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Mapping high-risk clusters and identifying place-based risk factors of mental health burden in pregnancy

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Abstract

Purpose: Despite affecting up to 20% of women and being the leading cause of preventable deaths during the perinatal and postpartum period, maternal mental health conditions are chronically understudied. This study is the first to identify spatial patterns in perinatal mental health conditions, and relate these patterns to place-based social and environmental factors that drive cluster development.

Methods: We performed spatial clustering analysis of emergency department (ED) visits for perinatal mood and anxiety disorders (PMAD), severe mental illness (SMI), and maternal mental disorders of pregnancy (MDP) using the Poisson model in SatScan from 2016 to 2019 in North Carolina. Logistic regression was used to examine the association between patient and community-level factors and high-risk clusters.

Results: The most significant spatial clustering for all three outcomes was concentrated in smaller urban areas in the western, central piedmont, and coastal plains regions of the state, with odds ratios greater than 3 for some cluster locations. Individual factors (e.g., age, race, ethnicity) and contextual factors (e.g., racial and socioeconomic segregation, urbanity) were associated with high risk clusters.

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CRediT authorship contribution statement
Sarah E. Ulrich: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Margaret M. Sugg:** Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Sophia C. Ryan:** Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Jennifer D. Runkle:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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.

Appendix A. Supplementary data
Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmmh.2023.100270.

Conclusions: Results provide important contextual and spatial information concerning at-risk populations with a high burden of maternal mental health disorders and can better inform targeted locations for the expansion of maternal mental health services.

Keywords

SaTScan; Maternal mental health; North Carolina; Perinatal mental health; Perinatal mood and anxiety disorders; Severe mental illness

1. Introduction

Maternal mental health disorders are the leading cause of preventable pregnancy-related deaths across all trimesters and in the first twelve months postpartum (Trost et al., 2021). Despite affecting one out of every five pregnant or postpartum people in the United States (approximately 800,000 people annually), these conditions are underdiagnosed and under-treated in the perinatal period (Cox et al., 2016; Margiotta et al., 2022). Poor mental health during pregnancy is a critical precursor to maternal and infant morbidity (Easter et al., 2019; Runkle et al., 2023), and increases the likelihood of preterm labor, postpartum mental health conditions, hypertension, diabetes, suicide, and other adverse outcomes for both patient and child (Cox et al., 2016; Franks et al., 2017; Griffen et al., 2021; Watson et al., 2019). Infants born to birthing people with untreated mental health disorders are at higher risk for low birth weight and longer-term behavioral and neuro-developmental problems in childhood and adolescence (Cox et al., 2016; Franks et al., 2017; Margiotta et al., 2022; Watson et al., 2019).

Mounting evidence highlights the importance of examining place-based contextual risk factors in addition to individual-level factors for maternal mental health conditions, which include racial residential segregation (Anthopolos et al., 2011; Salow et al., 2018), residential economic segregation (Crear-Perry et al., 2021; Giurgescu et al., 2017; Griffen et al., 2021; Franks et al., 2017; Moore, 2017; Nager et al., 2006), access to greenspace (Barton and Rogerson, 2017; Nutsford et al., 2013), rurality (Fisher et al., 2012; Ginja et al., 2020; Mollard et al., 2016) and access to community and social resources (Corrigan et al., 2015; Robertson et al., 2004).

Using a spatial epidemiological approach to investigate the spatial and temporal patterns of maternal mental health risks, we hypothesize social and physical neighborhood alters individual health (Gebread, 2018; Kirby et al., 2017; Beale et al., 2008; Elliott and Wartenberg, 2004). We combine epidemiology's focus on population health with a geographic analysis of spatial patterns and context to examine the spatial distribution of maternal mental health outcomes and their relationships with place-based contextual factors among North Carolina women from 2016 to 2019. Maternal mental health clusters are locations with higher-than-expected incidence given a location's population, and can be identified as targeted locations for the expansion of maternal mental health services. Clustering may be explained by exposure to community-level variables and other underlying contextual factors. The identification of maternal mental health clusters, informed by geographic and spatial epidemiological approaches, advances the understanding of how neighborhood contexts may influence both individual behavior and community-level mental health burden.

Limited research has examined geographic differences in maternal health (Harden et al., 2022), and none has examined maternal mental health. Research by Harden, Runkle, and Sugg (2021) identified systemic racism as an important predictor of geographic clustering of severe maternal morbidity (SMM) in South Carolina and is one of the few studies that go beyond an exclusive focus on patient-level rather than the distal more upstream social determinants. The objective of this study is to identify spatial patterns in perinatal mental health conditions and relate these spatial concentrations of risk to place-based social and environmental determinants in North Carolina. Kulldorff's spatial scan statistic is used to detect clusters of three seperate maternal mental health conditions. We also examined the influence of social determinants that may contribute to the clustering of perinatal mental health conditions. To our knowledge, this analysis is the first to examine spatial patterns of maternal mental health and provides new evidence on the individual and community drivers of adverse maternal mental health conditions among high-risk populations.

