Neighborhood Differences in COVID-19 Testing, Incidence, and Mortality in the State of Indiana

Abstract:

Background: COVID-19 is a highly contagious pandemic disease. This study aims to identify neighborhood-level sociodemographic, health behaviors, adherence to social distancing policies, and healthcare access factors associated with geographic variability of COVID-19 testing, case incidence, and mortality in the U.S. state of Indiana.

Methods: The study population included all Indiana residents. Geographic distribution of COVID-19 testing, positive cases, and mortality were estimated for each county and plotted using choropleth maps. Generalized bivariate and multivariable negative binomial regression were used to estimate effects of county-level factors.

Results: Higher rates of testing, case detection, and mortality were associated with a greater proportion of non-white residents. Counties with better scores in social distancing and greater proportion of older residents had lower incidence of laboratory testing. We found the highest socioeconomic tertile was associated with higher rates of cases, but no difference in testing or mortality. Improved social distancing lowered the incidence of COVID-19 testing and cases. Densely populated counties had higher testing and incidence of COVID-19 cases per capita, however, higher mortality rates were observed in rural/mixed counties.

Conclusion: Differences in COVID-19 testing, case detection, and mortality in Indiana are associated with neighborhood-level characteristics. Local contexts should be considered in COVID-19 response planning.

Introduction.

Globally, since the first case of COVID-19 was detected in December 2019, there are approximately 13.2 million reported tests with 1.7 million cases diagnosed and 103,000 reported deaths related to the pandemic COVID-19 as of April 10 2020. About 19% of COVID-19 tests, 30% of positive cases, and 18% of the deaths are observed in the US. Since the diagnosis of its first case on March 6, 2020, Indiana is among the top 15 U.S. states with the highest number of confirmed COVID-19 cases per capita. Most of the cases are seen among females, and those 40-69 years of age. The majority of deaths are observed among males and 60+ years of age. In the US, federal guidelines on social distancing were announced March 16, 2020; four days earlier Governor Holcomb announced a "stay at home" order for the state of Indiana.

COVID-19 related studies published in 2019 and 2020 have focused mainly on individual factors that directly or indirectly influence the presentation, transmission, progression, healthcare services and outcomes related to COVID-19. However, the role of the neighborhood environment on COVID-19 laboratory testing, case detection, and death rates has not been studied yet. Earlier studies have suggested that understanding neighborhood heterogeneity by studying area level demographic and socioeconomic variables may be helpful in explaining factors that influence the burden and rapid spread of pandemic conditions. The objective of this study was to identify the neighborhood-level sociodemographic, environmental, and lifestyle factors associated with the geographic variability of laboratory testing, case detection and mortality of COVID-19 in the state of Indiana, United States.

Methods.

Data and variables. Comprehensive county data on total number of COVID-19 tests, cases, and deaths were collected from March 6, 2020 to April 10, 2020 for the state of Indiana, US from the Indiana State Department of Health's COVID-19 data report. Total tests reflect those reported to the Indiana State Department of Health (ISDH). The positive tests further reflect results from ISDH, and those results submitted to ISDH by private laboratories. Deaths related to COVID-19 are announced officially by ISDH as they are received from admitting hospitals or community.

We used the socioeconomic status (SES) index, a county-level measure developed by Agency for Healthcare Research and Quality (AHRQ), to evaluate the influence of SES on the study outcomes. The SES Index is a weighted composite variable that includes occupation, income, poverty, wealth, education and crowding. AHRQ developed the SES index using principal component analysis where the factor loadings for different constructs of SES were regarded as the weights measuring correlations of those variables with the index. The component variables for SES Index at county levels were collected from U.S. Census database available for the most recent year, 2019. The SES Index was then categorized into low, medium and high tertiles. Demographic variable including age, gender, race, ethnicity, and population estimates for each county were also obtained from the US Census database. Uninsurance rate, percentage adults who smoke, percentage who are physically inactive, and Primary Care Physician to patient ratio were obtained from the 2019 County Health Rankings Data for Indiana.

