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City Planning 101: Introduction to Urban Data Analytics
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COVID-19 and Pandemic Preparedness Planning:

The implications of the county-level variability in vulnerability to and the impact of COVID-19

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Introduction

In the United States, the COVID-19 pandemic has reached over 1 million cases and caused almost 60 thousand deaths (Hern et al. 2020). However, the virus has had a very uneven impact across the country, especially between counties. The wide variation in the county-level health impact of COVID-19 in terms of the virus' infection and death rate illustrates the need for local disaster response plans that include provisions for pandemic preparedness planning.

There are a variety of factors that make a county population more likely to contract COVID-19 like population density and factors that, if a person contracts COVID-19, puts that individual at higher risk of dying or becoming seriously ill such as underlying health conditions and advanced age (Rocklöv and Sjödin 2020; CDC 2020). These factors all vary widely from county to county across the United States which can contribute to the highly varied local impact of the virus.

In order to understand the variability of the virus' impact and the implications of that variability in disaster response planning, I first mapped the progression of the COVID-19 pandemic across the United States at the county level from the first reported case on January 21, 2019 to April 5, 2020. I also mapped the infection rate in each county, weighted to account for how recent or late the date of the county's first confirmed case was. I then developed a Vulnerability Index (VI), an index for the vulnerability of members of a county's population to death or severe illness from COVID-19. The VI accounts for five factors that cause people to have a greater risk of falling seriously ill or dying from COVID-19: being diabetic, having lung disease, being an "older adult", living in a densely populated area, and belonging to a minority group (Rocklöv and Sjödin 2020; CDC 2020). Next, I identified superior and inferior responses to the COVID-19 outbreak based on a county's VI, and death and infection rate, analyzed each of these counties' disaster response plans to determine if the plan accounted for pandemic preparedness, and compared it to the available best practices in pandemic preparedness planning.

I found that the earliest outbreaks of COVID-19 in the U.S. occurred mainly in densely populated urban centers on the coasts such as the New York Metropolitan Area and San Francisco and Los Angeles County. Furthermore, while denser counties tended to have higher infection and death rates, many low-density counties had high rates as well. There was also similar variability in regards to the VI of low and higher density counties: Many low density counties also had high VI's because a large portion of their population had underlying conditions and/or belonged to a minority group. Finally, I used the VI to identify the 100 most vulnerable and 100 least vulnerable counties in the United States from which I selected a superior COVID-19 response case study, San Francisco County, California, and an inferior response case study, Toole County, Montana.

While Toole County had one of the lowest VI's, it's death and infection rates were as high as those of the most vulnerable counties. Toole County also had no pandemic preparations included in its disaster plans and its response to the COVID-19 outbreak was reactive, not well coordinated, and lacked transparency (Michels 2020; Toole County DES 2019). On the other hand, San Francisco County had low death and infection rates in comparison to other highly vulnerable counties. But while San Francisco County does have a short segment on pandemic preparations in its disaster plans, in comparison to available best practices in pandemic preparedness, its plans fall dramatically short (San Francisco Department of Emergency Management 2014; USAID 2009). However, the county's response was largely proactive, well coordinated, and transparent (Eby 2020). In summary, San Francisco County had a relatively low death and infection rate despite its sub-par pandemic preparedness planning and high VI. However, Toole County had a very low VI but had a high death and infection rate and no pandemic preparedness plans. Together, the variability in local vulnerability and the high death and infection rate in a low-vulnerability county, Toole County, suggest that local pandemic planning sensitive to a population's unique combination of risk-factors could decrease death and infection rates.

Background

On December 31, 2019, the Wuhan Municipal Health Commission in China reported on a cluster of pneumonia cases in Wuhan, Hebei Province whose cause was eventually identified as a novel coronavirus (WHO 2020). This novel coronavirus, later named COVID-19, an acronym for coronavirus disease 2019, spread quickly to multiple countries across the globe. The United States reported its first confirmed case of COVID-19 on January 21, 2020 (Eby 2020). On

January 31, 2020, ten days after the first reported case of COVID-19 in the United States, Alex Azar, secretary of U.S. Health and Human Services, declared a national public health emergency (Eby 2020). Then, on March 11, the Work Health Organization declared that the coronavirus was a pandemic, signifying that the disease was "having a global impact" (Eby 2020). Two days later, President Trump declared a national emergency which would make as much as $50 billion available in federal funding (Eby 2020).

Coronaviruses are common among humans and usually cause mild illnesses such as common colds (CDC 2020). However, the virus that causes COVID-19 is different from these coronaviruses and is caused by a coronavirus called SARS-CoV-2 (CDC 2020). People at the highest risk of death or severe illness from COVID-19 are those who have underlying medical conditions, are "older adults", and/or are immunocompromised (CDC 2020). Underlying medical conditions include serious heart conditions, chronic lung disease, asthma, obesity, diabetes, chronic kidney disease, and liver disease (CDC 2020). The CDC does not specify at what age a person is classified as an "older adult", but does report that "8 out of 10 deaths in the U.S. have been adults 65 years old and older" (CDC 2020). Furthermore, people who belong to minority groups have been disproportionately impacted by the pandemic (Ro 2020). This is due to a variety of factors such as unequal access to healthcare, environmental injustice, lack of access to decent housing, higher representation in occupations deemed essential, and difficulties understanding important public health messaging in English (Ro 2020). Finally, population density of an area can accelerate the spread of COVID-19, increasing residents' risk of infection (Rocklöv and Sjödin 2020). The differing prevalence of underlying health conditions as well as the differing age composition, population density, and percent of residents belonging to a minority group from county to county contribute to the high degree of variability in the vulnerability of local populations.

Federal laws regarding local hazard mitigation planning are governed by the Stafford Act which was passed in 1988 and most recently amended in 2019 and by federal regulations implementing the Stafford Act (Stafford 1988). Under the Stafford Act, state, local and tribal governments are required "to develop and submit for approval a mitigation plan that outlines processes for identifying the natural hazards, risks, and vulnerabilities of the jurisdiction" (San Francisco Department of Emergency Management 2014). However, addressing pandemic preparedness in these plans is not explicitly required. In the Stafford Act, the definition for "hazard" used in Title VI -- Emergency Preparedness "For purposes of this title only" is "an emergency or disaster resulting from– (A) a natural disaster; or (B) an accidental or man-caused event" (Stafford 1988). Furthermore, Title VI's definition of "natural disaster" does not include pandemic, epidemic, communicable disease, virus or any other synonym of those terms (Stafford 1988). It does, however, use the catch-all phrase "or other catastrophe in any part of the United States which causes, or which may cause, substantial damage or injury to civilian property or persons" which would seemingly include a pandemic (Stafford 1988). A pandemic is categorized as a biological natural hazard (IFRC 2020).