2. Methods

2.1. Hospital administrative data

The following primary mental health disorders were included: (1) perinatal and postpartum mood and anxiety disorders (PMAD); (2) maternal mental disorders of pregnancy (MDP); and (3) severe mental illness (SMI) for pregnant persons presenting to the Emergency Department (ED) in North Carolina between 2016 and 2019 (Sheps Center, 2022). All maternal mental health outcomes were defined using the International Classification of Disease (ICD) diagnosis and procedure codes, Tenth Revision, Clinical Modification (ICD-10-CM) (Supplemental Table 1). MDP is a diagnosis used to document any new mental disorder complicating pregnancy, childbirth, or the puerperium (Runkle et al., 2023). PMAD encompasses preexisting mental health conditions that persist during and following pregnancy, including depression, anxiety, obsessive-compulsive disorder, psychosis, and post-traumatic stress disorder; of these, depression and anxiety are among the most common conditions identified during pregnancy and the postpartum period (McKee et al., 2020). SMI entails mental, behavioral, or emotional disorders that substantially impact functional impairment, and include bipolar and psychotic disorders (McKee et al., 2020; Runkle et al., 2023). Of these three conditions, SMI is the least prevalent and the most severe. These three conditions contribute to significant maternal psychiatric morbidity and a range of adverse outcomes for pregnant populations and infants (Runkle et al., 2021); therefore each condition was examined separately.

Individual characteristics, including age, race and ethnicity, insurance type, and zip code of maternal residence were obtained directly from hospital emergency department administrative records (Table 2). Race was categorized into Asian, Black or African-American, Indigenous American, white, and 'other race' including Native Hawaiian, Pacific Islander, and mixed-race. Ethnicity was categorized into Hispanic and non-Hispanic. Age was grouped into three age range groups: 18–29 years, 30–39 years, and 40 years and older. Patients under age 18 were excluded from this study, as this is a distinctly vulnerable subgroup (Runkle et al., 2022). Insurance included Medicaid, other government insurance, self-pay, and commercial insurance. Insurance was used as a proxy for individual socioeconomic status (Margiotta et al., 2022; Ryan et al., 2023).

2.2. Community-level variables

Contextual and social exposures shared among individuals within communities may predict the formation of maternal mental health clusters, emphasizing the importance of examining community-level risks. Community-level contextual variables considered were: racial residential segregation (Anthopolos et al., 2011, 2014; Salow et al., 2018; Moore, 2017; Upadhyaya et al., 2014; Weil, 2021), economic residential segregation (Nager et al., 2006; Moore, 2017), access to greenspace (Sun et al., 2023; Kihal-Talantikite et al., 2013; Runkle et al., 2022; Feng and Astell-Burt, 2018), and rural vs. urban residence (Craemer et al., 2023; Ginja et al., 2020; Mollard et al., 2016; Ross et al., 2011). These variables were considered at the zip code tabulation area (ZCTA) level, which is the smallest spatial unit resolution available for this dataset.

2.2.1. Racial and income segregation—The Index of Concentration at the Extremes (ICE) was used to characterize racial and economic residential segregation (Krieger et al., 2016). The ICE was developed by Massey (1996) to measure spatial social polarization of extremes of deprivation and privilege simultaneously and is considered a useful complement to area-level poverty for public health monitoring (Krieger et al., 2016). ICE values were calculated using variables from the 2017 American Community Survey with 5-year estimates using the following equation: ICEq = (Taq-Tpq)/Tq, where Taq represents the population density at the q location, and Tpq represents the population density of group a, p in the location of q (Kramer, 2018). ICE scores range from −1 to −1. A score of 1 indicates that 100% of the population within a ZCTA was the most deprived (i.e., low-income or majority Black) while a score of 1 indicates that 100% of the population was the most privileged (i.e., high-income or majority white).

2.2.2. Greenspace—Literature suggests access to greenspace is a factor contributing to improved birth outcomes (Woods et al., 2017; Runkle et al., 2022; Kihal-Talantikite et al., 2013). Availability of greenspace was measured using the proportion of greenspace per person at the ZCTA level using cross-sectional data from PAD-US, following a methodology proposed by Runkle et al., 2022). The upper 25th percentile of ZCTAs with the highest proportion of greenspace per person were classified as having a high level of greenspace; the bottom 75th percentile was classified as having low greenspace (Runkle et al., 2022; Ryan et al., 2023).

2.2.3. Rurality—While prior research has examined residence in rural areas as a risk factor for adverse maternal mental health outcomes (Mollard et al., 2016), studies call for further examination of the potential moderating effect of race and income on perinatal mental health outcomes along the rural-urban continuum (Ginja et al., 2020; Mollard et al., 2016; Craemer et al., 2023). Rural and urban differences as contributing factors to maternal mental health clustering were investigated using Rural-Urban Commuting Area (RUCA) codes at the ZCTA level, which range from 1 (most urban) to 10 (most rural). As a measure of the rural-urban continuum, RUCA codes were aggregated into three levels to classify each ZCTA as rural, suburban, or urban. A RUCA code of 3 or less was classified as urban; 4–6 as suburban; and 7–10 as rural (USDA ERS, 2020).

