Spatial and Spatio-temporal Epidemiology 47 (2023) 100607

Contents lists available at ScienceDirect

Spatial and Spatio-temporal Epidemiology

journal homepage: www.elsevier.com/locate/sste

Evaluating co-occurring space-time clusters of depression and suicide-related outcomes before and during the COVID-19 pandemic

Sophia C. Ryan [a,*], Michael R. Desjardins [b], Jennifer D. Runkle [c], Luke Wertis [a], Margaret M. Sugg [a]

[a] Department of Geography and Planning, Appalachian State University, Boone NC, 28607, USA
[b] Department of Epidemiology & Spatial Science for Public Health Center, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, 21205, USA
[c] North Carolina Institute for Climate Studies, North Carolina State University, Raleigh NC, 27695, USA

A R T I C L E I N F O

Keywords:
Mental health
Cluster analysis
COVID-19
SaTScan
Depression
Self-injury
Self-harm

A B S T R A C T

Rapidly emerging research on the mental health consequences of the COVID-19 pandemic shows increasing patterns of psychological distress, including anxiety and depression, and self-harming behaviors, particularly during the early months of the pandemic. Yet, few studies have investigated the spatial and temporal changes in depressive disorders and suicidal behavior during the pandemic. The objective of this retrospective analysis was to evaluate geographic patterns of emergency department admissions for depression and suicidal behavior in North Carolina before (March 2017-February 2020) and during the COVID-19 pandemic (March 2020 - December 2021). Univariate cluster detection examined each outcome separately and multivariate cluster detection was used to examine the co-occurrence of depression and suicide-related outcomes in SatScan; the Rand index evaluated cluster overlap. Cluster analyses were adjusted for age, race, and sex. Findings suggest that the mental health burden of depression and suicide-related outcomes remained high in many communities throughout the pandemic. Rural communities exhibited a larger increase in the co-occurrence of depression and suicide-related ED visits during the pandemic period. Results showed the exacerbation of depression and suicide-related outcomes in select communities and emphasize the need for targeted and sustained mental health interventions throughout the many phases of the COVID-19 pandemic.

1. Introduction

The COVID-19 pandemic has been linked to a global mental health crisis (Hamza Shuja et al., 2020; Nochaiwong et al., 2021; Olff et al., 2021; Torales et al., 2020). Rapid disruptions to daily life have led to an unprecedented rise in poor mental health (Larsen et al., 2021; McGinty et al., 2020). In the initial months of the pandemic, suicide rates decreased (Larson and Bergmans, 2022; Pirkis et al., 2021), following a steady increase over the last two decades (Shiels et al., 2020). However substance abuse (Czeisler, 2020), anxiety and depression (Czeisler, 2020; Runkle et al., 2022; Xiong et al., 2020), suicide-related outcomes (Czeisler, 2020; Runkle et al., 2022; Veldhuis et al., 2021), stress (McKnight-Eily et al., 2021; Runkle et al., 2022), distress (Holingue et al., 2020; McGinty et al., 2020), and post-traumatic stress disorder (Liu et al., 2020; Olff et al., 2021) increased during the lockdown and stay at home orders.

Poor mental health during the pandemic has been more pronounced among vulnerable individuals (Lee and Singh, 2021; Runkle et al., 2021; Thomeer et al., 2022), including older adults (Pearman et al., 2022), Black (Pearman et al., 2022), low-income (Lee and Singh, 2021), and Hispanic individuals (Lee and Singh, 2021; Runkle et al., 2021), and LBGTQ youth (Fish et al., 2020; Ormiston and Williams, 2022; Salerno et al., 2020). Emerging evidence suggests that the disparity in reporting poor mental health also increased during the pandemic, with low-income, Hispanic, and individuals with lower educational attainment reporting higher rates of poor mental health (Lee and Singh, 2021).

Despite research examining mental health disparities during COVID-19, little research has examined the spatial clustering or concentrations of adverse mental health outcomes during the pandemic. Mental health and suicide clusters are locations with higher-than-expected case counts based on population (Gould and Lake, 2013). Clusters can form as a result of shared community-level exposures (Gould et al., 1994), such as rurality (Graves et al., 2020; Guo et al., 2019; Sugg et al., 2022), racial segregation (Sugg et al., 2022) and greenspace access (Beyer et al., 2014;

* Corresponding author.
E-mail address: ryansc@appstate.edu (S.C. Ryan).

https://doi.org/10.1016/j.sste.2023.100607
Received 14 November 2022; Received in revised form 8 June 2023; Accepted 14 July 2023
Available online 22 July 2023

Collins et al., 2020). The identification of mental health clusters can provide important information regarding the spatial and spatiotemporal distribution of heightened community mental health burdens throughout the pandemic.

The objective of this retrospective analysis was to examine spatio-temporal trends in mental health clustering for depression and suicide-related (self-injury and self-poisoning) emergency department (ED) admissions in North Carolina (NC) before (March 2017-February 2020) and during (March 2020-December 2021) in the COVID-19 pandemic. A secondary analysis examined the co-occurrence of space-time clusters for depression and suicide-related ED admission to identify regions with the largest burden of mental health. Our results will identify the most at-risk populations and areas in need of more targeted mental health services (Cromley and McLafferty, 2011).

2. Data

Emergency department (ED) data were obtained from the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT) (NC DETECT, 2021) from March 2017 through December 2021. NC DETECT provides complete spatio-temporal coverage of ED visits for 140 EDs in North Carolina (NC DETECT, 2021). For this analysis, duplicate cases were removed, as were cases that did not contain relevant demographic information (age, race, sex). In total, 1252,009 cases were removed out of 23,095,226 cases, representing 5.4% of total ED visits throughout the state of NC, producing a final dataset of 21,843,217 total ED visits from March 2017 to December 2021 (Supplemental Figure 1). Repeat patients were included as we sought to examine the cumulative burden of each mental health outcome.

The primary mental health outcomes of interest were coded using the International Classification of Diseases 10-CM codes (ICD-10) and included: (1) depression (ICD-10: F32-F339, F341) and (2) suicide-related outcomes (ICD-10: R45.85, T14.91, T36.xx2 (4) -T50.xx2 (4), T51.xx2 (4) -T65.xx2 (4), T71.xx2 (4), X71-X83). Suicide-related outcomes included ED visits for intentional self-harm, self-poisoning and toxic effects, suicidal ideation, and asphyxiation (Ridout et al., 2021). ED visits for each outcome were summed by month for each zip code. Patient billing zip code is provided in the ED data and is used as a proxy for residential location.

The unit of analysis was the zip-code tabulation area (ZCTA) level, with individual ED data converted from the zip code to ZCTA when applicable (AAFP, 2022). ZCTA is the finest spatial resolution available for this dataset. ZCTAs are US Census Bureau spatial geographies corresponding to US Postal Service zip codes; in NC, there are 802 ZCTAs, with an average population of 12,663 individuals (US Census Bureau, 2020). ZCTAs are more sensitive to clustering than larger geographic scales such as counties (Jones and Kulldorff, 2012).