County based social distancing score as of April 10, 2020, was created by Uncast using the geospatial human average mobility data. The details of the score are described elsewhere. In summary, the score ranks a county based on percentage decrease in human mobility using a grading system from A through F, where A is >70% decrease, B is 55-70% decrease, C is 40-55% decrease, D is 25-40%

decrease and F is <25% decrease. As a reference, 70% decrease was observed in Italy, while a complete shutdown was in place. For the purpose of this study, better social distancing was defined for those counties that ranked C- or higher.

Statistical analysis. To examine the geographic distribution of the laboratory testing, case incidence and mortality, we normalized each of these count variables by dividing them by county-specific population size. The normalized rates of tests, incidence of cases, and death rates were then plotted using choropleth maps. Generalized bivariate and multivariable negative binomial regressions with log link function was performed for each of the counts of testing, positive cases, and number of deaths. The variables included in the multivariable analysis were % non-white, % Hispanic, % of different adult age groups (20-44, 45-64, 65-84, 85+ years), log-transformed PCP ratio, uninsurance rate, % adult smokers, % physically inactive, tertiles of the SES Index, and social distancing score C-minus and above vs D-plus and below. The overdispersion because of higher variance than the mean was corrected by using negative binomial regression. The proportionality of the variance was also adjusted by using a scale parameter that was corresponding to the Pearson's chi-squared divided by the degrees of freedom in the generalized models. Case-wise approach of deviance test was used to evaluate the goodness of fit (G^2 statistics and its associated p-value were reported) for each model compared to the saturated model (A saturated model is defined as the model that leads to the perfect prediction of the outcome of interest). Estimated incidence rate ratios (IRR) with 95% CI were reported. All analyses set p=0.05, were two-sided, and performed using Stata/SE 14.2.

Results.

Since March 6, 2020 when the first confirmed case of COVID-19, and as of April 10, 2020, in total 35,040 tests, 6,907 incident cases, and 300 deaths related to COVID-19 were reported to the Indiana State Health Department. All 92 counties of Indiana reported COVID-19 tests with 2 counties reporting zero COVID-19 positive cases. About 57.6% of the counties reported at least one COVID-19 related death. On average, approximately 37 lab-tests per 10,000 county population, with seven COVID-19 positive cases per 10,000 population, and 5 related deaths per 10,000 population was reported in Indiana. On average, county populations were 5.4% nonwhite and 4% Hispanic in the state of Indiana. Though the AHRQ's SES Index ranged from 48 to 74, mean county level SES index was 53.7 (+/-4.3). About 17% of the population were 65+ years of age. The uninsurance rate was slightly below 10% and mean Population to Primary Care Physician (PCP) ratio equals to 1,500:1 which is higher than the US average where the population to PCP ratio is 1330:1 Based on distance travelled, on an average the social distancing scoreboard ranked the state of Indiana with D- (lower in the range of 25 - 40% reduction in average mobility). Within Indiana, however, there were 28 counties (30.4%) with a better score (C-minus and higher; >40% reduction in average human mobility) than the state average (score=D). Health behavior related variables, such as adult smoking and physical inactivity, were higher than the national averages (16.1% and 23.8%, respectively) (Table 1).