2.3. Spatial analysis

SaTScan, a descriptive visualization mapping tool, was used to examine the spatial clustering of PMAD; MDP; and SMI across the state of North Carolina (Fig. 1). SaTScan uses Kulldorf's spatial scan statistic to identify geographic hotspots of elevated health risk at user-specified window sizes (Kulldorff, 1997). The spatial scan statistic adjusts for heterogeneous background population densities and confounding covariates, such as demographic variables or socioeconomic status. This study used the discrete Poisson model to perform a purely spatial analysis scanning for clusters with high rates of PMAD, MDP, and SMI. Spatial clusters were calculated using a 10% moving window, with a minimum number of cases per cluster set to 100 over the 4-year study period to eliminate exceedingly small clusters. A 25% window was also tested and resulted in similar cluster locations; however, a smaller window size (i.e. 10%) allows for the identification of more localized clusters, which is more relevant for this exploratory analysis. All clusters were validated using Monte Carlo replications ($n > 999$) to test the likelihood of a given cluster outcome, and the null hypothesis was rejected at $p < 0.05$. The default reporting in SaTScan produces both Gini primary and secondary high-risk clusters. Primary clusters are those with the highest log likelihood ratio, while secondary clusters are other high-risk cluster locations. The Gini coefficient is used to identify a more refined collection of non-overlapping clusters to report, avoiding overly large clusters with smaller relative risk values. Gini primary and secondary cluster reporting is favorable when examining highly localized clusters at a smaller spatial scale, i.e. at the ZCTA level (Han et al., 2016). Relative risk (RR) with corresponding log likelihood ratio test is automatically calculated for each cluster (Cluster RR) and for each ZCTA (Local RR) in North Carolina. $RR < 1$ is considered lower risk, and an $RR > 1$ is considered higher risk. All SaTScan analyses were adjusted for age and race using quasi-poisson regression-fitted values to derive the expected number of cases per ZCTA. This method accounts for over-dispersion in the data and identifies cluster locations that cannot be explained by age and race alone (Fontanella et al., 2018, Fonseca-Rodríguez et al., 2021).The expected number of cases, the observed number of cases, the locations included, the relative risk, the p-value (<0.05), and the standard error were calculated for each cluster (Supplemental Table 2). All analyses were implemented in SaTScan v10.1 software.

2.4. Multivariable logistic regression

Spatial clusters identified in the study area (Fig. 1) using SatScan were merged with individual-level ED visits for maternal mental disorders and community-level factors at the ZCTA level. Multivariable logistic regression with maternal residence in a high-risk cluster (indicated as yes/no) as the dependent variable was used to investigate associations between patient-level and community risk factors for the spatial clustering of each mental health condition separately. Significance was assessed at alpha = 0.05, and multicollinearity was assessed for all variables by calculating the variance inflation factor (VIF). No variables exceeded the VIF threshold of 2, indicating a lack of collinearity between predictor variables

(Craney and Surles, 2002) (Supplemental Fig. 1). All statistical analyses were performed in RStudio (version 4.2.3).

3. Results

Our sample comprised 387,449 North Carolina emergency department visits for pregnant people. Total cases for PMAD, SMI, and MDP are shown in Table 1, which includes case counts by age, race, ethnicity, and insurance type. A large proportion of women who resided in high-risk clusters for PMAD, SMI, or MDP were Medicaid beneficiaries and identified as white.

3.1. Spatial clusters of PMAD, SMI, and MDP

Primary PMAD, MDP, and SMI clusters were located in the southeastern coastal region of NC (Fig. 2). All three outcomes displayed significant secondary clustering in the western region of the state. Additional secondary cluster locations varied spatially throughout the Piedmont and coastal plains regions, with 5 total clusters identified for PMAD, 4 for SMI, and 4 for MDP (Fig. 2; Supplemental Table 2). Primary cluster relative risk was as high as 3.63 for MDP, while relative risks were 2.95 and 2.61 within primary PMAD and SMI clusters, respectively. Secondary cluster relative risk ranged from 1.30 to 2.05 (Supplemental Table 2). Local relative risk at the ZCTA level varied spatially but was elevated in cluster locations (Fig. 3). SaTScan analyses were also performed with population values not adjusted for race or age, which resulted in higher cluster counts and minor variations in the geographic distribution of clusters (Supplemental Table 3, Supplemental Fig. 2).

3.2. Place-based factors that predict high-risk clusters

Fig. 4 and Table 2 show odds ratios and confidence intervals for individual- and community-level factors (e.g., explanatory or predictor variables) associated with geographic high risk spatial clusters for PMAD, SMI, and MDP among pregnant patients attending the ED in North Carolina from 2016 to 2019. In general, high-risk clustering across all three maternal mental health outcomes occurred among pregnant persons residing in urban areas. Contrary to what we expected, residence in a majority Black or low-income community was not associated with being in a high-risk cluster for any of the mental disorders, with the exception of MDP. Maternal residence in low-income ZCTAs (ICE Income Q1) was associated with a higher risk of residing in an MDP cluster, compared to high-income ZCTAs (ICE Income Q3). Further, we did not see a protective effect for mothers residing in areas with high greenspace per person.

4. Discussion

This exploratory analysis is the first to examine community-level determinants of spatially explicit clustering of maternal mental health conditions in North Carolina from 2016 to 2019. Our study identified high-risk clustering of PMAD, SMI, and MDP for pregnant populations in the southeastern coastal region of North Carolina. The development of multiple maternal health disorders in this region is concerning, as these conditions can increase the likelihood of preterm labor, preeclampsia, hypertension, diabetes, infanticide, and suicide (Cox et al., 2016; Franks et al., 2017; Watson et al., 2019; Runkle et al., 2023).

The presence of two significant secondary MDP clusters in the Piedmont suggests an elevated risk for the onset of new maternal mental health conditions in this region, while the presence of PMAD and SMI secondary clustering in the rural coastal plains region suggests a higher burden of pre-existing and persistent (i.e., PMAD) or more severe (i.e., SMI) mental health conditions during the perinatal period. For each mental health outcome, there are areas with high local RR values located outside of identified clusters, suggesting that a high prevalence of PMAD, MDP, or SMI may be present in these locations, but not enough to elicit significant clustering.

