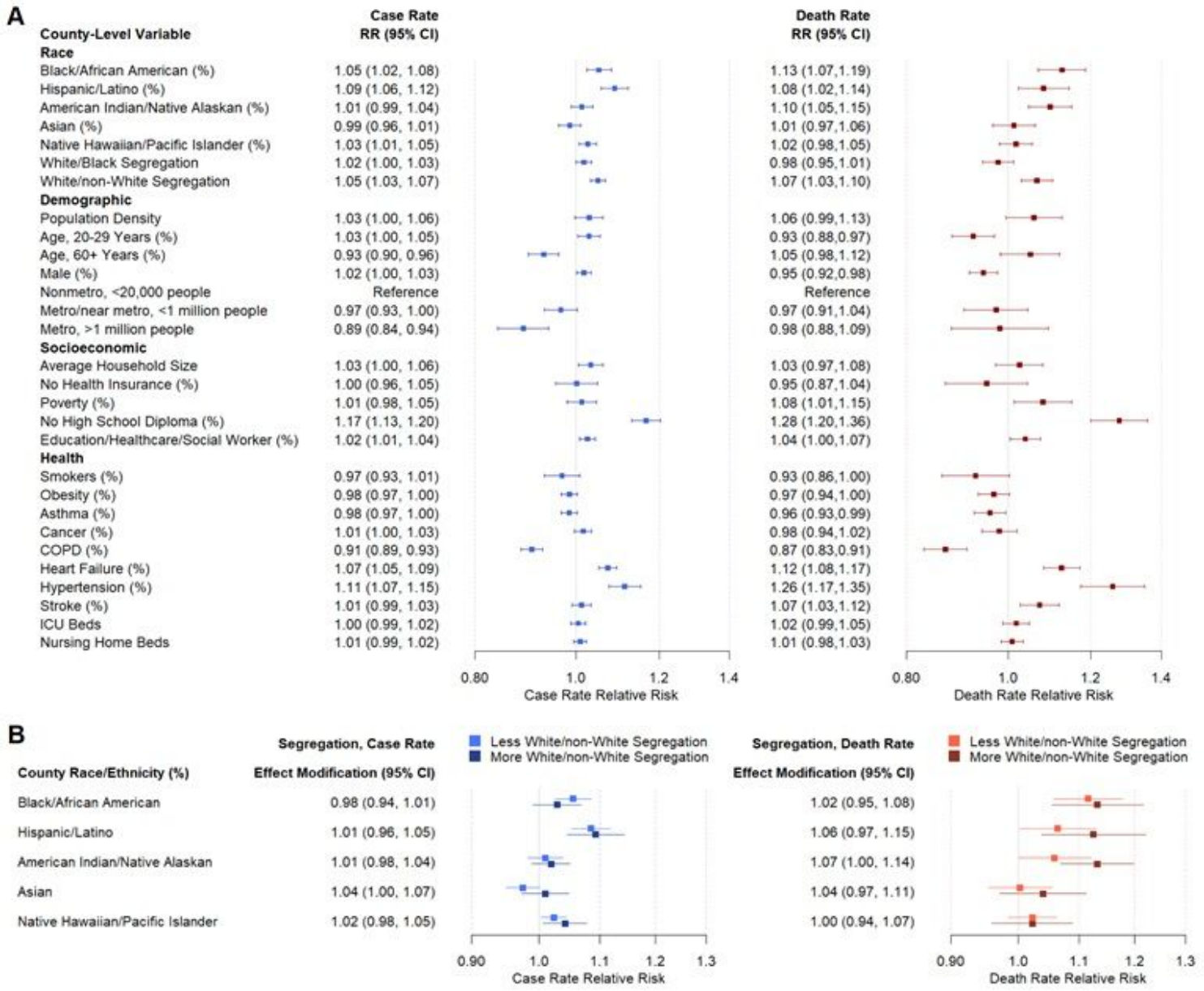

Figure 2

Adjusted cumulative case and death rate relative risks. (A) Adjusted relative risks of demographic, socioeconomic, and health comorbidity factors on cumulative COVID-19 case and death rates through 11/8/20. (B) Adjusted race/ethnicity relative risks stratified by counties with White/non-White segregation index of dissimilarity below and above the 75th percentile for case and death rates. Boxes are point estimates and error bars mark 95% confidence intervals. Relative risks are for a one standard deviation increase in a variable, except for the metro/nonmetro categorical variable.