While preparing for a pandemic is not explicitly required by law at the federal, state or local level, best practices in emergency planning suggest that pandemic preparedness is important due to a pandemic's global impact, long duration, and impacts on not only the health of a population but also on the economy and society as a whole (Logan 2008; USAID 2009). Furthermore, due to the aforementioned characteristics of a pandemic, taking action to prepare for this particular natural hazard would also improve the nation's ability to "respond to a variety of threats, including natural disasters and large-scale terrorist attacks" (Logan 2008). This suggests that local pandemic preparedness would therefore prepare counties for a variety of other hazards. Furthermore, the impact of a pandemic at the local level is largely dictated by local preparedness and response rather than actions taken or not taken by federal or state governments (USAID 2009). In addition, the global impact of a pandemic will likely cause "national governments, aid agencies, and neighboring municipalities" to be "overwhelmed" which means that in the event of a pandemic, "each municipality will need to be prepared to stand on its own" (USAID 2009).

The United States Agency for International Development (USAID) in collaboration with the Centers for Disease Control and Prevention as well as nonprofit health and media organizations developed a guidebook titled "Leadership During a Pandemic: What Your Municipality Can Do". This guidebook details fifteen tools to guide municipalities in their pandemic preparedness, response, and recovery (USAID 2009). Two critical aspects of pandemic preparedness according to USAID are to "develop policies on school, market, and business closing and re-opening and ways to reassure the public when it is safe to resume activities" and also to "maximize stockpiling before the pandemic" (USAID 2009). It also describes four steps that a municipality should take in the event of a pandemic: First, "Establish an emergency operations center'; second, "Continually assess needs, identify resources, and plan for response"; third, "Implement the response"; and fourth, "Prepare for community recovery" (USAID 2009). The second step, "Continually assess needs, identify resources, and plan for response", includes identifying and mapping key resources such as roads and essential infrastructure (USAID 2009). According to the USAID guidebook, robust pandemic preparedness at the county level can prevent deaths and ensure community resilience (USAID 2009). The municipal pandemic preparedness best-practices described by USAID suggests that only local policies can address the specific vulnerabilities of a county's population, quantify available health, food and financial resources, designate leadership roles during a crisis, and develop adequate plans for recovery.

Data and Methodology

Data

In conducting my research on county vulnerability to the COVID-19 pandemic and the varied health impacts from county to county, I used multiple sources to compile my datasets. For the data on the number of cases, number of deaths, and the date of the first confirmed case of each county, I used data from the NYtimes/Covid-19-Data dataset compiled between the first confirmed U.S. case on January 21, 2020 and April 5, 2020. This dataset contains cumulative state and county level data over time on COVID-19 cases and deaths (New York Times 2020). The data was compiled from state and local governments and health departments by journalists working across the country "to monitor news conferences, analyze data releases and seek clarification from public officials on how they categorize cases" (New York Times 2020). I received permission to use this dataset via email and complied with its terms of use. In the dataset, cases are recorded as occurring where patients are being treated, and a case is considered confirmed when a patient tests positive for the coronavirus and the case "is reported by a federal, state, territorial or local government agency" (New York Times 2020). Through April 5, 2020, the Times only counted lab-confirmed COVID-19 deaths and did not include "probable" deaths or cases (New York Times 2020).

For data on the prevalence of underlying conditions in county populations, I used data from the University of Wisconsin Population Health Institute repository County Health Rankings and Roadmaps (CHR&R). CHR&R provides public health data by state broken down by county. It does not have U.S.-wide datasets available so I compiled my own national dataset for various health factors state by state.

The final sources I used were the U.S. Census Bureau (USCB) and IndexMundi.com. I used the USCB dataset "Annual Estimates of the Resident Population for Selected Age Groups by Sex: April 1, 2010 to July 1, 2018" to calculate the percent of residents in each county that was over age 65 (U.S. Census Bureau 2018). Then, to calculate the percent of each county's population that belonged to a minority group, I used the UCSB dataset "Annual Estimates of the Resident Population by Sex, Race, and Hispanic Origin: April 1, 2010 to July 1, 2018" (U.S. Census Bureau 2018). To calculate this percent, I aggregated the counts for the female non-Hispanic White alone and male non-Hispanic White alone categories from 2018 and used the county's 2018 total population to calculate the population's percent non-Hispanic White alone. Finally, I subtracted this percent from 100% to find the percent of the population that belonged to a minority group. This method is based on the USCB definition of a minority which is "any group other than non-Hispanic White alone" (Ortman and Colby 2015). Lastly, I used the IndexMundi.com dataset "United States - Population per square mile, 2010 by County" (IndexMundi.com 2010). This site provides the population density of each county, state by state but does not have a composite, nationwide dataset on county population density so I compiled my own state by state. I received permission from IndexMundi.com via email to use this dataset and complied with its terms of use.

Methodology

While conducting my research, I used mapping, statistical analysis, and policy review and created an index for the vulnerability of a county's population to death or severe illness from COVID-19. I first compiled and cleaned my datasets using Python and then mapped the county-level spread and infection rate of COVID-19 across the United States using QGIS. Rather than using a county's raw infection rate,

$$\left(\frac{\#\ of\ Infections}{County\ Population\ Size} \times 100 = \ Infection\ Rate\ as\ a\ Percent \right)$$

I weighed the infection rate based on the date of the county's first infection (Utah Department of Health 2011). I did this because infection rates are measured during a specific time frame, but most counties's outbreaks began on different dates (Utah Department of Health 2011). Furthermore, because the number of confirmed cases per county increased over time, the infection rate of counties whose outbreaks started earlier might not reflect the severity of the outbreak but instead its duration (Utah Department of Health 2011). In order to compute the weighted infection rate, I used the Microsoft Excel DATEVALUE function to convert the date of each county's first confirmed case into a five digit number beginning with 43 because each first case occurred in the year 2020 (Microsoft 2020). I then subtracted 43000 from each value to obtain a three digit number. The DATEVALUE function assigns higher numbers to later dates (Microsoft 2020). This allowed me to multiply the value corresponding to a county's first case date by its infection rate in order to weight the infection rate according to the duration of the county's outbreak. I calculated each county's weighted death rate using the same method. Next, I developed a Vulnerability Index (VI), an index of the vulnerability of a county's population to dying or falling seriously ill from COVID-19.

To create the VI, I used the methods described in "The Urban Health Index: A Handbook for its Calculation and Use" published by the World Health Organization in collaboration with the Georgia State University School of Public Health (Weaver et al. 2014). I used this method because according to Weaver et. al., "there is nothing intrinsic in the UHI [Urban Health Index] linked to 'urban'. The intention behind the development of the UHI and its application was focused on urban areas, but the approach and methodology of the index could be applied to rural areas, too" (Weaver et al. 2014, 11). Furthermore, Weaver et al. describes the UHI as providing a "flexible approach to selection, amalgamation, and presentation of health data" (Weaver et al. 2014, 2). The UHI also "permits freedom to choose the scale (from small area estimates to national comparisons), the indicators (largely dependent on data availability), and the mode of presentation" (Weaver et al. 2014, 3). In addition, race and population density are measures, in addition to traditional health measures like diseases and conditions, that can be used in constructing an UHI (Weaver et al. 2014). The only measure that the UHI does not explicitly include that I did include in the VI is age, specifically the percent of a county's population over 65 years old. However, since age is a critical determinant of vulnerability, I included this variable in the VI.