Our finding that urban areas were significantly more likely to be identified in high-risk clusters for PMAD, SMI, and MDP is surprising, given that rural residence has been documented as a risk factor for adverse perinatal mental health outcomes (Ginja et al., 2020; Mollard et al., 2016). This analysis focused on the identification of spatially explicit clustering rather than the overall prevalence of maternal mental health conditions, which may partially explain the differences in our findings. Additionally, rural-urban differences are often operationalized as binary, whereas our study considered suburban in addition to rural and urban areas at a finer spatial scale (i.e., ZCTA versus county). Despite our finding of elevated risk in urban areas, the presence of clusters in the predominantly rural western and coastal plains regions reflect substantial rural health disparities that have been documented in North Carolina, due to poor social determinants of health including limited access to mental health care, lack of transportation, a high proportion of uninsured populations, and income disparities (MAHEC, 2022; Baxley, 2023). Rural populations as a whole experience lower rates of screening for mental health conditions (Craemer et al., 2023; Mollard et al., 2016; Anglim and Radke, 2022) and higher rates of maternal mortality and morbidity (CDC, 2023); thus, mental health conditions may be un(der)diagnosed in rural areas relative to urban areas, leading to more severe outcomes (e.g. SMI) without intervention (Hansen et al., 2022). Previous research has also noted the moderating effect that race and income have on the relationship between rural-urban status and perinatal mental health outcomes (Ginja et al., 2020; Mollard et al., 2016; Craemer et al., 2023). Our finding that urban areas were associated with an elevated risk of perinatal mental health clustering, adjusted for age and race relative to rural areas, highlights the need for further research investigating maternal health disparities along the rural-urban continuum.

Pregnant persons insured by Medicaid were more likely to reside in a high-risk cluster for MDP, a result that aligns with prior research supporting the impact of individual-level poverty on the development of adverse mental health conditions (Franks et al., 2017; Griffen et al., 2021). Furthermore, MDP was the only condition for which residence in the lowest ICE Income tertile (e.g., predominantly low-income community) was associated with an increased cluster risk. These results suggest that economic residential segregation may be a significant driver for the onset of new maternal mental health conditions, aligning with prior research that has associated economic segregation with adverse birth and maternal health outcomes (Harden et al., 2022; Chambers et al., 2019).

Similar to our study showing a high proportion of Black women with SMI, other studies have also noted higher incidences of Black women diagnosed with SMI in other subpopulations in the Southeastern U.S. (Runkle et al., 2023). SMI is the most severe maternal mental health outcome included in this study, and an increased prevalence among Black women indicates a greater vulnerability to the most severe mental health outcomes among this population that is not reflected in cluster results. These results further suggest that the onset of new maternal mental health conditions (e.g., MDP) is more sensitive to cluster associations than conditions that preexist before pregnancy (e.g., PMAD and SMI).

Our results showing availability of greenspace was not protective in reducing the concentration of maternal mental health burden is supported by prior studies which indicate that merely the presence of greenspace may not be sufficient to support mental well-being (Sun et al., 2023; Runkle et al., 2022; Feng and Astell-Burt, 2018; McEachan et al., 2016; Kihal-Talantikite et al., 2013; Mueller and Flouri, 2021; Feng and Astell-Burt, 2018). Rather, the influence of greenspace availability on moderating mental health is largely determined by the opportunity to use greenspace, which includes time and transportation, as well as ease of use and perceptions of safety in these spaces (Lachowycz and Jones, 2013; Feng and Astell-Burt, 2018). More studies are needed that explicitly focus on pregnant populations in the examination of the role of greenspace on mental health, as well as both race-based and rural-urban differences that may moderate this association (Runkle et al., 2022; Lachowycz and Jones, 2013; Feng and Astell-Burt, 2018).

4.1. Implications

Maternal mental health clusters are areas where the expansion of care is the most urgent. Our results and the significance of both individual and community-level variables highlight the importance of examining the influence of structural factors, like residential segregation and park space, in addition to patient-level characteristics. Policies that may improve access to mental health care will likely include the expansion of telehealth service and coverage (Meltzer-Brody and Kimmel, 2020; Moore et al., 2021; Griffen et al., 2021); co-location of services for both mom and infant (Pawar et al., 2019; Meltzer-Brody and Kimmel, 2020; Moore et al., 2021; Griffen et al., 2021); and enhancing the geographic distribution of and training the perinatal workforce that addresses the cultural and social contexts that drive maternal mental health disparities (Moore et al., 2021; Griffen et al., 2021). A local state program, NC Maternal Mental Health Matters, is already working to enhance the screening, assessment, and treatment of maternal mental health conditions during pregnancy and the postpartum periods (Kimmel, 2020).