3. Methods

We applied the retrospective univariate and multivariate space-time scan statistics (Kulldorff, 1997; Kulldorff et al., 2007) in SaTScan™ (V10.0 64 bit) to identify statistically significant space-time clusters of depression and suicide-related outcomes pre-COVID-19 pandemic (March 2017 to February 2020) and during the COVID-19 pandemic (March 2020 to December 2021). We utilized the discrete Poisson probability model, where observed cases are assumed to be Poisson distributed according to the at-risk population in North Carolina. The null hypothesis states that the model reflects an inhomogeneous Poisson process proportional to the at-risk population. Our alternative hypothesis states that the number of cases exceeds the number of expected cases derived from the null model. To better understand mental health clustering, we adjusted for the individual-level factors, including age, race, and sex, allowing for the detection of clustering that cannot be explained by these variables alone (Brotto et al., 2021; Kim and Kim, 2017). For this study, our expected cases were derived from Quasi-Poisson regression-fitted values (Supplemental Table 1) to account for overdispersion and adjust for patient age, race, and sex:

$$Y_{ij} \sim QuasiPoisson \tag{1}$$

$$log\ \left[E\left(Y_{ij}\right)\right] = \beta_0 + \beta_1 Race_i + \beta_2 Age_i + \beta_3 Sex_i \tag{2}$$

Where Y_{ij} was the observed depression or suicide-related outcome count in ZCTA i and month j, $E(Y_{ij})$ was the expected depression or suicide-related outcome count in ZCTA i and month j, which was adjusted for race, age, and sex as noted in Eq. (2). An adjusted SaTScan analysis was conducted using the regression-fitted values as the expected counts of depression or suicide-related outcomes.

A maximum likelihood ratio test statistic was utilized to evaluate hypotheses, which is defined in Eq. (3) below:

$$\frac{L(Z)}{L_0} = \frac{\left(\frac{y_Z}{E(Z)}\right)^{y_Z}\left(\frac{Y-y_Z}{Y-E_{(Z)}}\right)^{Y-y_Z}}{\left(\frac{Y}{E(A)}\right)^{Y}} \tag{3}$$

Where L(Z) was the likelihood function for cylinder/potential cluster Z, L_0 is the likelihood function for the null hypothesis of cylinder Z (the model reflects an inhomogeneous Poisson process). Parameter yZ is the observed cases in cylinder Z, $E(Z)$ is the expected cases in cylinder Z, Y is the total number of observed cases in the study area across all time periods, and $E(A)$ is the total number of expected cases in the study area across all time periods. Note that the expected cases were either based on population (unadjusted model) or regression-fitted values (for adjusted model), which represent the expected depression or suicide-related cases after adjusting for race, age, and sex. Eq. (3) compared the observed and expected cases within a cylinder to the total number of observed and expected cases outside of the cylinder across the entire study period. The cylinder will have an elevated risk of the log-likelihood ratio (LLR) is greater than 1, where $\frac{yz}{E(Z)} > \frac{Y-yz}{Y-E(Z)}$. Next, 999 Monte Carlo simulations were produced to determine the statistical significance of each potential cluster. Essentially, the statistic utilized moving cylinders to scan the study area and specified time period for space-time clusters of cases, where the base of the cylinder is the spatial scan, and the height is the temporal scan. Each cylinder was centered on the centroid of a particular ZCTA and expanded until a maximum spatial and temporal threshold was reached, where each cylinder was a potential cluster. In other words, a very large number of cylinders were generated around each ZCTA until the maximum spatial and temporal scanning windows were reached.

The multivariate space-time scan statistic determined the co-occurrence (simultaneous excess incidence) of both depression and suicide-related outcomes. The procedure was the same as the univariate statistic, where LLRs were determined separately for both outcomes in each cylinder, then the multivariate statistics summed the LLRs to produce a new LLR for that particular cylinder.

For both univariate and multivariate analyses, the maximum spatial scan was set to 10% of the at-risk population, the minimum temporal scan (i.e., cluster duration) was set to one month and the maximum temporal scan was restricted to 12 months (Larkin et al., 2010; Milner et al., 2018), with a minimum number of cases set at 10. We rejected the null hypothesis (significant clustering) at $p<0.05$.

To compare the univariate suicide and depression cluster locations and multivariate cluster locations pre-pandemic and during the pandemic, we examined the similarity between the clusters using the Rand Index from the fossil package (Vavrek, 2020) in RStudio version 2022.07.1 (RStudio Team, 2022). The Rand index is calculated as:

$$R = (a+b)/(nC2) \tag{4}$$

Where a was the number of times a pair of ZCTAs belong to a significant space-time cluster, b was the number of times a pair of ZCTAs belong to different clusters, and nC_2 is the number of unordered pairs in a set of *n* ZCTAs. The Rand index was constrained between 0 and 1, where 0 indicated no similarity between clusters and 1 indicated perfect similarity between the clusters (e.g., the same number of ZCTAs belonging to a cluster in both suicide and depression).

To determine if clusters shifted towards more rural or urban areas during the pandemic, we calculated the percentage of rural ZCTAs and urban ZCTAs identified in the univariate and multivariate clusters. Rurality was based on Rural-Urban Commuting Area (RUCA) Codes. RUCA codes 1–3 were considered urban, and codes 4–10 were considered rural (USDA, 2020).

4. Results

4.1. Descriptive statistics

Table 1 summarizes the demographic characteristics of all ED visits for depression and suicide-related outcomes for the pre-pandemic (March 2017 - February 2020) and pandemic periods (March 2020 - December 2021). During the pandemic, more males (1.7% increase), White individuals (4.1% increase), and Other Race individuals (0.6% increase), and fewer Black individuals (4.5% decrease) visited the ED for depression-related concerns. Depression ED visits declined in the months before the COVID-19 pandemic, before increasing in the initial months of the pandemic. In the latter part of the pandemic study period, depression ED monthly visits declined, with the lowest monthly cases reported in December 2021 (Supplemental Figure 2).

More White individuals (4.2% increase), Other Race individuals (0.8% increase), and adolescents (ages 10–19, 0.8–1.6% increase), and fewer Black individuals (5.7% decrease) visited the ED for suicide-related outcomes during the pandemic. Suicide-related ED visits varied throughout the study periods and increased in December 2021 (Supplemental Figure 2).

4.2. Univariate clustering analysis for depression

In the pre-pandemic period univariate SaTScan identified 26 spatiotemporal depression clusters affecting 201 ZCTAs (Fig. 1) (Supplemental Table 2). During the pandemic, univariate cluster analysis identified 20 spatiotemporal depression clusters affecting 268 ZCTAs.

Overall, during the pandemic, the relative risks for depression clusters were higher ($RR_{pandemic}$=4.46 vs. $RR_{pre\text{-}pandemic}$=4.05), and clusters were spatially larger as compared to pre-pandemic depression clusters. More ZCTAs were included in pandemic clusters ($n = 67$ more), than in the pre-pandemic period. Western NC was identified as the most likely cluster location, both before and during the pandemic, and clustering was prevalent in major urban areas, including Asheville, Charlotte, and Greensboro. More rural ZCTAs were identified in clusters during the pandemic, compared to before (11.6% higher) (Supplemental Table 3). Temporally, both before and during the pandemic, most clusters were persistent for 12 months (Supplemental Figure 3). During the pandemic, western and eastern North Carolina saw substantial increases in ZCTA-level risk for depression clustering, with some ZCTAs seeing over a 5% increase in risk (Fig. 2).

4.3. Univariate clustering analysis for suicide-related outcomes

In the pre-pandemic period univariate SaTScan identified 25 spatio-temporal suicide-related outcome clusters impacting 140 ZCTAs (Fig. 3) (Supplemental Table 4). During the pandemic, SaTScan identified 22 spatio-temporal suicide-related outcome clusters affecting 165 ZCTAs.

