Characterization of population-level risk factors for suicide in US counties

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OBJECTIVES

- To better understand regional patterns of suicide incidence and population risk factors
- Provide data to inform policy and education recommendations on suicide prevention

BACKGROUND

More than 800,000 people die by suicide each year, with 10 to 20 times that many making a suicide attempt.[1] In the United States, suicide is tenth leading cause of death with an annual, age-adjusted mortality of 13.4 per 100,000.[2] This translates to over 45,000 suicide deaths per year or 123 each day. Disturbingly, suicide incidence rose by over 25% between 1999 and 2016. In seven states, it increased by more than 40%.[3] The rate of suicide increases with age and is more common in men, unmarried persons and those with psychiatric disorders, although over half of individuals committing suicide have no known history of mental illness.[4]

There is marked regional variability worldwide in the incidence and predominant methods of suicide. In the US, researchers have proposed various explanations for increased mortality in the nine states of the western "suicide belt," including health status, stigma about mental illness, residential instability, economic conditions, access to methods and environmental factors such as population density and altitude.[5-7]

Interrelationships of causative factors may vary by location and be inadequately characterized by a single, or global, model applied to large geographic regions.[8] Geographically weighted regression (GWR) is an analytic technique that describes local relationships between population or environmental factors and outcomes. It has been applied to research questions in public health but has not – to our knowledge – been used to study the epidemiology of mental illness. In this study, we utilized global (i.e. multiple linear regression) and local analytic methods to explore relationships between population characteristics and rates of suicide.

METHODS

To better understand regional patterns of suicide incidence and potential population risk factors, we mapped US suicide mortality at the county level and analyzed its relationship to demographic, environmental, economic and health indicators.

Unit of analysis: US counties

Outcome variables: Mean, annual, age-adjusted suicide rates, 2007-2016 (all-cause, firearms, hanging, medication overdose).[9]

Map variables: Mean, annual, crude suicide rates (1999-2016)[9]

Independent variables

Population factors

- Population size and density[10]
- Altitude – Elevation data for the US[11] was merged with geospatial coordinate data for zip code tabulation areas (ZCTAs), and an altitude variable calculated using the average of the altitude for all ZCTAs in a county[10]

Sociodemographic factors

- Race/ethnicity: White, Black, Asian, Native American/Alaskan Native and Hispanic persons as a percentage of population[10]
- Educational attainment – Percent without a high school diploma or not attending a 4-year college[12]
- Unemployed, % adults[10]
- Individuals below poverty level, %[10]
- Social association rate, per 100,000[12]
- Heavy drinking past month, % adults[12]
- Cigarette smoking, % adults[12]
- Mortality due to drug overdose[9]
- Federally licensed firearms dealers (per 100,000)[13]
- Fraction of suicide due to firearms[9]

Health care and access

- Physically unhealthy days past month[12]
- Mentally unhealthy days past month[12]
- Lack of social emotional support, % adults[12]
- No health insurance, %[10]
- Primary care physician ratio[12]
- Mental health care provider ratio[12]

Data analysis

Bivariate correlation – Comparisons of population variables and suicide rates. Independent variable/ suicide rate comparisons yielding R ≥ 0.2 or ≤ -0.2 and p < 0.05 and were incorporated in regression analysis.

Ordinary least squares regression – Exploratory regression analyses were conducted to determine which independent variables produced best model fit.

Geographically weighted regression was performed on data from three regions of the US: Southeastern region, northern tier states of the Midwest and northeast, and the Intermountain west (the "suicide belt"[7])