Harden et al. identified a higher risk of severe maternal illness morbidity (SMIM) clustering for Black women in a similar state in the U. S. South (2022). Our finding of reduced cluster risk for perinatal mental health conditions among Black women may indicate that the conditions that contribute to elevated SMI risk in this population are not being identified and treated in time for effective intervention. These results may be indicative of race-based differences in how maternal mental health conditions are being identified, diagnosed, and reported. The potential for Black women to be underdiagnosed with maternal mental health conditions could be attributed to gendered racism, lack of cultural sensitivity in providers, and stigma (Giurgescu et al., 2017; Woods-Giscombe et al., 2016). Racialized discrimination or racialized stigma during pregnancy has surfaced as a potential explanation for why Black mothers may experience reduced access to quality and timely health services, resources, and support (Mehra et al., 2020). Interventions include anti-bias training, screening for racialized pregnancy stigma, improvements in the quality of care for Black birthing populations, and the provision of racially congruent care (Griffen et al., 2021; Matthews et al., 2021; Mehra et al., 2020; Moore, 2017). Black women in the South have the highest proportion of maternal morbidity in the U.S., and Black women overall are three times more likely to die from pregnancy-related causes than white women (Liese et al., 2019; Centers for Disease Control and Prevention, 2019), making the implementation of such interventions urgent and imperative (Crear-Perry et al., 2021; Howell, 2018; MacDorman et al., 2021).

4.2. Strengths & limitations

Results from this study are the first to enhance the understanding of individual and place-based factors that contribute to the spatial distribution of maternal mental health burden, an understudied area in current literature. Notable strengths of this study include the identification of place-based factors that underpin maternal mental health burden. The ZCTA level of analysis is the most sensitive to clustering when compared to larger geographic units (e.g., county), providing a more accurate depiction of clusters while illustrating geographic patterns at a smaller spatial scale (Jones and Kulldorff, 2012). The identification of broader community and structural factors that influence maternal mental health outcomes shifts the focus of intervention away from individual blame and towards a shared understanding of how inequities in race and class-based outcomes result from preexisting systems that ultimately influence the built environment.

A few limitations of this study are worthy to mention. Our analysis focused on one state in the Southern United States; future research should include data from additional states and regions. The ZCTA areas used in our spatial analysis may result in inflated odds ratio (OR) values due to the small population size of certain zip codes in rural and remote geographic locations. The use of address or other individual-level data risks the exposure of protected health information. Therefore, the aggregation of data to less precise scales (e.g. ZCTAs) mitigates the risk of exposing sensitive health information, but at the expense of potentially masking smaller, isolated high-risk areas (Jones and Kulldorff, 2012). Another limitation includes the hospital administrative data used for service billing, which does not include detailed data on maternal income, marital status, or family structure. Data on maternal mental health disorders are subject to bias from coding and diagnostic errors, but prior research shows higher reliability for well-defined disorders such as psychiatric disorders during pregnancy (Davis et al., 2016; Runkle et al., 2023).

As common in other maternal mental health analyses we excluded populations under age 18 (Runkle et al., 2023). In addition, our small samples and underlying data limited our ability to disaggregate the “other” race category. Further analysis is needed over a larger geographic extent to understand patterns across small sub-populations of pregnant persons.

While we operationalized the ICE measurement for racial residential segregation as a proxy for structural racism (Krieger et al., 2016; Chambers et al., 2019, Goel et al., 2022), we acknowledge that structural racism is a multilevel and multidimensional phenomenon and is reinforced in healthcare through provider biases, access to and availability of care, stigma, and a lack of culturally relevant and racially congruent care (Moore et al., 2021). Racial residential segregation is just one aspect of this phenomenon, which is difficult to quantify and is a major research priority in public health (Hardeman et al., 2022). A full and proper consideration of the complex and layered effects of structural racism on perinatal mental health outcomes is beyond the scope of this exploratory study.

The exploratory nature of this analysis presents additional limitations. There is a lack of established precedent in the methods used to examine spatial clustering of maternal mental health conditions, particularly concerning spatial scan window size and cluster adjustments. We chose to use a 10% at-risk window of population at risk to examine clustering at a more localized scale than SaTScan's 50% default, while also testing a 25% window that resulted in similar cluster locations. SaTScan's circular cluster window may not capture the exact pattern that PMAD, SMI, or MDP likelihood follows, and the software cannot explain the reason for risk variation in clusters (Chong et al., 2013).

5. Conclusion

This study highlights individual and community contextual factors that help explain the spatial concentration of maternal mental health burden for PMAD, SMI, and MDP. Our findings can be applied to expand state and local maternal mental healthcare services to achieve more effective screening, treatment, and preventative strategies that center health equity in the care of pregnant persons. Results highlight geographic areas in need of targeted maternal mental health interventions. Future research should consider the mediating and moderating effects of contextual neighborhood and individual socio-demographic factors on maternal mental health disparities along the rural-urban continuum.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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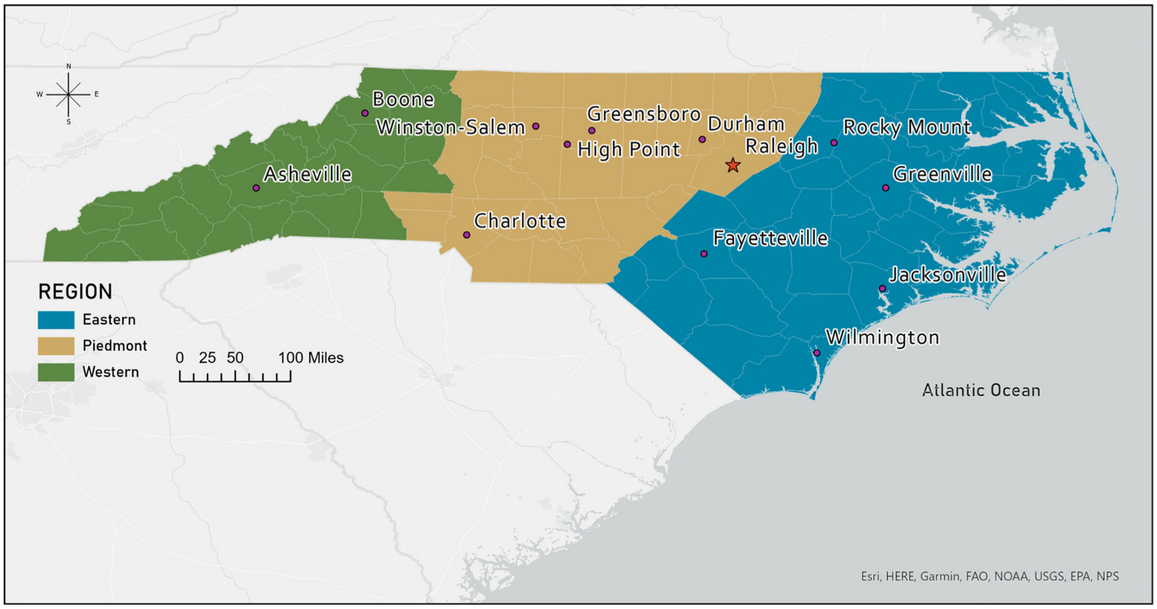