Table 1
Demographic characteristics of depression and suicide-related (intentional self-harm, self-poisoning and toxic effects, suicidal ideation, and asphyxiation) ED visits pre-pandemic and during the pandemic. P-values indicate significant demographic differences between the proportion of visits in the pre compared to pandemic period for each outcome.

	Depression Pre-Pandemic (March 2017-Feb, 2020)	Pandemic (March 2020-Dec, 2020)	P	Suicide-Related Outcomes Pre-Pandemic (March 2017-Feb, 2020)	Pandemic (March 2020-Dec, 2020)	P
n	509,203	185,644		163,771	87,612	
Average Monthly Visits	14,144.53	8438.36		4549.19	3982.36	
Sex (%)			<0.001			
Male	178,042 (35.0)	68,187 (36.7)		84,750 (51.7)	45,071 (51.4)	
Female	331,161 (65.0)	117,457 (63.3)		79,021 (48.3)	42,541 (48.6)	
Race (%)			<0.001			<0.001
Indigenous American	6891 (1.4)	2380 (1.3)		2720 (1.7)	1492 (1.7)	
Asian	2656 (0.5)	743 (0.4)		1247 (0.7)	6,37 (0.7)	
Black	105,985 (20.8)	30,346 (16.3)		43,721 (26.7)	18,433 (21.0)	
White	379,685 (74.6)	146,059 (78.7)		108,346 (66.2)	62,202 (71.0)	
Other Race	13,986 (2.7)	6116 (3.3)		7737 (4.7)	4848 (5.5)	
Average Age	50.34	49.74		34.84	34.49	
Age Group (%)			<0.001			<0.001
Under 9	689 (0.1)	171 (0.1)		1402 (0.8)	494 (0.6)	
10–14	11,253 (2.2)	5643 (3.0)		13,105 (8.0)	8367 (9.6)	
15–19	26,203 (5.1)	11,215 (6.0)		22,391 (13.7)	12,691 (14.5)	
20–24	27,786 (5.5)	11,041 (5.9)		18,008 (11.0)	9209 (10.5)	
25–29	31,775 (6.2)	11,644 (6.3)		17,648 (10.8)	8913 (10.2)	
30–34	31,799 (6.2)	12,465 (6.7)		15,060 (9.2)	8739 (10.0)	
35–39	33,345 (6.5)	11,501 (6.2)		14,489 (8.8)	7526 (8.6)	
40–44	34,440 (6.8)	11,691 (6.3)		12,840 (7.8)	6704 (7.7)	
45–49	41,053 (8.1)	12,926 (7.0)		13,048 (8.0)	5822 (6.6)	
50–54	45,236 (8.9)	14,397 (7.8)		12,450 (7.6)	6046 (6.9)	
55–59	47,714 (9.4)	16,510 (8.9)		10,614 (6.5)	5391 (6.2)	
60–64	41,860 (8.2)	15,137 (8.2)		5664 (3.5)	3444 (3.9)	
65–69	37,623 (7.4)	14,000 (7.5)		3217 (2.0)	1890 (2.2)	
70–74	33,025 (6.5)	13,124 (7.1)		1686 (1.0)	1103 (1.3)	
75–79	25,560 (5.0)	10,123 (5.5)		991 (0.6)	610 (0.7)	
80–84	19,184 (3.8)	7004 (3.8)		660 (0.4)	347 (0.4)	
Over 85	20,658 (4.1)	7052 (3.8)		498 (0.3)	316 (0.4)	

***Significant variability at $p<0.001$

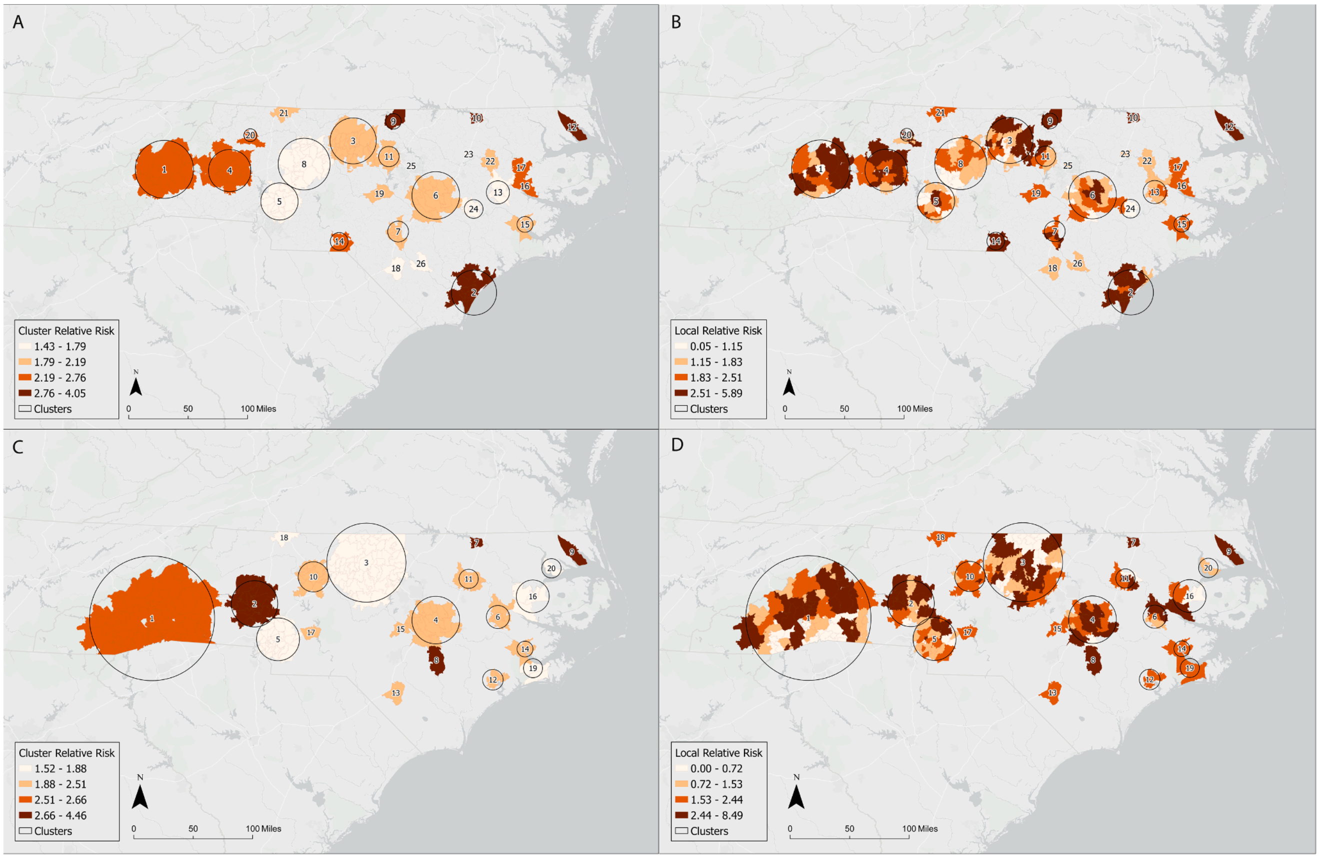

Fig. 1. Univariate depression clusters, pre-pandemic (A & B), and during the pandemic (C & D). Maps highlight cluster locations and cluster relative risk (A & C) and ZCTA (local) relative risk (B & D).