Table 1. *Descriptive statistics*

Variable	Mean	Min	Max	N
Suicide rates, age-adjusted per 100,000				
All causes[1]	16.1	5.0	99.3	2,254
Firearms[2]	9.4	0.5	55.2	1,847
Hanging, strangulation or suffocation[3]	4.1	1.5	55.9	886
Poisoning by medication or alcohol[4]	2.0	0.4	9.1	514
Geographic data				
Population	99,360	87	9,933,534	3,105
Population density	262.6	0.0	70,566.7	3,102
Altitude, population-adjusted	1,085.2	-1.2	11,546.8	3,048
Sociodemographic data				
White	83.1	2.7	99.2	3,102
Black/African American	8.7	0.0	85.7	3,102
Asian	1.1	0.0	43.9	3,102
Native American/Alaska Native	2.0	0.0	96.0	3,102
Hispanic/Latino	8.3	0.0	95.7	3,055
Individuals below poverty level, %	16.8	3.2	50.1	3,101
Did not graduate high school (of students who entered, %)	17.2	0.0	86.0	2,850
No college degree, % adults (25 and over)	45.9	9.4	81.5	2,860
Unemployed, % adults	7.3	0.9	27.7	3,099
Social association rate	13.8	0.0	82.5	3,100
Fraction of suicides due to firearms (proportion)	0.61	0.08	1	2,455
Federally licensed firearms dealers, per 100,000	2.9	0.0	24.5	2,576
Drug overdose mortality, per 100,000[5]	14.2	1.1	81.6	1,710
Health care and access				
Self-reported health status fair or poor, % adults	17.3	4.4	50.8	2,718
Physically unhealthy days past month, adults, age-adjusted	3.8	1.1	10.0	2,784
Mentally unhealthy days past month, adults, age-adjusted	3.6	1.0	10.1	2,569
Heavy drinking, % adults, age-adjusted	16.5	3.2	56.2	2,210
Smoking, % adults	21.3	3.1	51.1	2,692
Social/emotional support lacking, % adults	19.0	0.0	100.0	2,415
No health insurance, %	17.6	2.9	41.6	3,099
Primary care physician ratio (persons/physician)	2,808	218	17,377	2,750
Mental health provider ratio (persons/provider)	9,887	304	89,701	2,760

[1]ICD-10 codes X60-84
[2]ICD-10 codes X72-74
[3]ICD-10 code X70
[4]ICD-10 codes X60-65
[5]ICD-10 codes X40-X44, Y10-Y14

Table 2. *Correlation matrix[1] – suicide rates and population variables*

Population variable	Correlation coefficients: Population variable and suicide rate[2] All-cause	Firearms	Hanging	Medications/ alcohol
Population density	-0.605[3]	-0.682[3]	-0.620[3]	-0.483[3]
Population size	-0.532[3]	-0.698[3]	-0.561[3]	-0.470[3]
Altitude	0.450[3]	0.334[3]	0.353[3]	0.421[3]
White, %	0.150[4]	0.284[3]	0.172[4]	0.342[4]
Black, %	-0.429[3]	-0.321[3]	-0.588[3]	-0.401[3]
Asian, %	-0.412[3]	-0.643[3]	-0.561[3]	-0.431[3]
Native American/Alaska Native, %	0.312[3]	0.133[4]	0.252[4]	0.060
Hispanic/Latino, %	-0.148[4]	-0.326[3]	-0.275[4]	-0.290[4]
Individuals below poverty level, %	0.204[3]	0.259[3]	0.334[3]	0.150
Unemployed, % adults	0.058	0.089	0.093	0.009
Did not graduate high school (students who entered, %)	0.085	0.080	0.108	-0.023
No college degree, % adults (25 and over)	0.310[3]	0.437[3]	0.472[3]	0.165
Federally licensed firearms dealers, per 100,000	0.557[3]	0.618[3]	0.536[3]	0.495[3]
Fraction of suicides due to firearms (FSS)	0.338[3]	0.787[3]	-0.127[3]	0.228[3]
Self-reported health status fair or poor, % adults	0.157[4]	0.308[3]	0.226[4]	0.092
Physically unhealthy days/month, adults, age-adjusted	0.253[3]	0.366[3]	0.272[4]	0.212[5]
Mentally unhealthy days/month, adults, age-adjusted	0.223[3]	0.320[3]	0.222[4]	0.184
Heavy drinking, % adults, age-adjusted	-0.036	-0.221[3]	0.184[5]	-0.050
Smoking, % adults	0.376[3]	0.458[3]	0.549[3]	0.306[4]
Mortality due to drug overdose (MDO), per 100,000	0.418[3]	0.357[3]	0.304[3]	0.332[3]
Social/emotional support lacking, % adults	0.103[5]	0.085	0.169[5]	-0.109
Social association rate	0.031	0.161[4]	0.106	0.266[4]
No health insurance, %	0.342[3]	0.376[3]	0.170[5]	0.030
Primary care physician ratio (persons/physician)	0.122[5]	0.278[3]	0.155	0.022
Mental health provider ratio (persons/provider)	0.238[3]	0.369[3]	0.394[3]	0.262[3]
Preventable hospitalization rate	0.178[3]	0.287[3]	0.285[3]	0.061
Physician use delayed due to cost, age-adjusted %	0.235[3]	0.411[3]	0.190[5]	0.100