Fig. 1.
Map of geographic regions and major cities in North Carolina, USA.

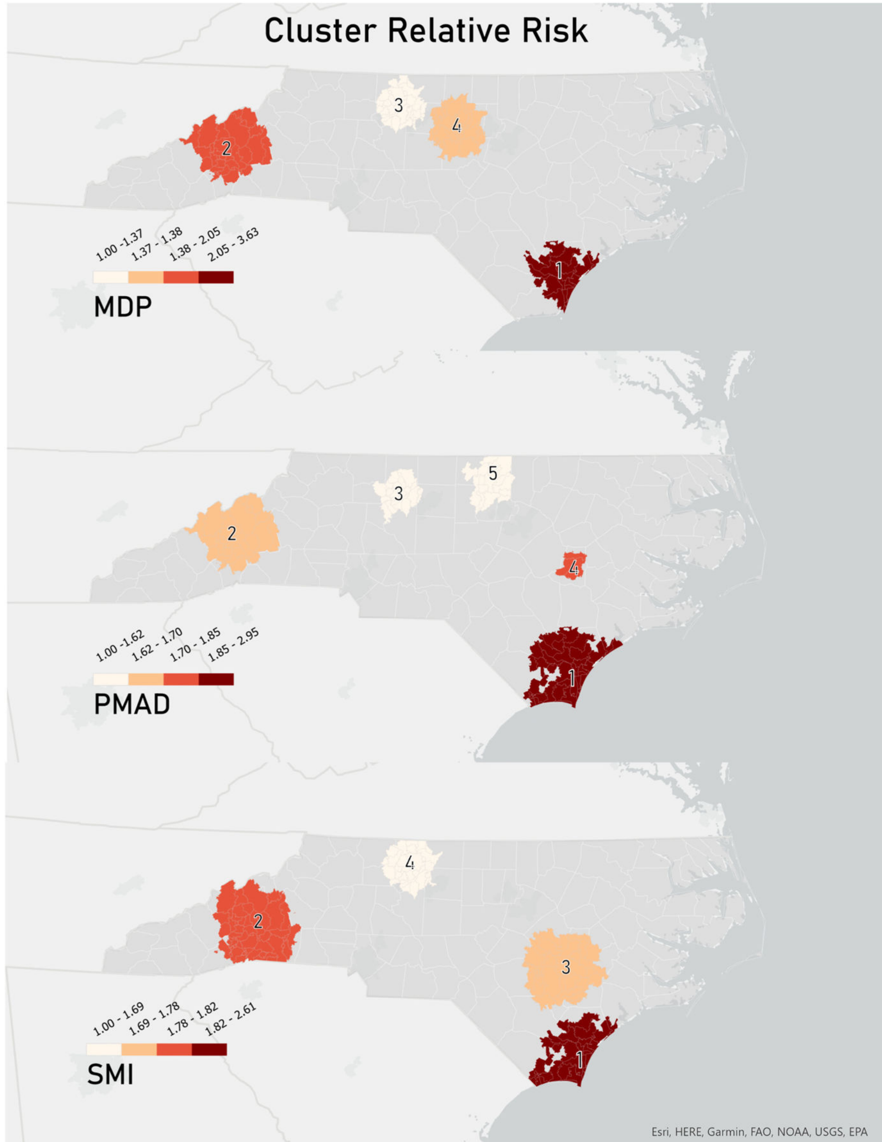

Fig. 2.

Univariate spatial cluster locations and cluster relative risk for maternal mental disorder of pregnancy (MDP), perinatal mood and anxiety disorder (PMAD), and severe mental illness (SMI) cases identified during the study period (2016–2019).