Overall, pre-pandemic, relative risks for suicide-related clustering were slightly higher as compared to during the pandemic ($RR_{pandemic}$=3.78 vs. $RR_{pre\text{-}pandemic}$=3.98). However, cluster location and duration remained similar during the pandemic as compared to before, with most clusters lasting 12 months (Supplemental Figure 4). During the pandemic, more ZCTAs (n = 25 more) were identified in the suicide-related outcome clusters. Before and during the pandemic, the largest clusters were identified near urban areas, with Charlotte, Greensboro and Durham indicating persistent clustering. Smaller clusters, typically affecting only one ZCTA were identified in rural communities, both pre-pandemic and during the pandemic. A moderate increase in the percentage of clusters identified in rural areas was noted during the pandemic compared to before (1.7% higher) (Supplemental Table 3). During the pandemic, many ZCTAs in western and eastern North Carolina experienced an increased risk of suicide-related clustering, with some seeing up to a 9% increase in risk (Fig. 2).

4.4. Co-occurrence of depression and suicide-related clusters

In the pre-pandemic period (March 2017 - February 2020), multivariate SaTScan identified 24 clusters affecting 207 ZCTAs, of these 20 were co-occurring depression and suicide-related outcome clusters (Fig. 4) (Supplemental Table 5). Multivariate pre-pandemic cluster analysis detected similar spatial and temporal clustering patterns as those identified in the univariate depression and suicide-related outcome analyses during the pre-pandemic period. Multivariate cluster analyses highlighted western NC as the primary cluster location.

During the pandemic (March 2020 - December 2021), 23 multivariate retrospective clusters were identified, affecting 291 ZCTAs (Supplemental Table 5). Of these clusters, 16 were co-occurring depression and suicide-related outcome clusters. Multivariate cluster analysis during the pandemic found more clusters identified as compared to the univariate depression clustering, and larger clusters as compared to the suicide-related outcome clustering. More multivariate clusters emerged in 2020 than 2021 (Supplemental Figure 5). The primary multivariate cluster identified during the pandemic was located in western NC. In line with findings from univariate clusters, more rural ZCTAs were identified in multivariate clusters during the pandemic (24.4%) as compared to before (17.9%) (Supplemental Table 3).

4.5. Rand index

Univariate suicide-related outcome cluster locations were the most similar pre-pandemic and during the pandemic (Rand: 0.79), though the multivariate clusters (Rand: 0.62) and univariate depression (Rand: 0.61) cluster locations also exhibited spatial cluster overlap (Supplemental Table 6).

5. Discussion

The aim of this study was to examine the spatiotemporal clustering of depression and suicide-related outcomes before and during the COVID-19 pandemic in North Carolina from 2017 to 2021. All three cluster analyses suggest poor mental health outcomes are pervasive during the ongoing public health response to the pandemic. Our results highlight that many locations have co-occurring mental health clusters, suggesting high mental health burdens among select populations. More rural communities were identified in clusters during the pandemic, as compared to before. Furthermore, the identification of primary depression and suicide-related co-occurrence in western North Carolina highlights a predominately rural population in immediate need of additional mental health resources during the pandemic and

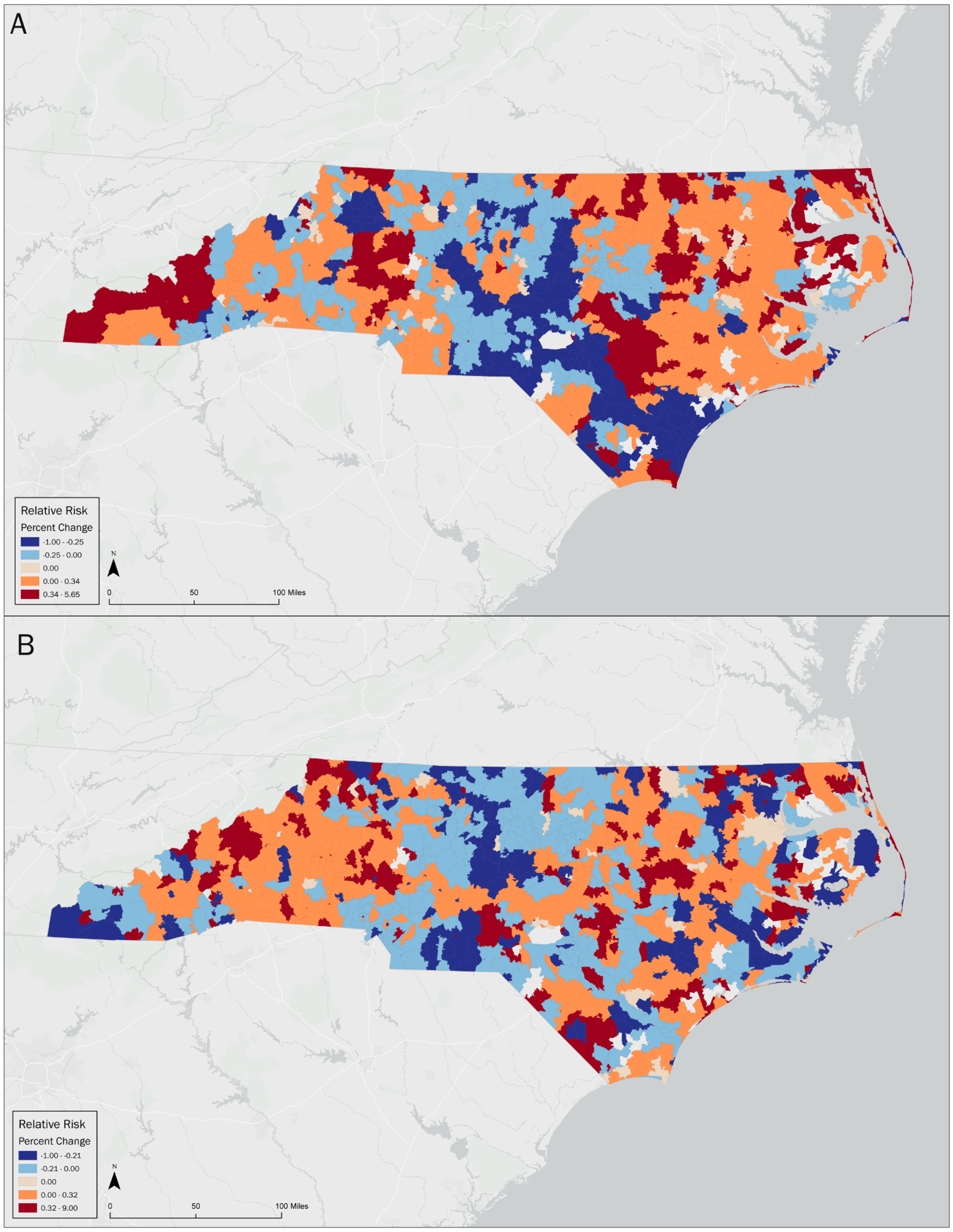

Fig. 2. Percent change in relative risk for (A) depression clusters, and (B) suicide-related clusters, during the COVID-19 pandemic as compared to before the COVID-19 pandemic.

corroborates past research which has also identified western NC as location with high mental health burden (Martin et al., 2010; Sugg et al., 2022).

Depression cluster analysis revealed that many depression clusters emerged in the early response to the COVID-19 pandemic (March-October 2020), with cluster duration extending through September 2021. The co-occurrence of depression and suicide-related outcome clusters showed that depression clusters emerged until January 2021 and extended through December 2021, suggesting heightened depression-related mental health burden during the pandemic. Depression clustering during the pandemic period may be attributed to pandemic-related stressors and events, with prior research illustrating increases in depression early in the pandemic (Czeisler, 2020; Runkle et al., 2022; Xiong et al., 2020), and sustained increases in depression through December 2020 (Lee and Singh, 2021; Thomas et al., 2021; Vahratian, 2021).