I chose which variables I would include in the VI based the CDC page on COVID-19 and articles written in medical journals and for major newspapers describing which health, demographic, and social factors determine a person's vulnerability to death or serious illness from COVID-19. According to the CDC, people that are at a higher risk of dying or falling seriously ill from COVID-19 are those with underlying conditions such as lung disease, asthma, heart conditions, severe obesity, diabetes, liver disease, kidney disease, those that are "older adults" or those that are immunocompromised (CDC 2020). From these risk factors, I accounted for chronic lung disease, heart disease, obesity, diabetes, and age based on the availability of complete datasets and the necessity of accounting for the co-occurrence of certain conditions. One co-occurrence I accounted for is the co-occurrence of diabetes and obesity. I utilized nationwide, county-level data on the prevalence of diabetes, but chose not to include data on obesity because obesity "is a major independent risk factor for developing [type 2 diabetes], and more than 90% of type 2 diabetics are overweight or obese" (American Society for Metabolic and Bariatric Surgery 2013). Therefore, including both diabetes and obesity data in the VI could exaggerate the vulnerability of a county's population due to the overlap between obesity and type 2 diabetes. Additionally, I used the percent of a county's population that smokes as a proxy measure for the prevalence of lung disease because I could not find a complete dataset on the prevalence of this condition. I chose smoking as a proxy because smoking can cause lung diseases such as COPD which includes emphysema and chronic bronchitis, and I was able to find a complete dataset for the percent of people 18 and over that smoke in each county through the CHR&R data portal (CDCTobaccoFree 2019). In addition, due to the fact that diabetes doubles a person's risk of cardiovascular disease and smoking makes a person's risk for coronary heart disease two to four times higher, I did not include data on heart disease to once again avoid exaggerating a population's vulnerability (Bhupathiraju and Hu 2016; CDCTobaccoFree 2019). For age, I chose to measure the percent of people in each county that are over 65 years old because, while the CDC does not specify at what age a person is classified as an "older adult", it does report that "8 out of 10 deaths in the U.S. have been adults 65 years old and older" (CDC 2020).

An additional factor I chose to include in the VI is the percent of a county population that belongs to a minority group because multiple articles in major newspapers as well as information on the CDC website cite evidence of higher death and infection rates among minorities. (As aforementioned in the *Data* section above, in calculating the VI, I used the USCB definition of a minority which is "any group other than non-Hispanic White alone" (Ortman and Colby 2015)). According to the CDC, "current data suggest a disproportionate burden of illness and death among racial and ethnic minority groups" (CDC 2020). Furthermore, in an article published by the BBC on April 20, 2020, the author describes the factors that make minority communities more vulnerable to COVID-19 (Ro 2020). One such factor is that minority groups are over-represented in occupations that have been deemed essential during the pandemic (Ro 2020). Adding to this, minority groups are more likely to lack access to decent housing and to live in crowded buildings or units where social distancing and isolation are difficult or even impossible (Ro 2020) Some housing may also lack clean or running water which prevents residents from taking basic prevention measures such as hand washing and disinfecting high-traffic surfaces (Ro 2020). Furthermore, for some people that belong to a minority group, understanding terms like "social distancing" and public health announcements made in English can be difficult (Ro 2020). Finally, health "disparities" due to "persistent environmental injustice" (i.e. high proportions of minority groups live, work, or go to school near pollution sources like highways, factories, and landfills) and unequal healthcare access can also make minority groups more vulnerable to dying or becoming seriously ill from COVID-19 (Ro 2020).

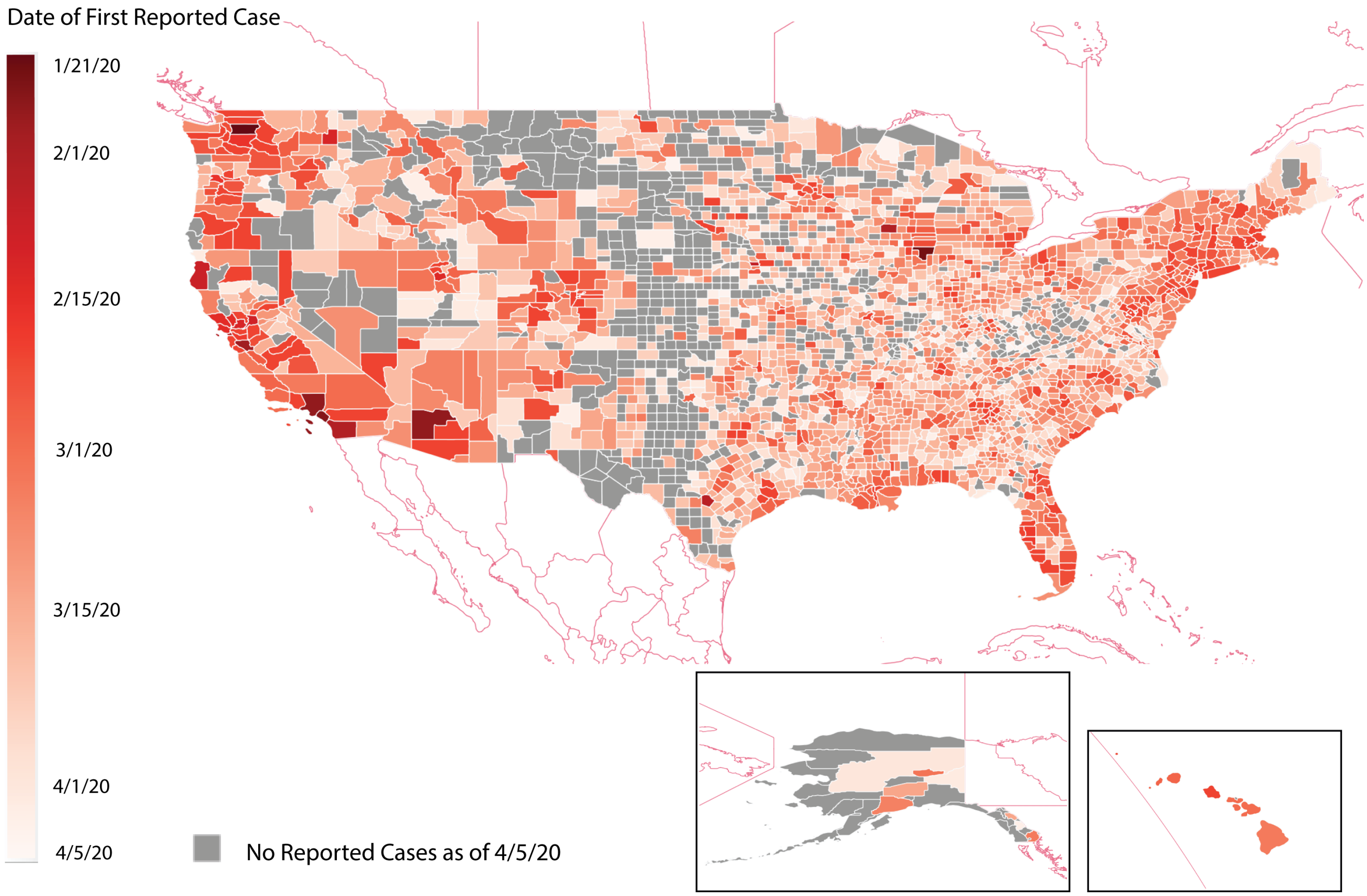
The final variable I included in the VI is population density. In a study conducted on two areas with different population densities that experienced an outbreak of a coronavirus called MERS-CoV (Middle East Respiratory Syndrome-Coronavirus) in 2012, the researchers found that population density seemed to have a "noticeable effect on the dynamics of disease spread" (Sumdani et al. 2014). Furthermore, a study on COVID-19 found that "Controlling contact rates is key to outbreak control, and such a strategy depends on population densities" (Bhupathiraju and Hu 2016). The contact rate "is proportional to population density" so higher population densities lead to higher contact rates and therefore make outbreak control more difficult (Bhupathiraju and Hu 2016). In counties with higher population densities, the virus can spread more rapidly which leads to higher infection rates and, especially if a high proportion of the population has health or social risk factors such as those mentioned previously, higher death rates.