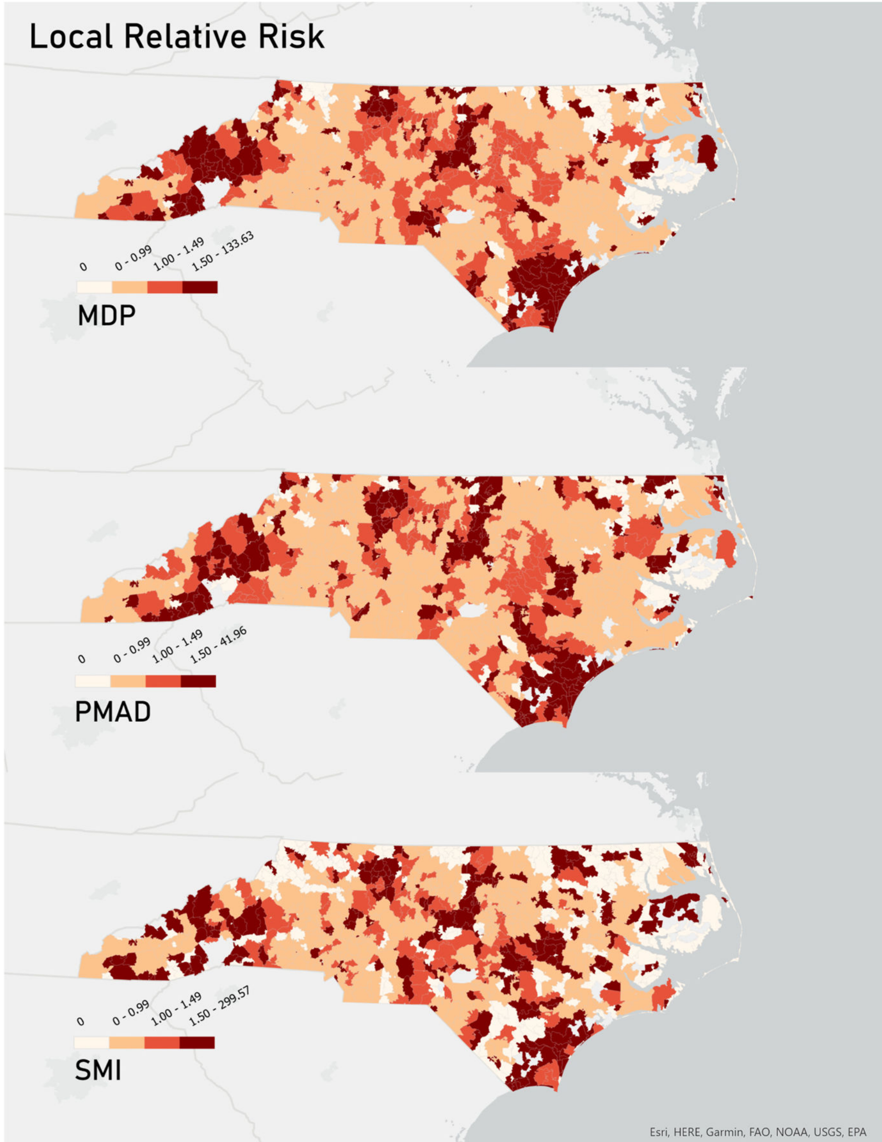

Fig. 3.

Local relative risk (LRR) at the zip code tabulation area (ZCTA) level for maternal mental disorder of pregnancy (MDP), perinatal mood and anxiety disorder (PMAD), and severe mental illness (SMI) cluster residence.

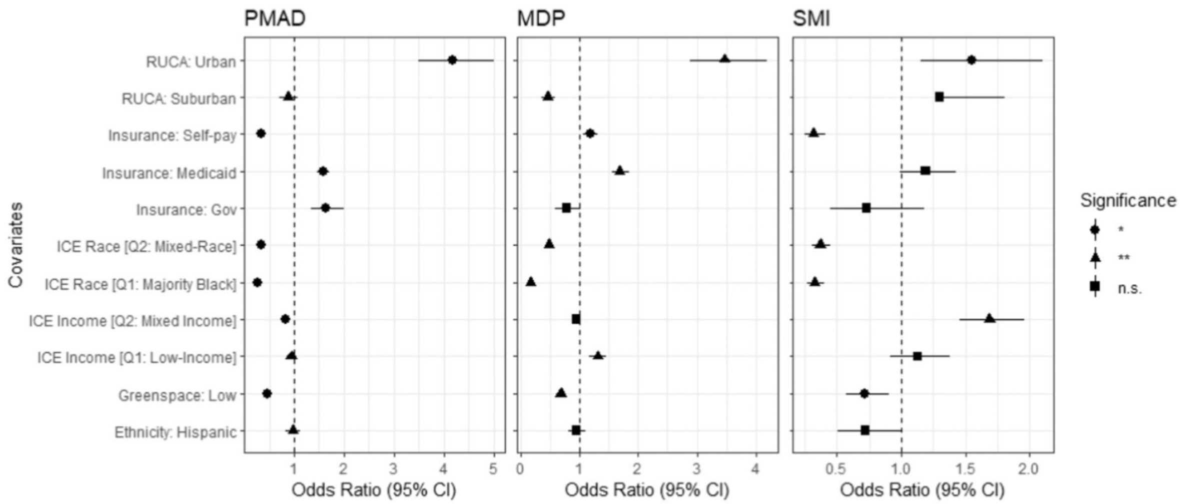

Fig. 4.

Forest plot of multivariable logistic regression results.

Table 1

Maternal characteristics for ED visits for PMAD, SMI, and MDP in high-risk compared to no-risk clusters, North Carolina (2016–2019).