Despite observed decreases in monthly depression ED visits and cases may have decreased statewide, specific locations, including western North Carolina, Charlotte, Greensboro, and many rural ZCTAs in eastern North Carolina, continued to show sustained mental health burden; with more clusters identified in rural ZCTAs during the pandemic as compared to before. The Rand Index also suggests that locations vulnerable to depression clustering changed somewhat during the pandemic, as compared to before, highlighting the need for frequent mental health assessments across different temporal periods. Furthermore, more communities were identified in depression clusters (n = 469) compared to suicide-related clusters (n = 305), and depression clusters occurred in urban, rural, wealthy, and poor communities, highlighting the pervasive nature of depression.

During the pandemic study period, suicide-related outcome clusters emerged through April 2021 and lasted through at least December 2021, suggesting a concerning sustained mental health burden relating to intentional self-harm, self-poisoning and toxic effects, suicidal ideation, and asphyxiation that may be attributed to the COVID-19 pandemic.

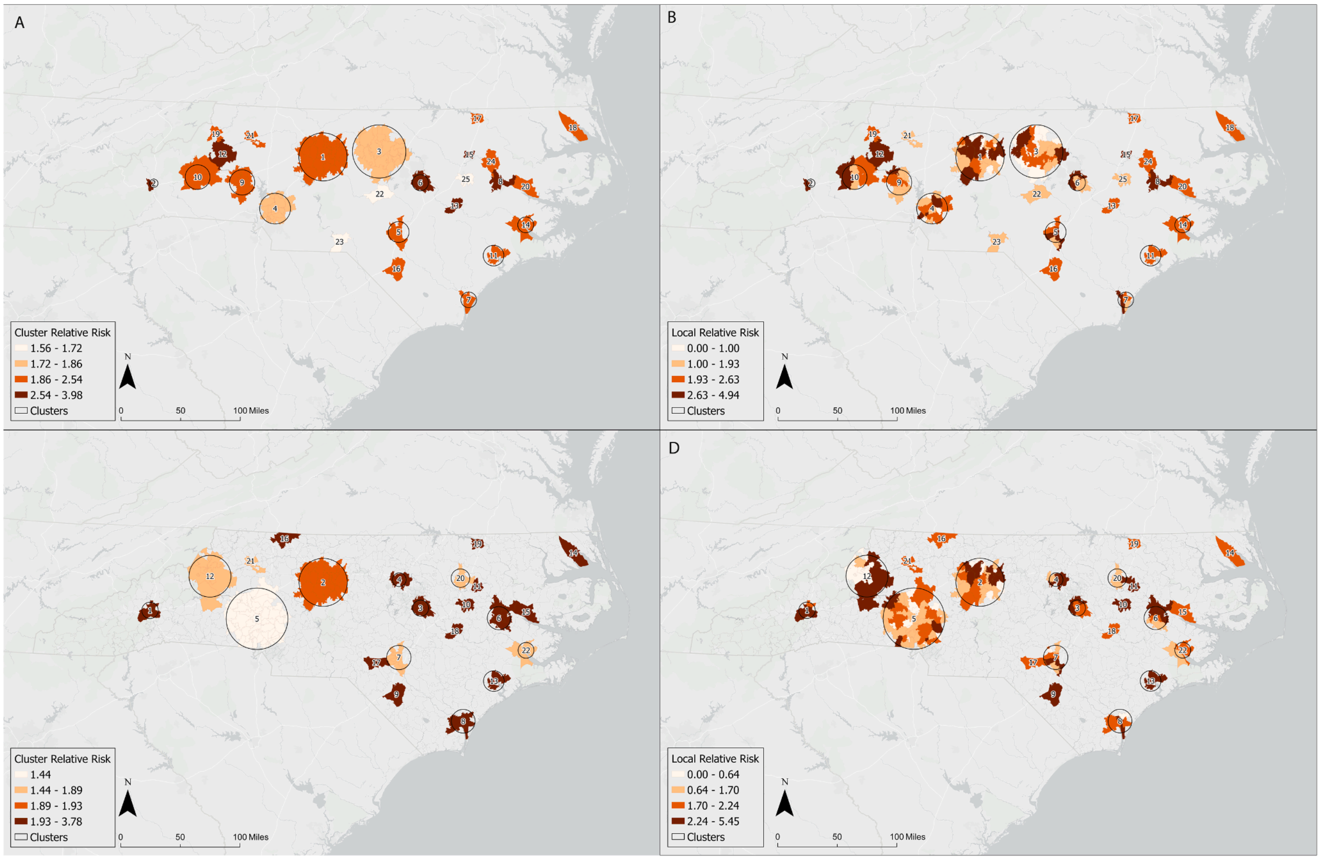

Fig. 3. Univariate suicide-related outcome clusters, pre-pandemic (A & B), and during the pandemic (C & D). Maps highlight cluster locations and cluster relative risk (A & C) and ZCTA (local) relative risk (B & D).

Prior long-term suicide-related outcome research during the COVID-19 pandemic found increases in suicide-related outcome ED visits among female youth through December 2020 (Ridout et al., 2021) and among the general population through October 2020 (Holland et al., 2021). Our cluster analyses support these past findings, with more suicide-related outcome clusters emerging in the later months of the pandemic (e.g., July 2020-April 2021) as compared to the early months of the pandemic (e.g., March 2020-June 2020), with the highest risk cluster emerging in January 2021.

Results from the Rand Index illustrate that locations vulnerable to suicide-related outcome clustering remained stable throughout the study period. These results stress the importance of mental health interventions in these vulnerable locations, with additional attention needed in western North Carolina, as it was identified as the primary cluster in all suicide-related cluster analyses. Western North Carolina is a region with heightened rural health disparities, facing unique transportation issues, limited access to mental health care, poor social determinants of health (high child poverty, high proportion of elderly, and an ongoing opioid epidemic), and above average behavioral health disorders (MAHEC, 2022). Western NC was identified as the primary cluster for the co-occurrence of depression and suicidality, highlighting the unique vulnerability of this location. Our work supports previous studies that have also identified mental health clustering in western NC prior to the pandemic period (Amin et al., 2022; Ryan et al., 2022; Sugg et al., 2022).

The Rand Index revealed that multivariate cluster locations remained somewhat stable, though not as stable as the suicide-related outcome clusters, suggesting some of the locations vulnerable to co-occurring clustering may have changed during the pandemic as compared to before.

5.1. Strengths and limitations

This analysis is strengthened because of the fine scale spatial and longer temporal nature of ED visit dataset from NC DETECT that provides statewide coverage of mental health at a sub-county spatial scale. Secondly, the use of standardized mortality ratios to calculate expected cases, based on actual case count, race, sex, and age, which were used as population values for SaTScan analysis, illustrates that clustering cannot be explained by these demographic factors alone. Additionally, the inclusion of the Rand Index highlights the stability of clustering, providing important information (e.g. suicide-related outcome clusters were the most stable) for mental health care. Finally, the application of both univariate and multivariate cluster analyses highlights communities with heightened mental health burdens relating to the co-occurrence of mental health concerns.