Lastly, after calculating the VI for each county, I separated out the 100 most vulnerable and 100 least vulnerable counties based on their VI. From the 100 most vulnerable counties I selected San Francisco County, California as a case study for a superior response to the COVID-19 pandemic because while it ranked the 8th most vulnerable county in the U.S., its weighted death and infection rates were well below those of most of the other 100 most vulnerable counties. Then, I selected Toole County, Montana as a case study for an inferior response to the COVID-19 pandemic because although it ranked as the 5th least vulnerabile county, both its death and infection rates were higher than most of the other 100 least vulnerable counties. I then analyzed the pandemic preparedness components, or lack there-of, of each county's disaster plan as well as their actual response to the pandemic. I compared the county's plans and responses to the best-practices described by USAID.

Results

The earliest reported cases of COVID-19 were on the west coast and east coast and in the south-southwest and midwest. The first confirmed U.S. case on January 21, 2020 was on the west coast in Snohomish County, Washington. Cook County, Illinois in the midwest had the second confirmed case in the country on January 24, 2020. Three west coast counties, California, Orange, Los Angeles, and Santa Clara County, as well as Maricopa County in southern Arizona also had confirmed cases in January. The first confirmed case on the east coast was in Suffolk County, Massachusetts on February 1, 2020. The pandemic then spread across the country, making its way along the coasts and inland.

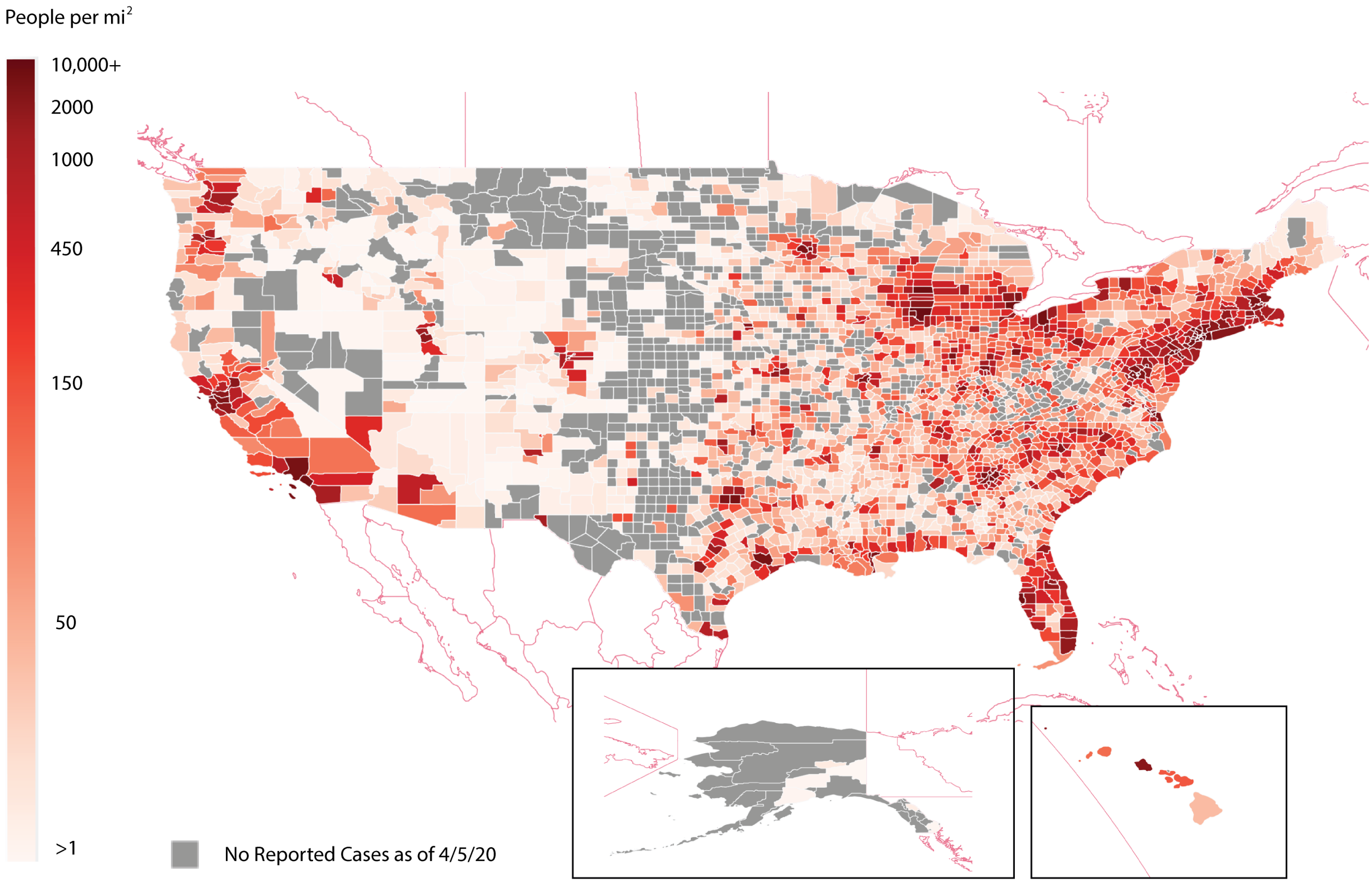
Date of First Reported Case by County



Source: nytimes/covid-19-data

The counties that had the earliest cases of COVID-19 also have high population density.

