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County-level spatial distribution and hotspots of Parkinson's disease mortality in the United States

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Abstract

Introduction

Parkinson's disease (PD) is a common age-related neurodegenerative condition ranking second after Alzheimer's disease. According to the Centers for Disease Control and Prevention (CDC), PD was the ninth leading cause of death among adults aged 65 years and older in 2024. Although geographic variation in PD burden has been documented, little is known about county-level patterns of PD mortality. Therefore, this study examined the spatial distribution and clustering of PD mortality across U.S. counties.

Methods

We conducted an ecological cross-sectional spatial analysis of county-level mortality data. The data used in the analyses were obtained from the CDC WONDER Underlying Cause of Death database (2018–2024). We used Indirect age standardization to calculate county-level standardized mortality ratios (SMRs). Global Moran's I was used to quantify spatial autocorrelation, and Local Moran's I and Getis-Ord Gi* statistics were used to identify clusters and hotspots of PD mortality.

Results

A total of 263,531 PD deaths were recorded during the study period. Age-adjusted mortality rates (AAMR) increased from 8.6 per 100,000 in 2018 to 9.8 per 100,000 in 2020 and 2021, then declined to 9.3 per 100,000 in 2024. Although AAMR declined after the COVID-19 pandemic, it remained above pre-pandemic levels. AAMR was higher among males and the White population. Significant positive spatial autocorrelation was observed (Moran's I = 0.223, p = 0.001), indicating nonrandom geographic clustering of PD mortality. Local Moran's I identified 114 high-high and 115 low-low clusters. Hotspot analysis revealed areas of elevated mortality concentrated in parts of the Midwest and South regions of the United States.

Conclusion

Our study found significant county-level geographic clustering of PD mortality in the United States. These results, therefore, highlight substantial local variation in mortality burden and the utility of spatial analyses for identifying counties disproportionately affected by PD. Future studies may investigate the determinants of these geographic patterns and their implications for disease burden.

Clinical Trial: Not Applicable

Introduction

Parkinson's disease (PD) is the fastest-growing neurological disorder globally.[1] The disease represents a growing public health challenge due to increasing prevalence, disability, and mortality.[1–3] Approximately

90,000 people are diagnosed each year, and nearly 1 million people in the United States (U.S.) are living with the disease.[4] PD is a progressive neurodegenerative disorder that primarily affects movement and worsens over time.[5] Prior studies show that PD burden varies across population groups.[6] Specifically, PD prevalence is higher among White populations compared to other racial groups.[6] Men are affected more than women, with men being nearly twice as likely to be diagnosed with PD.[7] Over the past two decades, mortality from PD has increased.[6,8] In 2024, the disease was the ninth leading cause of death among adults aged 65 years and older.[8] The age-adjusted mortality rates (AAMR) from PD increased from 5.4 per 100,000 in 1999 to 8.8 per 100,000 in 2019.[6,8] The rate later increased to 9.8 per 100,000 in 2020 during the global COVID-19 pandemic.[9] Some studies have projected that deaths from PD will continue to increase over the coming decades, largely because of population growth and aging.[10,11]

Despite evidence of the growing burden of PD, most studies have focused on national trends in prevalence and incidence, as well as individual–level factors.[2,3] Among studies that have focused on PD mortality, trends have often been explored at the national and state levels.[9,11–13] Few studies have investigated localized spatial patterns of mortality burden across smaller geographic units.[9,11–15] As such, less is known about how PD mortality burden varies across U.S. counties. Prior studies also show that PD burden is not uniformly distributed.[14,15] Regional variation and spatial clustering of PD have been reported across the U.S.[14,15] These findings suggest that place-based factors may contribute to differences in disease burden.[14,15] Geographic variation may reflect differences in environmental exposures, demographic characteristics, healthcare access, and other contextual factors that influence health outcomes.[3,16] A population-based study among U.S. Medicare beneficiaries identified nonrandom geographic clustering of PD, with higher concentrations in the Midwest and Northeastern regions.[15]

While national and state-level analyses provide important information on overall PD mortality patterns, they may mask substantial geographic variation at smaller spatial scales. Counties within the same state can differ in demographic composition, environmental exposures, and socioeconomic conditions that influence mortality patterns.[17] As such, county-level analyses may help identify localized areas with disproportionately elevated mortality burdens that could otherwise remain undetected in broader analyses.