This study also has several limitations. First, selection bias may exist in how we defined our mental health outcomes. To mitigate this bias, patients with depression and/or suicide-related outcomes coded as either primary or secondary ICD-10-CM codes were included in this analysis. In addition, data were removed with missing demographic information (approximately 5%), and this removal process may have spatial or temporal bias. Second, mental health ED visits do not include therapy or outpatient care; thus, this analysis did not capture the true burden of depression or suicide-related outcomes. However, as our analysis is focused on ED visits it represents an extremely vulnerable population with limited access to care or knowledge of other mental health resources. Third, like many studies using administrative hospital datasets, we were not able to account for individuals who relocated or moved from 2017 to 2021, yet our analysis of mental health burdens was conducted at the community level. Fourth, our space-time cluster approach utilized fixed scanning window sizes (i.e., cylindrical), which

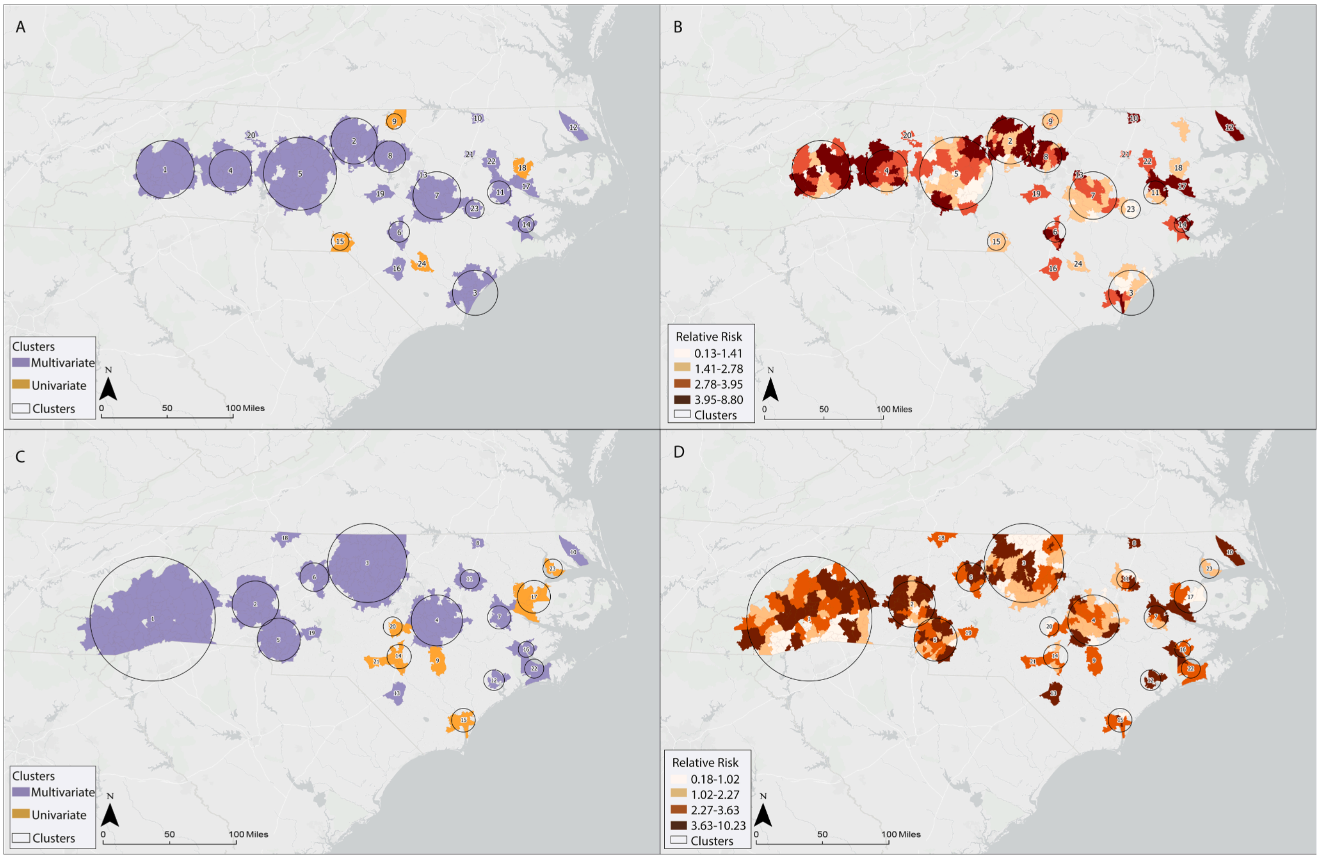

Fig. 4. Multivariate depression and suicide-related outcome cluster pre-pandemic (A & B), and during the pandemic (C & D). Maps highlight cluster locations and whether clusters are univariate or multivariate (A & B), and ZCTA relative risk of combined depression and suicide-related clustering (C & D).

may not capture the "true" shape of the clusters. However, visualizing the RR of each location that belonged to a cluster mitigates this issue by highlighting the highest-risk ZCTAs within each cluster. Future research can adjust for potential accessibility and availability of ED providers. Finally, we acknowledge that the timing of social distancing, quarantines, and other public health mandates and hospital restrictions have varied spatially and temporally, which may have influenced the detection of clusters during the COVID-19 pandemic. Depending on data availability, future research can explicitly account and adjust for spatially- and temporally-varying mandate variables when computing expected cases.

6. Conclusions

To the authors' knowledge, this is the first analysis to consider co-occurring mental health clustering during the COVID-19 pandemic. The inclusion of ED visit data extending through December 2021 provides one of the longest-term mental health and COVID-19 analyses to date. Our results highlight concerning trends in sustained depression and suicide-related outcome clustering, illustrating a prolonged mental health burden for many communities, particularly in western North Carolina. Our results revealed important differences in spatio-temporal depression and suicide-related outcome clustering before and during the COVID-19 pandemic. More rural communities were identified in clusters during the pandemic as compared to before, highlighting the need for additional mental health resources in these rural communities. Findings identified geographically vulnerable locations with mental health burden during the pandemic and can help guide future mental health interventions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Funding information

This work was supported by the Faculty Early Career Development Program (CAREER) award (grant #2044839) from the National Science Foundation, the American Foundation for Suicide Prevention (#SRG-0-160-19), and the National Institute of Environmental Health Sciences (NIEHS) award (grant # 1R15ES033817-01).

Acknowledgements

The North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT) is an advanced, statewide public health surveillance system. NC DETECT is funded with federal funds by the North Carolina Division of Public Health (NC DPH), Public Health Emergency Preparedness Grant (PHEP), and managed through a collaboration between NC DPH and the University of North Carolina at Chapel Hill Department of Emergency Medicine's Carolina Center for Health Informatics (UNC CCHI). The findings and conclusions in this publication are those of the author(s) and do not necessarily represent the views of the North Carolina Department of Health and Human

Services, Division of Public Health.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sste.2023.100607.

References

AAFP. (2022). *ZIP Code to ZCTA Crosswalk*. UDS-Mapper. https://udsmapper.org/zip-code-to-zcta-crosswalk/.

Amin, R., Guttmann, R.P., Rivera-Muñiz, B., Holley, M., Uher, M., 2022. Spatial and space-time clusters of suicides in the contiguous USA (2000–2019). Ann. Epidemiol. 76, 150–157. https://doi.org/10.1016/j.annepidem.2022.07.005.

Beyer, K.M.M., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F.J., Malecki, K.M., 2014. Exposure to neighborhood green space and mental health: evidence from the survey of the health of Wisconsin. Int. J. Environ. Res. Public Health 11 (3), 3453–3472. https://doi.org/10.3390/ijerph110303453.