In bivariate analyses (Table 2), we found that there exists neighborhood level demographic, racial, ethnic and socioeconomic disparities in COIVD-19 testing, incidence of cases and mortality. For each 1% increase in the percentage non-whites and Hispanics in the population, the incidence of COVID-19 related laboratory testing (IRR=1.17 and IRR=1.28), positive cases (IRR=1.1 and IRR=1.27), and mortality (IRR=1.14 and IRR=1.22) increased significantly compared to counties with lower proportion of racial and ethnic minorities. Counties with a higher percentage female population were significantly more likely to have a larger number of tests, incidence of COVID-19 positive cases, and mortality related to the viral infection. Our access to care measure, as defined by PCP ratio, was inversely related to number of tests, infections and mortality from COVID-19. Though county level percent of adult smokers was not associated with any COVID-19 related outcomes, sedentary behavior was associated with lower incidence of laboratory testing, but not COVID-19 infection and mortality. Compared to low SES index, counties with medium SES index were significantly more likely to be tested for COVID-19 with higher incidence of the cases and mortality. In the bivariate analysis, better social distancing score at the county level was associated with lower incidence of cases in the county. In multivariable analyses (Table 3), we found that for each percent increase in non-white population, the incidence rate ratio of COVID-19 laboratory testing increased by 9 percentage points (Adj. IRR=1.09, 95% CI: 1.05, 1.14; p-value<0.001), the positive cases by 14 percentage points (Adj. IRR=1.14, 95% CI: 1.07, 1.21; p-value<0.001) and mortality by 18 percentage points (Adj. IRR=1.18, 95% CI: 1.09, 1.28; p-value<0.001). Hispanic ethnicity, which was significant in bivariate analyses, was not associated with the COIVD-19 testing, incidence and mortality rates. Counties with higher percentages of residents 85 years and older were less likely to have laboratory tests for COVID-19 (Adj. IRR=0.54, 95% CI: 0.34, 0.84; p-value=0.007), had lower positive case detection rates (Adj. IRR=0.39, 95% CI: 0.21, 0.72; p-value=0.003), and lower COVID-19 related mortality rates (Adj. IRR=0.26, 95% CI: 0.09, 0.72; p-value=0.01).

Higher incidence of COVID-19 positive cases was found to be significantly associated with counties having a larger percentage of female residents (Adj. IRR=1.25, 95% CI: 1.01, 1.55; p-value=0.042). High quartile of SES Index was also found to be associated with higher incidence of COVID-19 cases. Lab testing (Adj. IRR=0.6, 95% CI: 0.41, 0.86; p-value=0.006) and incidence of COVID-19 cases (Adj. IRR=0.55, 95% CI: 0.32, 0.94; p-value=0.029) in counties with better social distancing scores were less likely to occur than in counties with worse social distancing scores. The models used in these estimations were evaluated for their goodness of fit using a case-wise approach of deviance test and found that the fit of each model was not significantly different from the fit of a saturated model, demonstrating better fit of the selected models.

Choropleth maps (Figures 1-3) exhibit that the densely populated counties in Indiana, particularly around Marion county, had higher testing and incidence of COVID-19 cases per 10K population with central, eastern and southeastern counties being more impacted by the COVID-19. However, more deaths per 1,000 population was observed in rural/mixed counties than the urban counties.

Discussions.

This study showed that the 2019-2020 COVID-19 pandemic demonstrated early evidence of geographical clustering and demographic, socioeconomic, and social mobility dependence. Prior studies of pandemic disease, for example 1918 H1N1 influenza, suggested that the H1N1 virus indiscriminately affected populations irrespective of social class . However, in agreement with this study, there were other studies that indicated adverse burden of the pandemic influenza among socially and economically disadvantaged population. Though the raw mortality numbers due to COVID-19 pandemic in Indiana are higher in urban counties, the mortality rate per 1000 population was higher in rural and mixed counties, in contrast with the earlier findings. The inverse relationship of social distancing score observed in this study reinforce the effectiveness of this public health intervention in minimizing the risk of local transmission, as was observed in 1918 pandemic influenza.

The choropleth map (Figure 1-2), for testing and incidence rates, demonstrated an increased risk among counties with a higher proportion of non-white residents and higher SES index. This finding suggests that urban areas with greater racial diversity, higher likelihood of travelling outside the state, and greater population density were more likely to have access to COVID-19 testing, as well as be infected with the virus. Further, due to the initial limited availability of tests, most Indiana residents who were tested were critically ill in a hospital located in Marion County or were healthcare providers. The pharmaceutical company Eli Lilly partnered with Indiana State Department of Health, and with support from the Food and Drug Administration, opened its testing site for healthcare workers in Marion County during the time under study.