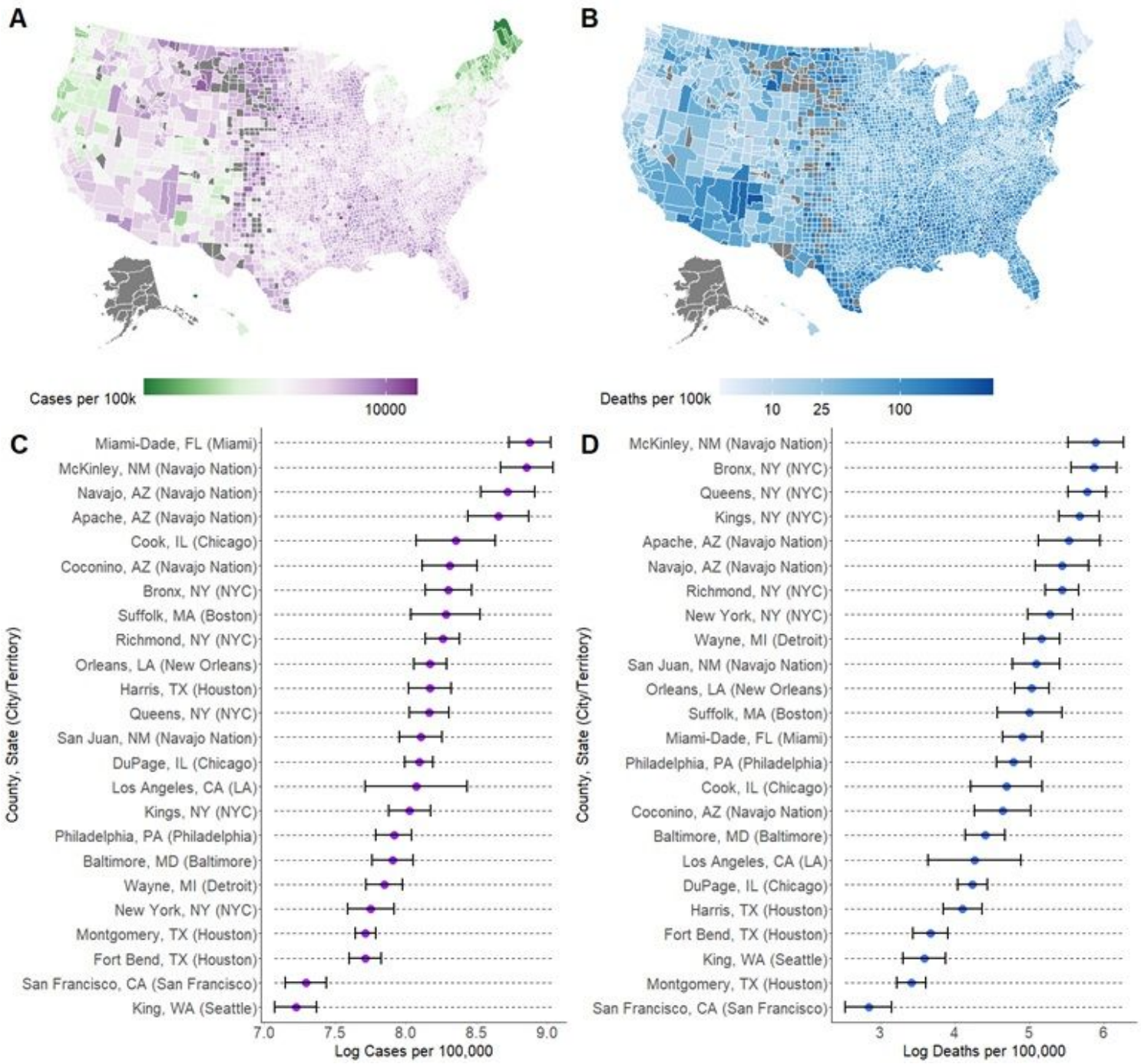

Figure 3

County estimated cumulative rates. Estimated cumulative case (A) and death (B) rate heat maps from 1/22/20-11/8/20. Estimated rates are similar to observed rates. Estimated case (C) and death (D) rates for selected counties. The estimated rates were calculated using fitted Poisson mixed models. Circles are point estimates; error bars are 95% CIs. Gray counties had missing covariates.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- COVIDDisparitiesSupplement.docx