Population Density of Counties with Reported Cases of COVID-19*

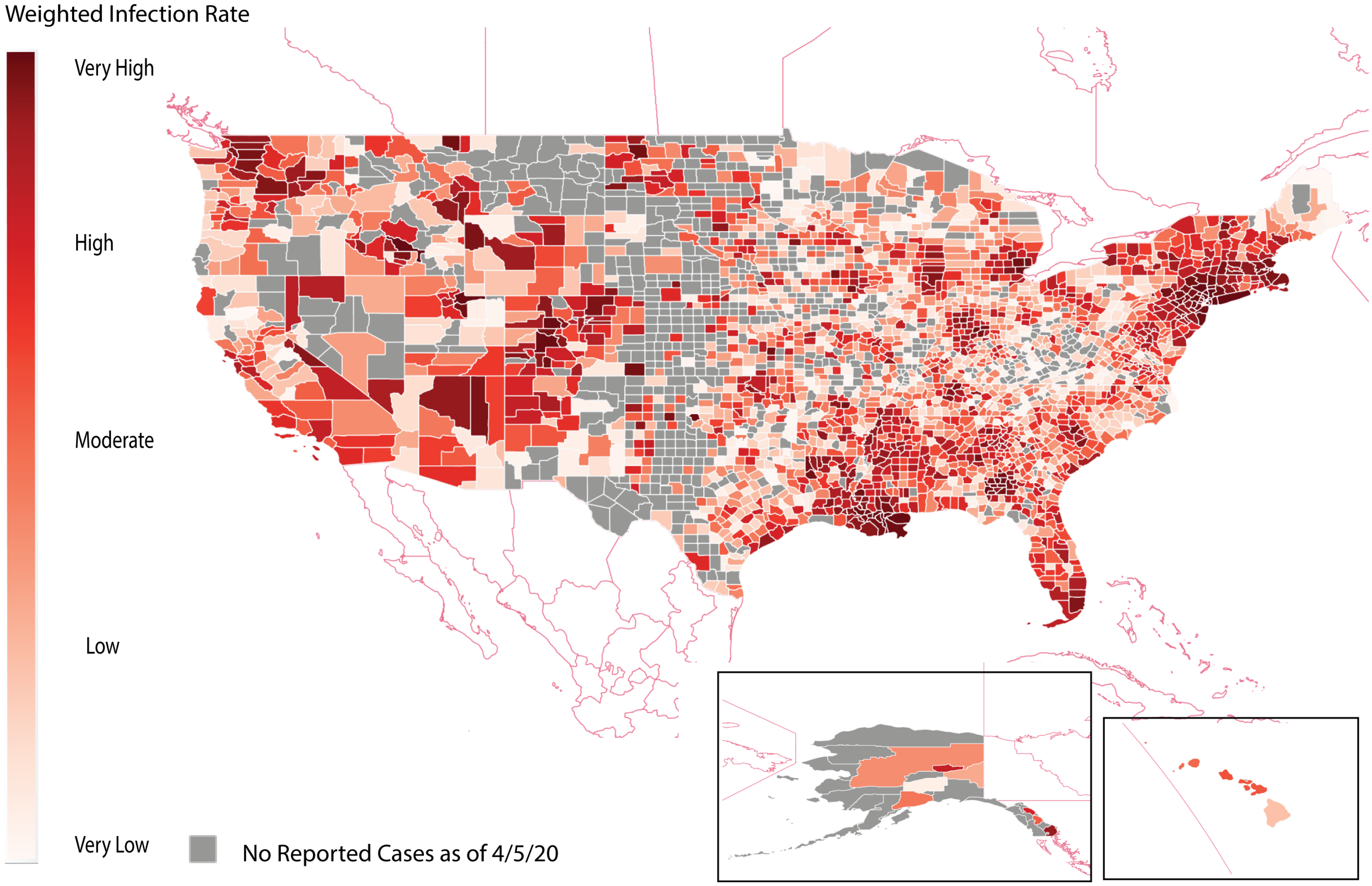


*Counties with reported cases of COVID-19 as of 4/5/20

Sources: nytimes/covid-19-data; IndexMundi.com

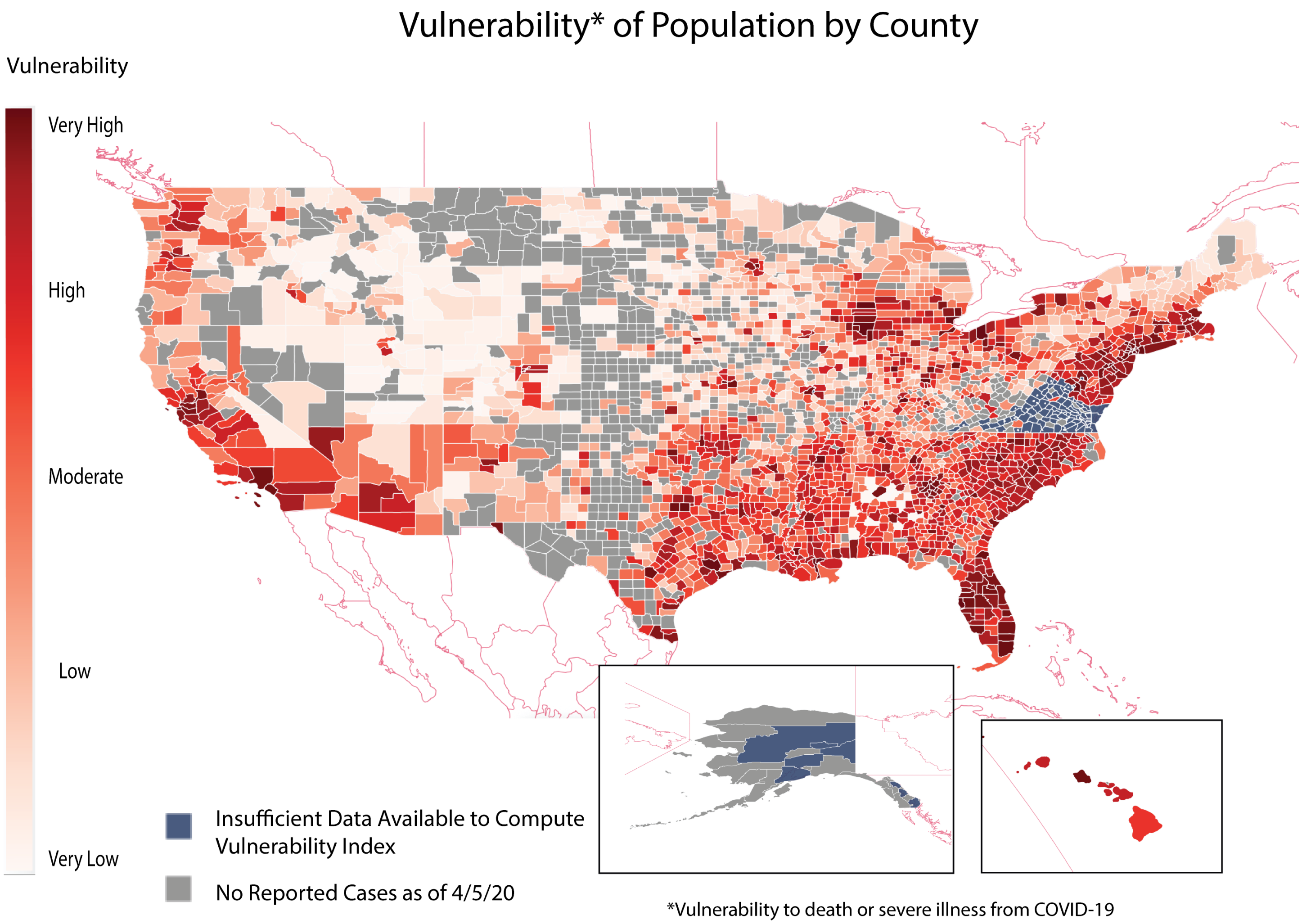
The densest counties also tended to have very high weighted infection rates. However, some low density counties also had very high weighted infection rates. County population density and weighted infection rate among all counties were loosely correlated with r = 0.44. However, among the top 100 most vulnerable counties as measured by their VI, population density and weighted infection rate were more closely correlated with r = .58, while among the bottom 100 least vulnerable counties these two variables had a very low correlation with r = .19.