Spatial approaches, including hotspot and cluster analyses, have been used to identify geographic concentrations of disease burden and characterize spatial patterns across a range of health conditions.[18–20] Despite their broad application, county-level spatial patterns of PD mortality in the United States have not been well characterized. Therefore, this study aimed to examine county-level spatial patterns and identify hotspots of PD mortality across the United States.

Methods

Study Design and Data Sources

Our study is an ecological cross-sectional spatial analysis using county-level data. We used data from the Centers for Disease Control and Prevention Wide-ranging Online Data for Epidemiologic Research (CDC WONDER) Underlying Cause of Death Database.[21] This is a publicly available mortality database maintained by the National Center for Health Statistics (NCHS).[22] We focused on county-level data from 2018 to 2024. County-level PD mortality was identified using the International Classification of Diseases (ICD-10) code G20. CDC WONDER data are based on death certificates of residents of the United States. The database includes information on the underlying cause of death and demographic data. We generated additional datasets by stratifying mortality data by county and other variables of interest.[23] We used data from the U.S. Census Bureau American Community Survey (ACS) 5-year estimates for poverty and income variables.[26, 27] Poverty data were generated from Table S1701 (Poverty Status in the Past 12 Months),[24] while median household income data were obtained from Table S1901 (Income in the Past 12 Months). [4] Shapefiles were sourced from the U.S. Census Bureau's TIGER/Line geographic files.[25] These shapefiles were used for spatial visualization and hotspot analysis. PD mortality, ACS, and the U.S. Census Bureau's TIGER/Line geographic files were merged using Federal Information Processing Standard (FIPS) codes. We used FIPS as unique geographic identifiers for all counties.

Study Setting and Population

Our study focused on all counties in the United States that registered PD deaths. County-level data enabled assessment of geographic variation in PD mortality. The study included adults aged 45 years and older. We restricted the study to this age group as PD mortality most commonly occurs in elderly populations.[11,11,13,21] Because the study used publicly available de-identified data, it was exempt from institutional review board approval.

Measures and Variables

The variable of interest was PD mortality. PD mortality was defined as death with PD listed as the underlying cause of death. PD mortality data for the standard population were retrieved from CDC WONDER to examine national temporal trends and sociodemographic disparities in PD mortality. County-level spatial analyses were conducted using standardized mortality ratios (SMRs). County-level SMRs were calculated using indirect age standardization because CDC WONDER does not provide county-level age-adjusted mortality rates. National age-specific PD mortality rates across five age groups (45–54, 55–64, 65–74, 75–84, and ≥ 85 years) served as the reference standard. County-level age-specific population counts from the 2024 ACS B01001 table were multiplied by seven to approximate person-years over the study period. Expected deaths were calculated by applying national rates to county person-years and summing across age groups; SMRs were calculated as observed deaths divided by expected deaths. Exact Poisson-based 95% confidence intervals were calculated for each SMR. Connecticut's eight legacy counties were excluded due to a FIPS code mismatch with the 2024 ACS planning-region geography.

Sociodemographic and county-level characteristics

Other variables included sociodemographic and county-level characteristics, including sex, race, ethnicity, age group, median household income, poverty rate, urbanization status, and census region. The CDC WONDER defined sex as being male or female. Race was divided into White, Black or African American, Asian, American Indian or Alaska Native, Native Hawaiian or Other Pacific Islander, and more than one race. Hispanic or non-Hispanic was recorded as ethnicity. Age was categorized into five groups: 45–54, 55–64, 65–74, 75–84, and ≥ 85 years. Median household income represented the estimated median annual household income for each county. The poverty rate was defined as the percentage of county residents living below the federal poverty level. Urbanization status was classified using the 2013 National Center for Health Statistics (NCHS) Urban–Rural Classification Scheme for Counties.[26] The census region was categorized as Northeast, Midwest, South, or West.

Statistical and Spatial Analysis

We used descriptive analyses to summarize PD mortality across sociodemographic characteristics. Our study summarized categorical variables using frequencies and percentages, and continuous variables using the mean and standard deviation. Annual PD crude mortality rates (CMRs), age-adjusted mortality rates (AAMRs), and corresponding 95% confidence intervals (CIs) were obtained from the CDC Wonder. Results were presented using AAMRs with corresponding 95% CIs.