Brotto, L.A., Chankasingh, K., Baaske, A., Albert, A., Booth, A., Kaida, A., Smith, L.W., Racey, S., Gottschlich, A., Murray, M.C.M., Sadarangani, M., Ogilvie, G.S., Galea, L., 2021. The influence of sex, gender, age, and ethnicity on psychosocial factors and substance use throughout phases of the COVID-19 pandemic. PloS One 16 (11), e0259676. https://doi.org/10.1371/journal.pone.0259676.

Collins, R., Spake, R., Brown, K.A., Ogutu, B., Smith, D., Eigenbrod, F., 2020. *A systematic map of research exploring the effect of greenspace on mental health* [Review]. Landsc. Urban Plan. https://doi.org/10.1016/j.landurbplan.2020.103823.

Cromley, E.K., McLafferty, S.L., 2011. GIS and Public Health, Second Edition. Guilford Press.

Czeisler, M.É., 2020. Mental Health, Substance Use, and Suicidal Ideation During the COVID-19 Pandemic—United States, June 24–30, 2020. MMWR. Morbid. Mortality Wkly. Rep. 69 https://doi.org/10.15585/mmwr.mm6932a1.

Fish, J.N., McInroy, L.B., Paceley, M.S., Williams, N.D., Henderson, S., Levine, D.S., Edsall, R.N., 2020. I'm Kinda Stuck at Home With Unsupportive Parents Right Now": LGBTQ Youths' Experiences With COVID-19 and the Importance of Online Support. J. Adolesc. Health 67 (3), 450–452. https://doi.org/10.1016/j.jadohealth.2020.06.002.

Gould, M.S., Lake, A.M., 2013. The contagion of suicidal behavior. Contagion of Violence: Workshop Summary. National Academies Press, US. https://www.ncbi.nlm.nih.gov/books/NBK207262/.

Gould, M.S., Petrie, K., Kleinman, M.H., Wallenstein, S., 1994. Clustering of attempted suicide: new Zealand national data. Int. J. Epidemiol. 23 (6), 1185–1189. https://doi.org/10.1093/ije/23.6.1185.

Graves, J.M., Abshire, D.A., Mackelprang, J.L., Amiri, S., Beck, A., 2020. Association of Rurality With Availability of Youth Mental Health Facilities With Suicide Prevention Services in the US. JAMA Netw. Open 3 (10), e2021471. https://doi.org/10.1001/jamanetworkopen.2020.21471.

Guo, Y., Chau, P., Chang, Q., Woo, J., Wong, M., Yip, P., 2019. The geography of suicide in older adults in Hong Kong: an ecological study. Int. J. Geriatr. Psychiatry 35. https://doi.org/10.1002/gps.5225.

Hamza Shuja, K., Aqeel, M., 2020. Foundation University Islamabad, Rawalpindi Campus, Islamabad, PakistanShanghai Jiao Tong University, Shanghai, China, Ahmed, A., & Quaid-i-Azam University, Islamabad, Pakistan. (2020). COVID-19 pandemic and impending global mental health implications. Psychiatria Danubina 32 (1), 32–35. https://doi.org/10.24869/psyd.2020.32.

Holingue, C., Kalb, L.G., Riehm, K.E., Bennett, D., Kapteyn, A., Veldhuis, C.B., Johnson, R.M., Fallin, M.D., Kreuter, F., Stuart, E.A., Thrul, J., 2020. Mental Distress in the United States at the Beginning of the COVID-19 Pandemic. Am. J. Public Health 110 (11), 1628–1634. https://doi.org/10.2105/AJPH.2020.305857.

Holland, K.M., Jones, C., Vivolo-Kantor, A.M., Idaikkadar, N., Zwald, M., Hoots, B., Yard, E., D'Inverno, A., Swedo, E., Chen, M.S., Petrosky, E., Board, A., Martinez, P., Stone, D.M., Law, R., Coletta, M.A., Adjemian, J., Thomas, C., Puddy, R.W., Houry, D., 2021. Trends in US Emergency Department Visits for Mental Health, Overdose, and Violence Outcomes Before and During the COVID-19 Pandemic. JAMA Psychiatry 78 (4), 1–8. https://doi.org/10.1001/jamapsychiatry.2020.4402.

Jones, S.G., Kulldorff, M., 2012. Influence of Spatial Resolution on Space-Time Disease Cluster Detection. PLOS ONE 7 (10), e48036. https://doi.org/10.1371/journal.pone.0048036.

Kim, J., Kim, H., 2017. Demographic and environmental factors associated with mental health: a cross-sectional study. Int. J. Environ. Res. Public Health 14 (4), 431. https://doi.org/10.3390/ijerph14040431.

Kulldorff, M., 1997. A spatial scan statistic. Commun. Stat. - Theory Methods 26 (6), 1481–1496. https://doi.org/10.1080/03610929708831995.

Kulldorff, M., Mostashari, F., Duczmal, L., Katherine Yih, W., Kleinman, K., Platt, R., 2007. Multivariate scan statistics for disease surveillance. Stat. Med. 26 (8), 1824–1833. https://doi.org/10.1002/sim.2818.

Larkin, G.L., Beautrais, A.L., Xu, H., 2010. Geospatial mapping of suicide clusters in Cantebury New Zealand. Inj. Prevent. 16 (Suppl 1), A258. https://doi.org/10.1136/ip.2010.029215.918. –A258.

Larsen, L., Helland, M.S., Holt, T., 2021. The impact of school closure and social isolation on children in vulnerable families during COVID-19: a focus on children's reactions. Eur. Child Adolesc. Psychiatry. https://doi.org/10.1007/s00787-021-01758-x.

Larson, P.S., Bergmans, R.S., 2022. Impact of the COVID-19 pandemic on temporal patterns of mental health and substance abuse related mortality in Michigan: an interrupted time series analysis. Lancet Regional Health - Americas 10, 100218. https://doi.org/10.1016/j.lana.2022.100218.

Lee, H., Singh, G.K., 2021. Monthly trends in self-reported health status and depression by race/ethnicity and socioeconomic status during the COVID-19 Pandemic, United States, April 2020 – May 2021. Ann. Epidemiol. 63, 52–62. https://doi.org/10.1016/j.annepidem.2021.07.014.

Liu, C.H., Zhang, E., Wong, G.T.F., Hyun, S., Hahm, H, 2020. Factors associated with depression, anxiety, and PTSD symptomatology during the COVID-19 pandemic: clinical implications for U.S. young adult mental health. Psychiatry Res. 290, 113172 https://doi.org/10.1016/j.psychres.2020.113172.

MAHEC. (2022). *Rural Health Disparities in WNC*. https://mahec.net/rhi/wnc-health-disparities.

Martin, S.L., Proescholdbell, S., Norwood, T., Kupper, L.L., 2010. Suicide and homicide in North Carolina: initial findings from the North Carolina Violent Death Reporting System, 2004-2007. North Carolina Med. J. 71 (6), 519–525.

McGinty, E.E., Presskreischer, R., Han, H., Barry, C.L., 2020. Psychological Distress and Loneliness Reported by US Adults in 2018 and April 2020. JAMA 324 (1), 93–94. https://doi.org/10.1001/jama.2020.9740.

McKnight-Eily, L.R., Okoro, C.A., Strine, T.W., Verlenden, J., Hollis, N.D., Njai, R., Mitchell, E.W., Board, A., Puddy, R., Thomas, C., 2021. Racial and Ethnic Disparities in the Prevalence of Stress and Worry, Mental Health Conditions, and Increased Substance Use Among Adults During the COVID-19 Pandemic—United States, April and May 2020. Morbid. Mortality Wkly. Rep. 70 (5), 162–166. https://doi.org/10.15585/mmwr.mm7005a3.