Non-white people are more likely to live in densely populated areas and in multigenerational housing conditions which increases the likelihood of virus transmission. Due to the racial disparity of mortality outcomes of COVID-19 reported nationally and here, it appears that those who were tested, were critically ill and died early in the pandemic, were minority patients with lower SES, higher uninsurance rate, and lower access to primary care. More patient level analyses in the future might reveal clarity to this hypothesis will complement these observations.

The reduced likelihood of areas with older residents receiving testing suggests that older adults may either be more likely to comply with recommended social-distancing guidelines or are less mobile in general. Furthermore, older adults may be less likely to need to go to work, have less access to community activities, or not have easy access to reduced or closed public transportation.

We also observed higher testing among medium (vs. low) SES counties which may be due to greater access to testing in areas with more resources and capacity, as well as higher relative SES of employed healthcare workers (e.g. nurses). Studies have shown that higher SES was significantly associated with higher rates of healthcare utilization including laboratory testing. Further research is needed to examine the factors driving these inequalities in access and utilization of laboratory testing. Moreover, lower death rates among low SES counties could be due to misascertainment of COVID-19 related deaths to other causes; as was seen in reporting deaths due to 1918 pandemic influenza where each revision of death toll has been upward. Since the symptoms of COVID vary greatly, bias in cause of death ascertainment due to COVID-19 should be carefully monitored over time.

The association between a higher proportion of females in a county being associated with worse COVID related outcomes highlights the importance of considering individual and community-level factors separately. Among individuals, females diagnosed with COVID-19 have a better prognosis than males. However, geographic areas with a higher proportion of females having higher COVID-related infections and deaths could be due to these areas having more single parent female households and thereby more often having women who need to work outside the home. This explanation seems more plausible than a greater prevalence of women who have lost their husband given the negative correlation between area-level age and COVID-19 related outcomes.

Access to primary care was associated with less infection and mortality adding yet another piece of evidence to the population-level benefit of primary care access for public health. Higher rate of death in rural/mixed than urban counties may be due to reduced access to advanced healthcare, a pattern exacerbated by the reduction of services and closure of rural hospitals in the last decade.

Indiana's below average levels of social distancing may explain in part the high rates of infection relative to other states. Nonetheless, as observed in 1918 influenza pandemic, spontaneous or enforced social distancing appears to be associated with less COVID-19 infection within the state, reinforcing the importance of this public health intervention wherever it is practiced.

This study has several limitations. First, the number of cases in the community might be under-reported as only those tests that were reported to ISDH were used in the analysis. Second, using the social distance measurement grading system that was calibrated by complete lockdown in Italy might not be applicable to the US. However, the benefits of the available social distancing score is empirically demonstrated in this study. Third, Hispanic populations deserve further study because small numbers may have limited our study's power to detect the differences in COVID-19 related outcomes in adjusted models. Fourth, our measurement of demographic and socioeconomic status variables at neighborhood levels, however, may need careful interpretation as the estimates from this ecological study is based on census indicators of social and economic disadvantage, rather than individual patient level indicators as noted already in the discussion. This study provides correlations between social/geographic characteristics and COVID-related outcomes and hence the findings should not be considered definitive at patient level. Although the local nature of this study limits its generalizability; we saw an evidence of the effect of demographic and socioeconomic on COVID-19 tests, diagnosis and outcomes. Further, the statistical models used in these estimations were robust and did not have any evidence of deviation from a saturated model which is defined as the model that perfectly predict outcomes.

The conclusions from this study will help to identify neighborhood level characteristics and inform ongoing modelling of laboratory testing and incidence of and mortality from COVID-19 pandemic. The study demonstrates important sociodemographic, disparities among vulnerable nonwhite and rural populations. Further, the study provides additional evidence of the effects of social and geographical proximity upon the spread, and possible trajectory of the pandemic outcomes over time. The findings from this study may inform stakeholders in the development and implementation of public health policy guidelines to mitigate the extent and the effect of COVID-19 pandemic upon both vulnerable and the general population.