We explored geographic patterns of PD mortality by linking county-level mortality data with county shapefiles. County-level mortality and geographic datasets were merged using FIPS codes. Spatial relationships between counties were defined using a queen contiguity spatial weights matrix.[27] Furthermore, we used Global Moran's I to assess overall spatial autocorrelation.[28] Local Moran's I was then used to identify county-level spatial clusters and outliers of PD mortality.[29] Counties were categorized as High–High clusters, Low–Low clusters, High–Low outliers, Low–High outliers, and not statistically significant.

We used R version 4.5.1 on Windows for all analyses and visualizations.[30] The key tools for data cleaning were readr, dplyr, tidyr, stringr, and purr.[31] For spatial data and spatial analysis, we used sf, spdep, and spatialreg. We used broom for statistical summaries and model output.[32] Tables and publication formatting used knitr and gt. Data visualization used ggplot2.[30]

Results

A total of 263,531 PD deaths were recorded across the US between 2018 and 2024. As shown in Table 1, PD deaths were more common among males than females. Males accounted for 61.9% of deaths, while females accounted for 38.1% of deaths. Deaths were higher in older age groups, with 45.5% of deaths occurring among adults aged 75–84 years and 39.2% of deaths among adults aged 85 years and older.

Together, adults aged 75 years and older accounted for approximately 84.7% of PD deaths. By race, most deaths occurred among white people, who accounted for 93% of all deaths (93.0%). By ethnicity, non-Hispanics or Latinos accounted for 94.4%. According to the census region, the South accounted for the largest share of PD deaths (38.7%), followed by the Midwest (22.7%), West (22.2%), and Northeast (16.4%1). By urbanization, PD deaths were most concentrated in large fringe metro (25.9%) and large central metro (24.9%) counties, accounting for over half of the PD deaths. Nonmetropolitan counties, including micropolitan (9.8%) and noncore (6.0%) areas, together accounted for 15.8% of deaths. At the county level, the mean number of PD deaths per county was 112 (SD = 264.1) while the mean crude PD mortality rate was 14.1 per 100,000 (SD = 4.9). The mean county population was 964,970 (SD = 2,659,412). The mean county poverty rate was 14.0% (SD = 5.2), and the mean median household income was $69,743 (SD = $18,289).

Additional characteristics of PD mortality are shown in Supplementary Table S1. By place of death, PD deaths most often occurred at the decedent's home (39.6%) or in a nursing home/long-term care facility (38.9%), together accounting for nearly four out of five deaths. Less than 1% of deaths occurred in outpatient or emergency department settings. The annual number of PD deaths increased steadily during the study period, from 27,190 deaths (12.3%) in 2018 to 34,106 deaths (15.4%) in 2024. The largest increases were observed after 2019, with annual deaths exceeding 31,000 from 2020 onward.

Table 1
Sociodemographic and county-level characteristics of Parkinson's disease mortality, United States, 2018–2024

	Overall (N = 263,531)
	n (%)
Sex	
Female	97,560 (38.1%)
Male	158,638 (61.9%)
Age group	
45–54 years	28 (< 0.1%)
55–64 years	2,387 (1.0%)
65–74 years	35,079 (14.3%)
75–84 years	111,316 (45.5%)
85 + years	95,870 (39.2%)
Race	
American Indian or Alaska Native	262 (0.1%)
Asian	6,963 (2.7%)
Black or African American	10,563 (4.1%)
More than one race	286 (0.1%)
Native Hawaiian or Other Pacific Islander	17 (< 0.1%)
White	240,313 (93.0%)
Ethnicity	
Hispanic or Latino	14,448 (5.5%)
Not Hispanic or Latino	246,835 (94.4%)
Not Stated	129 (< 0.1%)

Notes: Values are presented as n (%) or mean (SD). The overall number of PD deaths was 263,531. Denominators for some decedent characteristics were smaller because CDC WONDER suppresses cells containing fewer than 10 deaths. As a result, 7,333 deaths were not represented in the sex-specific tabulation, 18,851 in the age-group tabulation, 5,127 in the race tabulation, and 2,119 in the ethnicity tabulation. Percentages were calculated using the available non-suppressed observations for each characteristic: sex, n = 256,198; age group, n = 244,680; race, n = 258,404; ethnicity, n = 261,412; census region, n = 263,531; and urbanization, n = 263,531. County-level summaries were based on 2,352 counties with available mortality data. Percentages may not total 100% because of rounding. PD = Parkinson's disease; SD = standard deviation.