Weighted Infection Rate by County



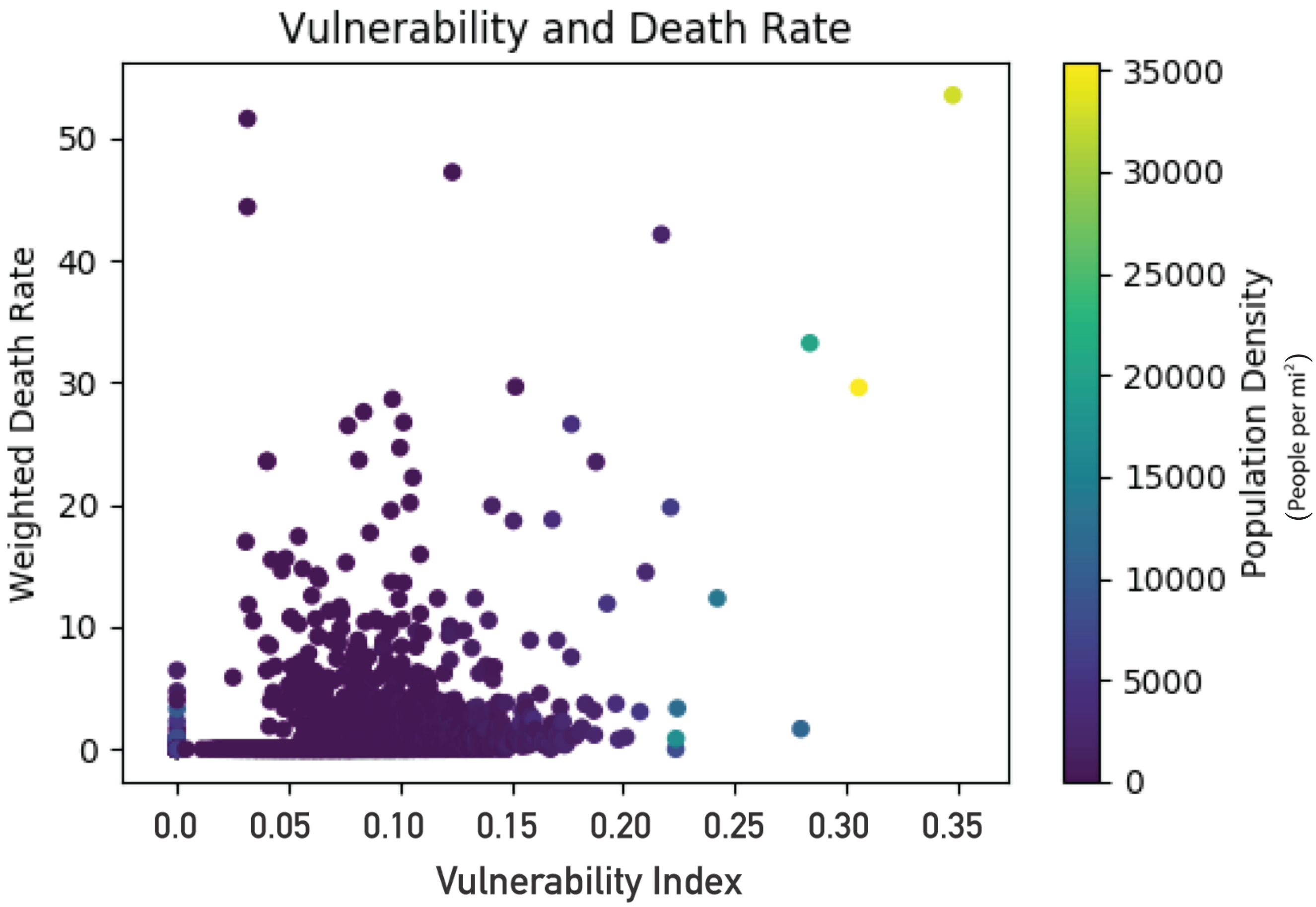
Source: nytimes/covid-19-data

Most counties with a high or very high VI also had a high weighted death rate. However, some inland counties in the northwest had a low or very low VI but a high weighted death rate.