References

Table 1: County Characteristics

Characteristics	**Mean**	**SD**	**Median**	**IQR**
COVID-19 Lab-tests per 10K	37.16	20.94	33.51	5.08
COVID-19 positive per 10K	6.75	7.18	4.16	0
COVID-19 Deaths per 1K	48.8	73.13	29.81	0
% Non-white	5.38	6.04	3.05	0.40
% Hispanics	3.96	3.55	2.85	0.10
AHRQ's SES Index	53.74	4.33	53.01	47.75
% Age 20-44 years	30.00	2.90	29.4	24.40
% Age 45-64 years	27.41	2.11	27.75	19.60
% Age 65-84 years	14.87	1.94	15.00	9.30
% Age 85 years+	2.04	0.43	2.00	1.20
% Female	50.17	1.11	50.20	46.3
log of PCP ratio	7.79	0.67	7.71	6.18
Uninsurance rate	9.70	2.19	9.39	5.28
% Smokers	19.75	1.92	19.85	12.85
% Physically inactive	27.10	3.54	27.35	14.00
SES Index by tertiles				
Low: 47.7-51.2	49.91	0.90	50.13	1.56
Medium: 51.2-54.8	53.03	0.99	53.05	1.79
High: 54.8-73.7	58.41	4.25	57.01	3.87
Social Distance score C-minus and above, (n, %)	28, 30.43			

SD – Standard deviation, IQR – Inter-quartile range, AHRQ – Agency for Healthcare Research and Quality, SES – Socioeconomic Status, PCP- Primary Care Physician

Table 2: Bivariate analyses of county characteristics and COVID related tests, diagnosis and mortality

County characteristics	Tests		Cases		Deaths	
	IRR [95% CI]	p-value	IRR [95% CI]	p-value	IRR [95% CI]	p-value
% Non-white	1.17 [1.11, 1.22]	<0.001	1.16 [1.1, 1.23]	<0.001	1.14 [1.08, 1.19]	<0.001
% Hispanics	1.28 [1.15, 1.43]	<0.001	1.27 [1.12, 1.43]	<0.001	1.22 [1.08, 1.38]	0.002
AHRQ's SES Index	1.07 [0.87, 1.32]	0.5	1.09 [0.86, 1.37]	0.492	1.07 [0.89, 1.3]	0.481
% Age 20-44 years	1.36 [1.15, 1.62]	<0.001	1.41 [1.11, 1.79]	0.005	1.24 [0.95, 1.64]	0.119
% Age 45-64 years	1.22 [0.99, 1.5]	0.065	1.39 [1.04, 1.86]	0.024	1.18 [0.83, 1.68]	0.357
% Age 65-84 years	0.73 [0.6, 0.89]	0.002	0.67 [0.51, 0.89]	0.006	0.74 [0.52, 1.06]	0.1
% Age 85 years+	1.03 [0.55, 1.94]	0.924	0.91 [0.38, 2.2]	0.832	0.68 [0.23, 2.05]	0.496
% Female	1.71 [1.29, 2.27]	<0.001	2.05 [1.53, 2.75]	<0.001	2.47 [1.56, 3.89]	<0.001
log of PCP ratio	0.39 [0.23, 0.67]	0.001	0.42 [0.23, 0.77]	0.005	0.3 [0.11, 0.81]	0.017
Uninsurance rate	0.94 [0.64, 1.37]	0.753	0.89 [0.57, 1.39]	0.613	0.92 [0.62, 1.35]	0.662
% Smokers	0.99 [0.73, 1.33]	0.941	0.98 [0.72, 1.35]	0.907	1 [0.74, 1.34]	0.981
% Physically inactive	0.81 [0.68, 0.97]	0.024	0.84 [0.7, 1.02]	0.071	0.88 [0.73, 1.06]	0.181
SES Index tertiles						
Low: 47.7-51.2	Reference		Reference		Reference	
Medium: 51.2-54.8	5 [1.65, 15.16]	0.004	6.04 [1.74, 20.94]	0.005	5.06 [1.26, 20.38]	0.023
High: 54.8-73.7	2.96 [0.97, 9.06]	0.057	3.69 [1.05, 12.94]	0.042	3.13 [0.75, 13.06]	0.117
Social Distance Score						
D- and below	Reference		Reference		Reference	
C- and above	0.28 [0.08, 0.96]	0.042	0.23 [0.06, 0.85]	0.028	0.23 [0.05, 1.02]	0.053