Strata		**PMAD (n = 23950)**		**SMI (n = 5801)**		**MDP (n = 19721)**	
Residence in cluster		**Yes n = 6298 n (%)**	**No n = 17652 n (%)**	**Yes n = 1744 n (%)**	**No n = 4057 n (%)**	**Yes n = 5788 n (%)**	**No n = 13933 n (%)**
Age (%)	18–29	4248 (67.4)	11584 (65.6)	1265 (72.5)	2846 (70.2)	3880 (67.0)	9369 (67.2)
	30–39	1906 (30.3)	5664 (32.1)	450 (25.8)	1133 (27.9)	1795 (31.0)	4309 (30.9)
	40+	144 (2.3)	404 (2.3)	29 (1.7)	78 (1.9)	113 (2.0)	255 (1.8)
Race (%)	Asian	21 (0.3)	84 (0.5)	0 (0.0)	17 (0.4)	23 (0.4)	60 (0.4)
	Black	1556 (24.7)	5678 (32.2)	523 (30.0)	1635 (40.3)	1492 (25.8)	4751 (34.1)
	Indigenous American	18 (0.3)	183 (1.0)	11 (0.6)	75 (1.8)	27 (0.5)	161 (1.2)
	Native Hawaiian/Pacific Islander	5 (0.1)	5 (0.0)	0 (0.0)	1 (0.0)	4 (0.1)	4 (0.0)
	Other	192 (3.0)	1053 (6.0)	38 (2.2)	203 (5.0)	210 (3.6)	820 (5.9)
	Unknown	132 (2.1)	194 (1.1)	17 (1.0)	34 (0.8)	129 (2.2)	147 (1.1)
	White	4374 (69.5)	10455 (59.2)	1155 (66.2)	2092 (51.6)	3903 (67.4)	7990 (57.3)
Ethnicity (%)	Hispanic	278 (4.4)	978 (5.5)	51 (2.9)	162 (4.0)	266 (4.6)	731 (5.2)
	Non-Hispanic	5890 (93.5)	16415 (93.0)	1674 (96.0)	3845 (94.8)	5392 (93.2)	13008 (93.4)
	Unknown	130 (2.1)	259 (1.5)	19 (1.1)	50 (1.2)	130 (2.2)	194 (1.4)
Insurance	Commercial	1522 (24.2)	4216 (23.9)	219 (12.6)	494 (12.2)	1161 (20.1)	3218 (23.1)
	Other Government	177 (2.8)	337 (1.9)	27 (1.5)	79 (1.9)	68 (1.2)	295 (2.1)
	Medicaid	3914 (62.1)	7600 (43.1)	1271 (72.9)	2236 (55.1)	3182 (55.0)	6338 (45.5)
	Self-Pay	604 (9.6)	5349 (30.3)	172 (9.9)	1187 (29.3)	1316 (22.7)	3947 (28.3)

PMAD=Perinatal mood and anxiety disorders; SMI=Severe mental illness; MDP=Maternal mental disorder of pregnancy.

Table 2

Community and individual-level predictors of PMAD, SMI, and MDP among recorded hospital births in North Carolina from 2016 to 2019. Results illustrate the odds ratio of living in a high-risk cluster for each outcome as compared to the referent population.

Metric	PMAD				SMI				MDP			
	OR	LL	UL	p	OR	LL	UL	p	OR	LL	UL	p
Insurance: Gov	1.63	1.33	2.00	<0.001	0.73	0.45	1.18	0.212	0.78	0.58	1.03	0.087
Insurance: Medicaid	1.59	1.47	1.72	<0.001	1.19	0.99	1.43	0.068	1.69	1.55	1.85	<0.001
Insurance: Self-pay	0.33	0.30	0.37	<0.001	0.32	0.25	0.41	<0.001	1.19	1.07	1.31	0.001
Insurance: Commercial	Reference											
Ethnicity: Hispanic	0.97	0.83	1.12	0.650	0.72	0.51	1.00	0.052	0.95	0.81	1.11	0.523
Ethnicity: Not Hispanic	Reference											
ICE Income [Q1: Low-Income]	0.94	0.85	1.05	0.271	1.13	0.92	1.38	0.234	1.31	1.17	1.46	<0.001
ICE Income [Q2: Mixed Income]	0.83	0.77	0.89	<0.001	1.69	1.46	1.96	<0.001	0.95	0.88	1.03	0.194
ICE Income [Q3: High Income]	Reference											
ICE Race [Q1: Majority Black]	0.26	0.24	0.29	<0.001	0.33	0.27	0.40	<0.001	0.17	0.15	0.19	<0.001
ICE Race [Q2: Mixed-Race]	0.33	0.30	0.36	<0.001	0.37	0.31	0.45	<0.001	0.49	0.44	0.54	<0.001
ICE Race [Q3: Majority White]	Reference											
Greenspace: Low	0.46	0.41	0.52	<0.001	0.72	0.57	0.91	0.006	0.68	0.6	0.77	<0.001
Greenspace: High	Reference											
RUCA: Urban	4.17	3.49	5.00	<0.001	1.55	1.15	2.10	0.005	3.46	2.88	4.18	<0.001
RUCA: Suburban	0.88	0.71	1.08	0.210	1.30	1.30	1.81	0.106	0.46	0.36	0.58	<0.001
RUCA: Rural	Reference											

OR= Odds Ratio; UL = 95% Confidence Interval: Upper Limit; LL = 95% Confidence Interval: Lower Limit.