Milner, A., Too, L.S., Spittal, M.J., 2018. Cluster Suicides Among Unemployed Persons in Australia Over the Period 2001–2013. Soc. Indicators Res. 137 (1), 189–201. https://doi.org/10.1007/s11205-017-1604-6.

NC DETECT. (2021). *NC DETECT*. https://ncdetect.org/.

Nochaiwong, S., Ruengorn, C., Thavorn, K., Hutton, B., Awiphan, R., Phosuya, C., Ruanta, Y., Wongpakaran, N., Wongpakaran, T., 2021. Global prevalence of mental health issues among the general population during the coronavirus disease-2019 pandemic: a systematic review and meta-analysis. Sci. Rep. 11 (1), 1. https://doi.org/10.1038/s41598-021-89700-8. Article.

Olff, M., Primasari, I., Qing, Y., Coimbra, B.M., Hovnanyan, A., Grace, E., Williamson, R. E., Hoeboer, C.M., Consortium, the G.-C, 2021. Mental health responses to COVID-19 around the world. Eur. J. Psychotraumatol. 12 (1), 1929754 https://doi.org/10.1080/20008198.2021.1929754.

Ormiston, C.K., Williams, F., 2022. LGBTQ youth mental health during COVID-19: unmet needs in public health and policy. Lancet (London, England) 399 (10324), 501–503. https://doi.org/10.1016/S0140-6736(21)02872-5.

Pearman, A., Hughes, M.L., Coblenz, C.W., Smith, E.L., Neupert, S.D., 2022. Experiencing and Forecasting COVID-19 Daily Stress on Mental Health Reactivity Across Age and Race. J. Gerontol. 77 (4), e16–e22. https://doi.org/10.1093/geronb/gbab197.

Pirkis, J., John, A., Shin, S., DelPozo-Banos, M., Arya, V., Analuisa-Aguilar, P., Appleby, L., Arensman, E., Bantjes, J., Baran, A., Bertolote, J.M., Borges, G., Brečić, P., Caine, E., Castelpietra, G., Chang, S.S., Colchester, D., Crompton, D., Curkovic, M., Spittal, M.J., 2021. Suicide trends in the early months of the COVID-19 pandemic: an interrupted time-series analysis of preliminary data from 21 countries. Lancet Psychiatry 8 (7), 579–588. https://doi.org/10.1016/S2215-0366(21)00091-2.

Ridout, K.K., Alavi, M., Ridout, S.J., Koshy, M.T., Awsare, S., Harris, B., Vinson, D.R., Weisner, C.M., Sterling, S., Iturralde, E., 2021. Emergency Department Encounters Among Youth With Suicidal Thoughts or Behaviors During the COVID-19 Pandemic. JAMA Psychiatry 78 (12), 1319–1328. https://doi.org/10.1001/jamapsychiatry.2021.2457.

RStudio Team. (2022). *RStudio: integrated Development Environment for R* [PBC]. RStudio. https://www.rstudio.com/.

Runkle, J.D., Sugg, M.M., Yadav, S., Harden, S., Weiser, J., Michael, K., 2021. Real-Time Mental Health Crisis Response in the United States to COVID-19. Crisis. https://doi.org/10.1027/0227-5910/a000826.

Runkle, J.D., Yadav, S., Michael, K., Green, S., Weiser, J., Sugg, M.M., 2022. Crisis response and suicidal patterns in US youth before and during CoViD-19: a latent class analysis. J. Adolesc. Health 70 (1), 48–56.

Ryan, S.C., Runkle, J.D., Andersen, L.M., Sugg, M.M., 2022. Spatial analysis of mental health and suicide clustering among older adults in North Carolina: an exploratory analysis. SSM - Mental Health 2, 100162. https://doi.org/10.1016/j.ssmmh.2022.100162.

Salerno, J.P., Devadas, J., Pease, M., Nketia, B., Fish, J.N., 2020. Sexual and Gender Minority Stress Amid the COVID-19 Pandemic: implications for LGBTQ Young Persons' Mental Health and Well-Being. Public Health Rep. 135 (6), 721–727. https://doi.org/10.1177/0033354920954511.

Shiels, M.S., Tatalovich, Z., Chen, Y., Haozous, E.A., Hartge, P., Nápoles, A.M., Pérez-Stable, E.J., Rodriquez, E.J., Spillane, S., Thomas, D.A., Withrow, D.R., Berrington de González, A., Freedman, N.D., 2020. Trends in Mortality From Drug Poisonings, Suicide, and Alcohol-Induced Deaths in the United States From 2000 to 2017. JAMA Netw. Open 3 (9), e2016217. https://doi.org/10.1001/jamanetworkopen.2020.16217.

Sugg, M.M., Runkle, J.D., Andersen, L.M., Desjardins, M.R., 2022. Exploring Place-Based Differences in Suicide and Suicide-Related Outcomes Among North Carolina Adolescents and Young Adults. J. Adolesc. Health. https://doi.org/10.1016/j.jadohealth.2022.06.013.

Thomas, D., Lawton, R., Brown, T., Kranton, R., 2021. Prevalence, severity and distribution of depression and anxiety symptoms using observational data collected before and nine months into the COVID-19 pandemic. Lancet Regional Health – Americas 1. https://doi.org/10.1016/j.lana.2021.100009.

Thomeer, M.B., Moody, M.D., Yahirun, J., 2022. Racial and Ethnic Disparities in Mental Health and Mental Health Care During The COVID-19 Pandemic. J. Racial Ethnic Health Disparities. https://doi.org/10.1007/s40615-022-01284-9.

Torales, J., O'Higgins, M., Castaldelli-Maia, J.M., Ventriglio, A, 2020. The outbreak of COVID-19 coronavirus and its impact on global mental health. Int. J. Soc. Psychiatry 66 (4), 317–320. https://doi.org/10.1177/0020764020915212.

US Census Bureau. (2020). *Census.gov*. Census.Gov. https://www.census.gov/en.html.

USDA. (2020). *Rural-Urban Commuting Area Codes*. https://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes/.

Vahratian, A., 2021. Symptoms of Anxiety or Depressive Disorder and Use of Mental Health Care Among Adults During the COVID-19 Pandemic—United States, August 2020–February 2021. MMWR. Morbid. Mortality Wkly. Rep. 70 https://doi.org/10.15585/mmwr.mm7013e2.

Vavrek, M. (2020). *R: rand Index and Adjusted Rand Index*. https://search.r-project.org/CRAN/refmans/fossil/html/rand.index.html.

Veldhuis, C.B., Nesoff, E.D., McKowen, A.L.W., Rice, D.R., Ghoneima, H., Wootton, A.R., Papautsky, E.L., Arigo, D., Goldberg, S., Anderson, J.C., 2021. Addressing the critical need for long-term mental health data during the COVID-19 pandemic: changes in mental health from April to September 2020. Prevent. Med. 146, 106465 https://doi.org/10.1016/j.ypmed.2021.106465.

Xiong, J., Lipsitz, O., Nasri, F., Lui, L.M.W., Gill, H., Phan, L., Chen-Li, D., Iacobucci, M., Ho, R., Majeed, A., McIntyre, R.S., 2020. Impact of COVID-19 pandemic on mental health in the general population: a systematic review. J. Affect. Disord. 277, 55–64. https://doi.org/10.1016/j.jad.2020.08.001.