AHRQ – Agency for Healthcare Research and Quality, SES – Socioeconomic Status, PCP- Primary Care Physician, Adj. IRR – Adjusted Incidence rate ratio, CI – Confidence Interval

Table 3: Multivariable analysis of county characteristics and COVID related tests, diagnosis and mortality

County Characteristics	Tests		Cases		Deaths	
	Adj. IRR [95% CI]	p-value	Adj. IRR [95% CI]	p-value	Adj. IRR [95% CI]	p-value
% Non-white	1.09 [1.05, 1.14]	<0.001	1.14 [1.07, 1.21]	<0.001	1.18 [1.09, 1.28]	<0.001
% Hispanics	1.02 [0.96, 1.08]	0.537	0.95 [0.87, 1.03]	0.205	0.9 [0.79, 1.03]	0.126
% Age 20-44 years	1.12 [0.97, 1.29]	0.13	1.01 [0.82, 1.24]	0.902	0.75 [0.55, 1.02]	0.069
% Age 45-64 years	1.1 [0.92, 1.32]	0.292	1.11 [0.85, 1.46]	0.438	0.79 [0.53, 1.19]	0.261
% Age 65-84 years	0.9 [0.77, 1.04]	0.158	0.79 [0.65, 0.97]	0.023	0.84 [0.61, 1.14]	0.253
% Age 85 years+	0.54 [0.34, 0.84]	0.007	0.39 [0.21, 0.72]	0.003	0.26 [0.09, 0.72]	0.01
% Female	1.15 [0.99, 1.33]	0.066	1.25 [1.01, 1.55]	0.042	1.19 [0.84, 1.69]	0.323
log of PCP ratio	0.97 [0.75, 1.26]	0.834	0.97 [0.7, 1.35]	0.873	1.06 [0.6, 1.87]	0.852
Uninsurance rate	0.96 [0.86, 1.08]	0.499	0.93 [0.79, 1.09]	0.382	0.83 [0.65, 1.07]	0.154
% Smokers	1.07 [0.96, 1.2]	0.203	1.17 [0.99, 1.38]	0.058	1.18 [0.94, 1.48]	0.15
% Physically inactive	0.99 [0.94, 1.05]	0.826	1.04 [0.97, 1.11]	0.297	1.08 [0.97, 1.2]	0.168
SES Index tertiles						
Low: 47.7-51.2	Reference		Reference		Reference	
Medium: 51.2-54.8	0.97 [0.65, 1.45]	0.875	1.07 [0.61, 1.87]	0.807	1.03 [0.44, 2.42]	0.937
High: 54.8-73.7	1.43 [0.86, 2.39]	0.169	2.58 [1.29, 5.18]	0.007	2.46 [0.86, 7.01]	0.091
Social Distance Score						
D- and below	Reference		Reference		Reference	
C- and above	0.6 [0.41, 0.86]	0.006	0.55 [0.32, 0.94]	0.029	0.62 [0.26, 1.45]	0.267
Case-wise approach of deviance test - Goodness of fit, G^2						
G^2	36.49		53.32		69.79	
p-value*	0.999		0.967		0.617	

*Failed to reject the null hypothesis i.e. each model was of no difference than its saturated model

PCP- Primary Care Physician, Adj. IRR – Adjusted Incidence rate ratio, CI – Confidence Interval