[1] Pearson correlation coefficients; bivariate correlations performed using mean, age-adjusted suicide rates for years 2007-2016.
[2] Non-normally distributed variables were transformed using the natural logarithm or square root with additional arithmetic transformations as needed; for some variables, a two-step transformation was performed (as described by Templeton[18]).
[3]$p < 0.001$, [4]$p < 0.01$, [5]$p < 0.05$ (two-tailed significance); statistically significant results bolded.

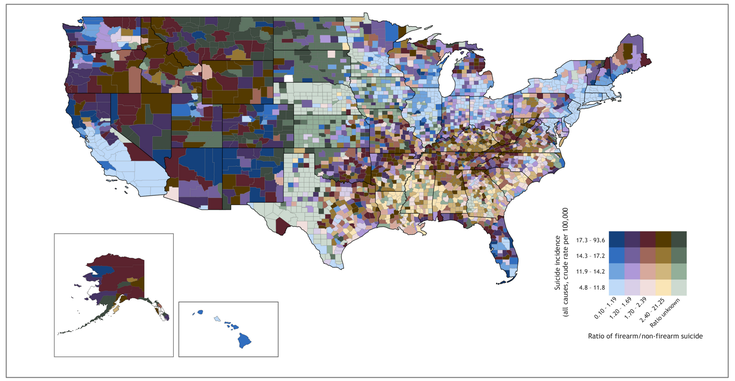

Figure 1. *County suicide rates, 1999-2016.* Bivariate map of suicide incidence (crude rates, all cause suicide, N=2,870) and ratio of firearm to non-firearm suicide (N=2,157). Quartiles of firearm to non-firearm suicide ratios are indicated by color, with brown corresponding higher relative rates of firearm suicide and blue to lower relative rates. Darker shades indicate counties in higher quartiles for crude rate of all-cause suicide. Counties for which ratios could not be calculated due to unavailability of county-level data on firearm suicide are shown in green (N=978). Of these, 713 counties provided data on crude rates of all-cause suicide; rates for the other 265 counties are imputed using statewide data.

Table 3. *Ordinary least squares and geographically weighted regression analysis of all-cause and firearm suicide in 3 regions of the US*

	Dependent variable	Ordinary least squares regression[5] Overall model[4]	Explanatory variables	β	p-value	Globally weighted regression[5] Overall model	Explanatory variables
Western Region[1]	All-cause suicide	Adj. R^2 = 0.435	Altitude	0.436	<0.001	Adj. R^2 = 0.402	Drug overdose mortality
			FSS	0.353	<0.001		Federally licensed firearms dealers
			Mentally unhealthy days	0.332	<0.001		Mentally unhealthy days
			Physically unhealthy days	0.239	<0.001		Physically unhealthy days
	Firearm suicide	Adj. R^2 = 0.714	Population density	-0.274	<0.001	Adj. R^2 = 0.655	Population density
			FSS	0.626	<0.001		FSS
			Mentally unhealthy days	0.190	<0.001		Mentally unhealthy days
Northern Region[2]	All-cause suicide	Adj. R^2 = 0.611	FSS	0.615	<0.001	Adj. R^2 = 0.661	FSS
			Heavy drinking, % adults	0.231	<0.001		Heavy drinking, % adults
			Drug overdose mortality	0.201	<0.001		Drug overdose mortality
			Smokers, % adults	0.145	<0.002		Smokers, % adults
	Firearm suicide	Adj. R^2 = 0.872	FSS	0.652	<0.001	Adj. R^2 = 0.888	FSS
			Heavy drinking, % adults	0.067	<0.005		Heavy drinking, % adults
			Mentally unhealthy days	0.051	<0.022		
			Population density	-0.300	<0.001		
Southeastern Region[3]	All-cause suicide	Adj. R^2 = 0.345	Drug overdose mortality	0.377	<0.001	Adj. R^2 = 0.424	Drug overdose mortality
			FLFD	0.221	<0.001		FSS
			Smokers, % adults	0.182	<0.001		
			Heavy drinking, % adults	0.154	<0.001		
	Firearm suicide	Adj. R^2 = 0.558	FSS	0.605	<0.001	Adj. R^2 = 0.500	FSS
			Mentally unhealthy days	0.092	<0.025		Mentally unhealthy days
			Heavy drinking, % adults	0.145	<0.001		