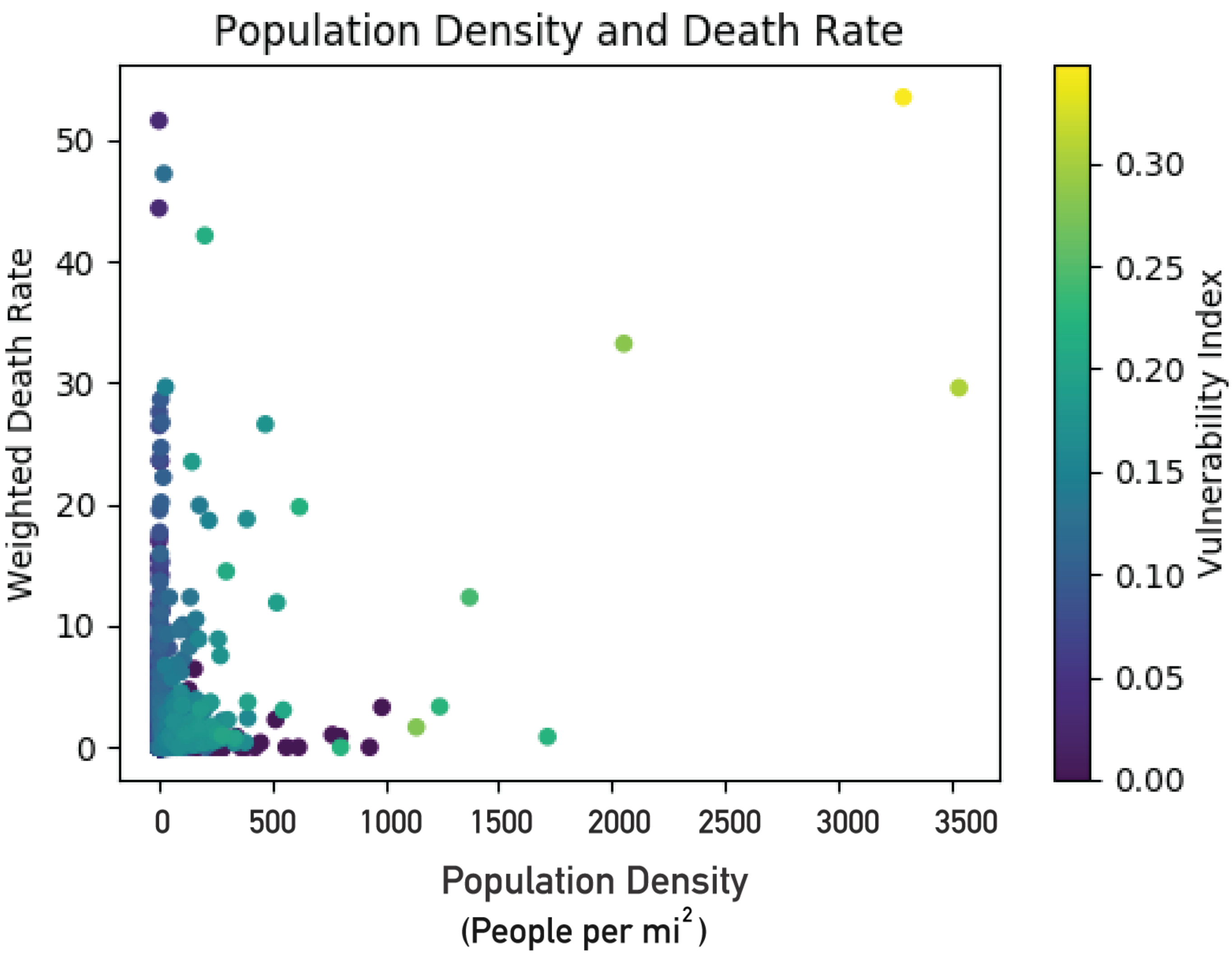
Sources: nytimes/covid-19-data; IndexMundi.com; U.S. Census Bureau County Population by Characteristics: 2010-2018

Among all counties, VI and weighted death rate had a low correlation with r = .26. However, among the top 100 most vulnerable counties, VI and weighted death rate were more closely correlated with r = .63. However, among the bottom 100 least vulnerable counties, VI and weighted death rate had almost no correlation with r = -.02.



Sources: nytimes/covid-19-data; IndexMundi.com; U.S. Census Bureau County Population by Characteristics: 2010-2018

While population density and weighted infection rate were loosely correlated among all counties (r = .44), population density and weighted death rate had a lower correlation with r = .38. However, population density and weighted death rate were more closely correlated (r = .61) than population density and weighted infection rate (r = .58) among the top 100 most vulnerable counties. Among the bottom 100 least vulnerable counties, population density and weighted death rate had almost no correlation (r = -.06) and population and weighted infection rate had a very low correlation (r = .19).



Sources: nytimes/covid-19-data; IndexMundi.com; U.S. Census Bureau County Population by Characteristics: 2010-2018

Of the 100 most vulnerable counties, San Francisco County had the 8th highest VI. However, its weighted infection rate was the 56th highest and its weighted death rate was the 66th highest of the 100 most vulnerable counties. However, of the 100 least vulnerable counties, Toole County had the 5th lowest VI but its weighted infection rate was the 4th highest and its weighted death rate was *the* highest.

San Francisco County's response to the COVID-19 pandemic was proactive, well coordinated, and transparent. On February 25, 2020, San Francisco County declared a local emergency even though it had no confirmed cases (Eby 2020). On March 5, the county reported its first two cases of COVID-19, and on March 6 it recommended that vulnerable populations decreased their public outings, that businesses cut back on travel and the number of employees working in their offices, and that "large non-essential gatherings be canceled" (Eby 2020). Over the next week and a half, the county banned public gatherings of 100 or more people and implemented a shelter in place order, and the San Francisco Unified School District closed all schools (Eby 2020). On March 19, Governor Gavin Newsom announced a statewide shelter at home order. On March 24, San Francisco reported its first confirmed death from the virus (Eby 2020). The county extended its shelter in place order through May 3 on March 31 and later on April 18 announced that face coverings would be required (Eby 2020).

San Francisco County has a pandemic preparedness component in its Hazard Mitigation Plan (Plan) developed by the county's Department of Emergency Management (DEM). According to the DEM's Plan, "Pandemic influenza is one of the most pressing public health planning needs today" and even a "moderate" pandemic can have a high health and healthcare impact due to a pandemic's typically long duration (San Francisco Department of Emergency Management 2014). The Plan describes the potential impacts of a pandemic which include an overwhelmed healthcare system, an increase in intensive care unit (ICU) admissions, emergency department (ED) admissions, isolation, and deaths (San Francisco Department of Emergency Management 2014). Furthermore, the health system's capacity to provide medical care including basic emergency medical services (EMS) may be reduced (San Francisco Department of Emergency Management 2014). The Plan also lists older residents and people who are immunocompromised as among the county's most vulnerable populations during a pandemic (San Francisco Department of Emergency Management 2014). According to the Plan, while the DEM expects a pandemic to have a "uniform effect geographically", it acknowledges that different populations will have varying morbidity and mortality rates (San Francisco Department of Emergency Management 2014). Citing the Bay Area Regional Risk Assessment of 2011, the Plan posits that the chance of a mild to moderate pandemic in San Francisco County is high due in part to the amount of travel in and to the area (San Francisco Department of Emergency Management 2014). The Plan also has a general asset inventory of essential facilities and infrastructure within the county among which are 18 Department of Public Health (DPH) facilities and one DEM facility (San Francisco Department of Emergency Management 2014). Additionally, it identifies the Public Health Emergency Preparedness Cooperative Agreement, a competitive grant program, as a source of federal funding which is "intended to upgrade state and local public health jurisdictions' preparedness and response to bioterrorism, outbreaks of infectious diseases, and other public health threats and emergencies" (San Francisco Department of Emergency Management 2014). Finally, the County of San Francisco has one regulatory resource that addresses pandemics, the City and County of San Francisco Health Code (Health Code) (San Francisco Department of Emergency Management 2014). Article 2: Communicable Diseases of the Health Code gives the DPH the power to quarantine people, houses and entire places or districts "when deemed necessary" (City and County of San Francisco 2006). It also mandates that a physician that has treated a patient with a communicable disease as well as a "keeper", "manager" or "owner" of a place housing an infected person must report to the DPH within 24 hours (City and County of San Francisco 2006).

In comparison to San Francisco County, Toole County's response to the COVID-19 pandemic was reactive, poorly coordinated, and lacked transparency. The first confirmed case of COVID-19 in the county was on March 26, 2020 (Walter 2020). By April 1, the county had 3 of Montana's 5 total confirmed deaths from COVID-19 meaning that 3 out of the 6 people infected with the virus in Toole County had died (Michels 2020). On April 13, the National Guard was called in to remedy a staffing shortage at the assisted living facility where the first confirmed case occurred (Walter 2020). Earlier in the month, the Toole County Health Department, "citing privacy laws", refused to provide details regarding how many of the six confirmed cases in the county were connected to the assisted living facility where the county's outbreak began (Michels 2020).