Figures

Figure 1: County-wise reported COVID-19 tests per 10K population

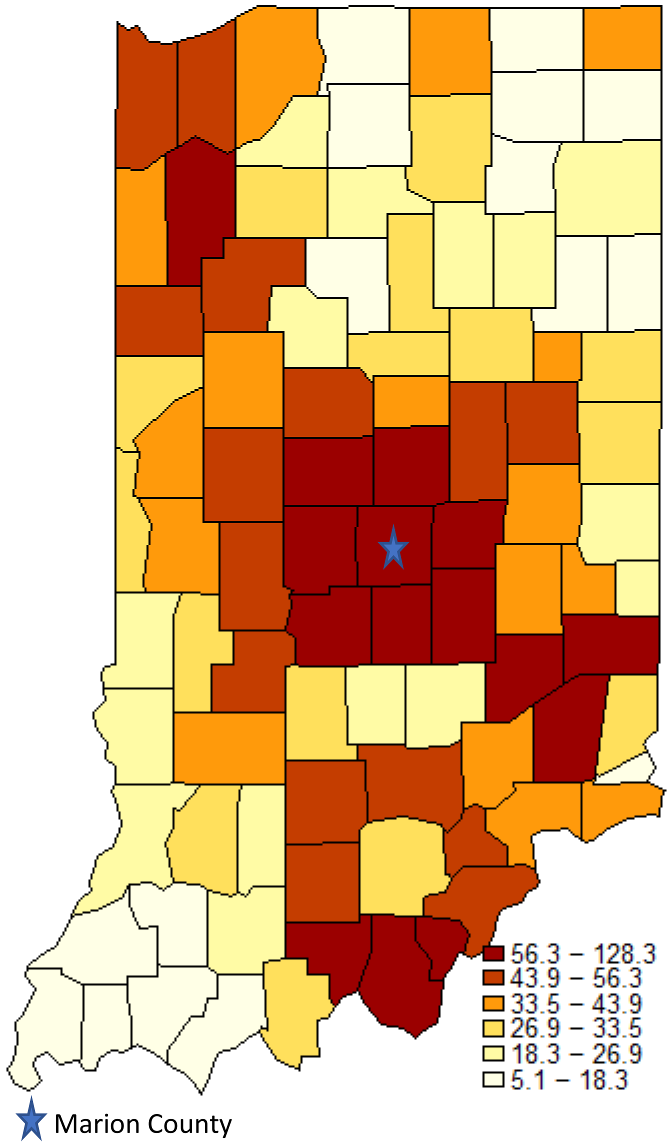

Figure 2: County-wise COVID-19 incidence per 10K population

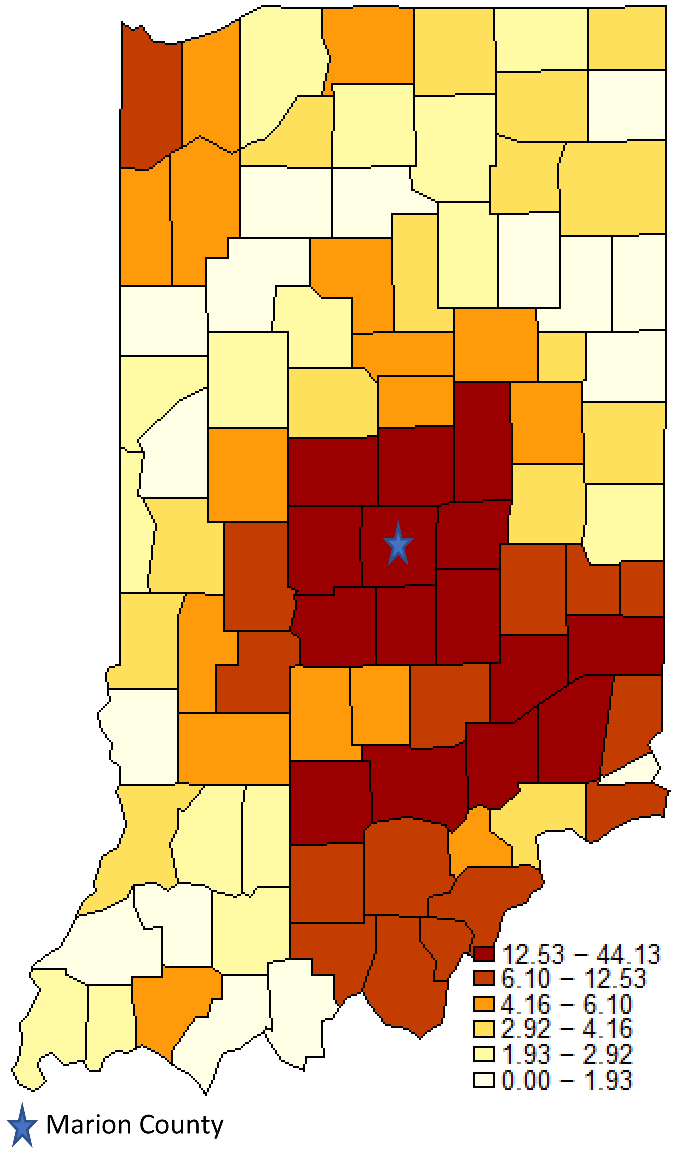