OLS=ordinary least squares, GWR=geographically weighted regression, β = standardized coefficient, Adj. R^2=adjusted R^2

[1]Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming

[2]Connecticut, Delaware, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, Wisconsin

[3]Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, North Carolina, South Carolina, Tennessee, Virginia, West Virginia

[4]All OLS regression models demonstrated spatial autocorrelation of residuals, indicating that a significant independent variable is missing from the regression equation. This may be a variable influenced by an underlying spatial process not reflected in other model predictors.

[5]Overall regression models and corresponding explanatory variables presented in the table are those with the best model fit. In addition to adjusted R2 values, regression models were assessed with regression diagnostics: for OLS regression - assessment of residual distributions using scatter, histogram and probability (Q-Q) plots; corrected Akaike Information Criterion (AICc) value, a measure of relative model performance; variance inflation factor (VIF), a measure of multicollinearity; the Jarque-Bera statistic (JB statistic), which assesses normality of residual distributions; and Moran's I testing of standardized residuals to evaluate for the presence of spatial autocorrelation; and for GWR – AIC_C, JB statistic.

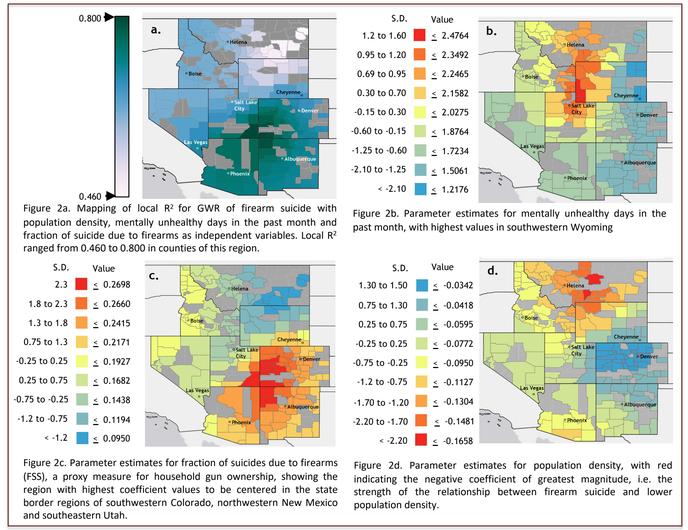

Figure 2a. Mapping of local R^2 for GWR of firearm suicide with population density, mentally unhealthy days in the past month and fraction of suicide due to firearms as independent variables. Local R^2 ranged from 0.460 to 0.800 in counties of this region.

Figure 2b. Parameter estimates for mentally unhealthy days in the past month, with highest values in southwestern Wyoming

Figure 2c. Parameter estimates for fraction of suicides due to firearms (FSS), a proxy measure for household gun ownership, showing the region with highest coefficient values to be centered in the state border regions of southwestern Colorado, northwestern New Mexico and southeastern Utah.

Figure 2d. Parameter estimates for population density, with red indicating the negative coefficient of greatest magnitude, i.e. the strength of the relationship between firearm suicide and lower population density.

Figure 2. *Mapping of globally weighted regression of firearm suicide for states in the western region of the US*

SUMMARY AND CONCLUSIONS

- The results of this analysis support the contribution of psychological distress and access to methods of self-harm to the population risk of suicide.
- Also, the findings support previous work on the risk conferred by poor physical health, the potential effects of smoking and the role of adverse economic circumstances – the latter as reflected in the rate of drug overdose deaths, which has been proposed as a proxy for cumulative economic burden.[5]
- Standard regression methods were confounded by unmeasured factors, possibly reflecting a variable (or variables) influenced by spatial processes
- Geographically weighted regression permits visualization of the geographic patterns of variable relationships, and identification of potential "hot spots" for the association of certain population characteristics with suicide occurrence
- Analytic methods that consider geospatial factors have the potential to inform further research and guide local implementation of policy on suicide prevention.

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