The Toole County Department of Emergency Services (DES) Pre-Disaster Emergency Mitigation Plan has no mention of pandemics or hazards related to viruses or diseases (Toole County, Beck Consulting, and AMEC Environment and Infrastructure, Inc. 2013). The Toole County Health Department 2017 Annual Report, the most recent available on the county website, does state that the Health Department would work to educate healthcare providers and students on communicable diseases and that it had given healthcare professionals lists of communicable diseases (Walter 2020). Furthermore, the county's website had no mention of the COVID-19 pandemic as of May 1, 2020 (Toole County 2020).

Discussion

The COVID-19 pandemic has not impacted all counties across the United States equally. Many counties with highly vulnerable populations have been heavily impacted as is reflected by those counties' high death and infection rates. Densely populated counties have also largely been hard-hit by the pandemic. In addition, each county has a unique combination of risk factors that contribute to its VI which suggests the need for nuanced, locally sensitive pandemic preparedness planning.

San Francisco County is an example of a county with a very high VI and a high weighted infection rate when compared to all counties but a very low weighted infection and death rate when compared to the other most vulnerable counties. Its VI is .22 and is the 8th highest in the country. The county's high VI is due to its high population density (It is the 5th densest county in the country and has a population density of 17,179.1 people per square mile (IndexMundi.com 2020; State of New York 2020)), the relatively high percentage of its population that belongs to a minority group, and the relatively high percentage of its population that is over 65 years old. Its unweighted infection rate on April 5, 2020 was .07%, and its unweighted death rate was .0001%.

Population density, as aforementioned, is only one of the variables accounted for in a county's VI so many sparsely populated counties also have highly vulnerable populations. One such low-density, low vulnerability county that also has a very high death and infection rate is Toole County.

Toole County has a very low VI (VI = .03), the 5th lowest in the country, but a very high weighted death and infection rate when compared to all counties in the country. Its unweighted infection rate on April 5, 2020 was .3%, over 4 times higher than San Francisco County's, and its unweighted death rate was .05%, 50 times that of San Francisco County, even though its outbreak started two months later. Its low VI is due to its super low population density (2.8 people per square mile (U.S. Census Bureau 2010)) and the very low percentage of its populations that belongs to a minority group.

Toole County has a low VI but was heavily impacted by the pandemic. The county has no pandemic preparedness component in its disaster plan. On the other hand, San Francisco has a very high VI but was not as heavily impacted by the pandemic in terms of its death and infection rates even though its outbreak started over a month earlier. San Francisco County does have a pandemic preparedness component in its emergency response plan, but it still falls dramatically short of the level of detail suggested by the USAID's guide to municipal pandemic preparedness and response. San Francisco County's pandemic preparedness component does not address issues such as food security or include medical supply inventories. It also does not identify spaces that can act as temporary hospitals and/or social isolation facilities. While it does identify two populations in the county that are more vulnerable, elderly people and people who are immunocompromised, it fails to include people that belong to minority groups, a group that makes up nearly 60% of its total population (U.S. Census Bureau 2018). It also does not describe how it will address the unique needs of these populations to mitigate the potentially disproportionate impact on these groups.

The varied impact of and vulnerability to the COVID-19 pandemic between counties illustrates the need for pandemic preparedness components in local disaster plans. Furthermore, the superior outcome in terms of death rates, infection rates, and response in San Francisco County which is very densely populated and has a very high VI suggests that even a pandemic preparedness plan that falls short of avaiable best practices can save lives and prevent residents from becoming infected.

Limitations and Ethical Considerations

Limitations

The main limitations of this study are threefold: gaps in the datasets used, the exclusion of certain variables from the VI, and not accounting for some factors that can affect infection rates. One gap in my data is due to the CHR&R portal's lack of sufficient county-level health data on diabetes and smoking for North Carolina which means I was unable to calculate a VI for all the counties in the state. Another potential gap in my data stems from the uncoordinated reporting of confirmed COVID-19 cases and deaths by governments and health departments across the United States. According to the New York Times Company which compiled the county-level COVID-19 cases and deaths dataset that I used for this study, the difficulty of collecting, interpreting, and confirming this information means that its data "will in some cases not exactly match with the information reported by states and counties" (New York Times 2020). I therefore do not know if any counties have inaccurate case and death counts. If some counties' data were inaccurate, then the correlations I reported in the **Results** section above could also be inaccurate and either understated or overstated.

In creating the VI and calculating the VI for each county, I followed the rigorous method developed by the World Health Organization and Georgia State University School of Public Health experts outlined in the UHI document. However, due to the aforementioned lack of complete, county-level health datasets, I did not include some of the underlying conditions (chronic kidney disease, liver disease, diseases that cause immunodeficiencies, and asthma) that, according to the CDC, put a person at higher risk of dying or falling seriously ill from COVID-19 (CDC 2020). I also did not include other factors that can increase a person's risk such as their gender, having a disability or their lack of (adequate) healthcare or access to testing or medical facilities (Henriques 2020; NPR 2020; Ro 2020).

In addition, while I did account for the date of a county's first case when calculating its weighted infection rate, I did not account for other factors that can affect a county's infection rate. These factors include the presence of certain facilities such as airports, prisons and meatpacking plants in a county, the amount of tourism, the number of tests conducted, and the holding of major events before such activities were banned or greatly reduced by nation or statewide orders (Krasney 2020).

Ethical Considerations

The exclusion of certain variables from the VI may cause the vulnerability of some county population's to be overstated while the vulnerability of others may be understated. Furthermore, I do not know exactly what methods the journalists who have contributed to the New York Times Company dataset used to collect the data. Some county and state governments and health departments may be unable to count cases or deaths of people who belong to groups that do not have access to technology, transportation, and/or medical facilities. These groups tend to be minority populations, those with limited financial resources, those with disabilities, and the unsupported elderly. County infection and death rates that under represent the impact of COVID-19 on these groups could perpetuate the structural inequities they already face, especially if municipal bodies reference the data in developing pandemic preparedness components for their disaster plans.

Implications and Conclusion

The COVID-19 pandemic is not the first pandemic nor will it be the last. Across the United States, over a million people have been infected by the virus and almost 60 thousand people have lost their lives (Hern et al. 2020). While neither federal, state nor local laws require including a pandemic preparedness component in disaster plans, the regional variability in the local impact of and vulnerability to the COVID-19 pandemic illustrates the necessity of including such a component in county disaster plans. The Stafford Act should be amended again to require counties to include pandemic preparedness components in their disaster plans that address their populations' unique vulnerabilities and draw upon their strengths. The VI that I developed can be used by municipal governments to develop such locally sensitive pandemic preparedness plans because it identifies a county population's highest risk factors as well as its overall level of vulnerability. If every county in the United States develops its own pandemic plan, then when the next pandemic sweeps across the globe and arrives on American soil, we will be prepared.

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