Figure 3: County-wise COVID-19 related death rates per 1K population

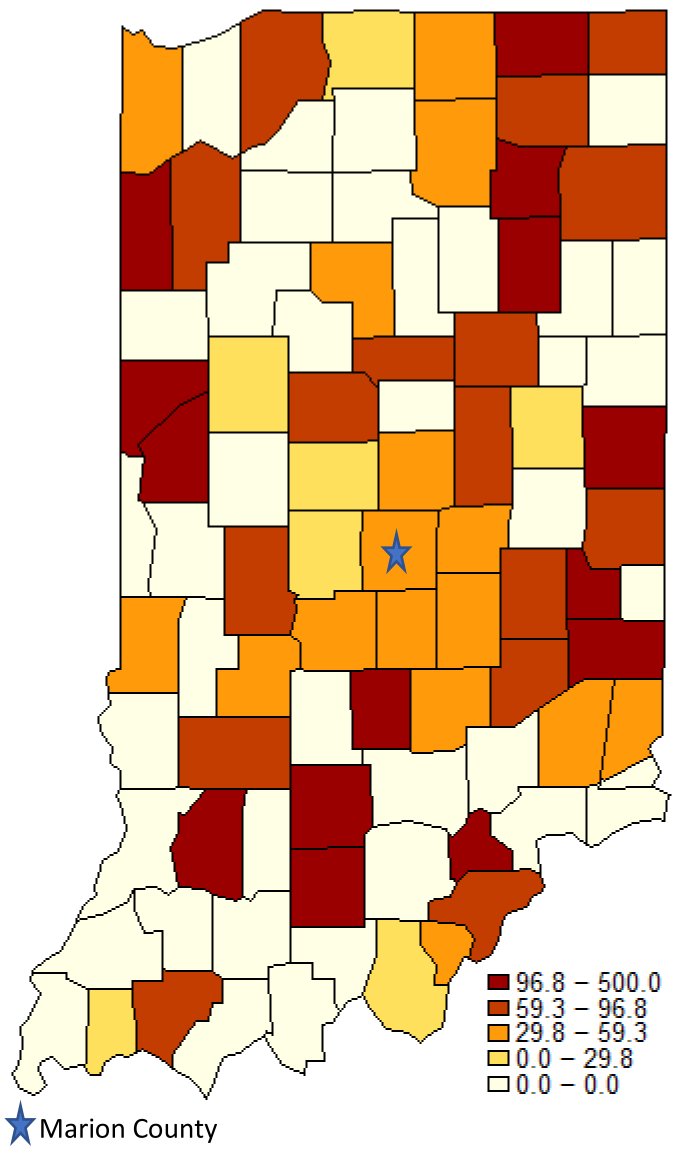

Figure 4: Number of COVID-19 related cases and deaths by the number of laboratory testing reported to Indiana State Health Department (ISDH)