	Overall (N = 263,531)
	n (%)
Census region	
Northeast	43,201 (16.4%)
Midwest	59,748 (22.7%)
South	102,054 (38.7%)
West	58,528 (22.2%)
Urbanization	
Large Central Metro	65,514 (24.9%)
Large Fringe Metro	68,356 (25.9%)
Medium Metro	59,997 (22.8%)
Micropolitan (Nonmetro)	25,747 (9.8%)
NonCore (Nonmetro)	15,762 (6.0%)
Small Metro	28,155 (10.7%)
County-level measures	
PD deaths per county, mean (SD)	112 (264.1)
Population (2018–2024), mean (SD)	964,970 (2,659,412)
Crude PD mortality rate, mean (SD)	14.1 (4.9)
Poverty rate, mean (SD)	14 (5.2)
Median household income, mean (SD)	$69,743 ($18,289)

Notes: Values are presented as n (%) or mean (SD). The overall number of PD deaths was 263,531. Denominators for some decedent characteristics were smaller because CDC WONDER suppresses cells containing fewer than 10 deaths. As a result, 7,333 deaths were not represented in the sex-specific tabulation, 18,851 in the age-group tabulation, 5,127 in the race tabulation, and 2,119 in the ethnicity tabulation. Percentages were calculated using the available non-suppressed observations for each characteristic: sex, n = 256,198; age group, n = 244,680; race, n = 258,404; ethnicity, n = 261,412; census region, n = 263,531; and urbanization, n = 263,531. County-level summaries were based on 2,352 counties with available mortality data. Percentages may not total 100% because of rounding. PD = Parkinson's disease; SD = standard deviation.

Annual trends in age-adjusted PD mortality rates

Figure 1 shows annual age-adjusted PD mortality rates in the United States from 2018 to 2024. PD mortality rates increased from 8.6 deaths per 100,000 (95% CI: 8.5–8.7) in 2018 to 8.8 per 100,000 (95%

CI: 8.7–8.9) in 2019. The rate increased to 9.8 per 100,000 (95% CI: 9.7–9.9) in 2020, coinciding with the onset of the COVID-19 pandemic. Rates remained elevated at 9.8 per 100,000 (95% CI: 9.7–9.9) in 2021, then declined to 9.5 per 100,000 (95% CI: 9.4–9.6) in both 2022 and 2023. By 2024, the age-adjusted mortality rate had further decreased to 9.3 per 100,000 (95% CI: 9.2–9.3). While there was a post-pandemic decline, the 2024 rate remained higher than pre-pandemic levels observed in 2018 and 2019 at 8.6 and 8.8 per 100,000, respectively.

Age-adjusted PD mortality trends by sex

Males consistently had higher PD mortality rates than females across all the study years (Fig. 2). Among males, rates increased from 12.8 per 100,000 (95% CI: 12.6–13.0) in 2018 to a peak of 14.4 per 100,000 (95% CI: 14.2–14.6) in both 2020 and 2021, before declining to 13.5 per 100,000 (95% CI: 13.4–13.7) in 2024. Among females, rates followed a similar pattern, rising from 5.7 per 100,000 (95% CI: 5.6–5.8) in 2018 to a peak of 6.5 per 100,000 (95% CI: 6.4–6.6) in 2020 and 2021, before declining to 6.1 per 100,000 (95% CI: 6.0–6.2) in 2024. Throughout the study period, male PD mortality rates were approximately two times higher than those among females. For both males and females, rates in 2024 remained higher than pre- pandemic rates.

Age-adjusted PD mortality trends by race

Figure 3 shows age-adjusted PD mortality rates by race from 2018 to 2024. White populations consistently had the highest mortality rates throughout the study period, increasing from 9.2 per 100,000 (95% CI: 9.1–9.3) in 2018 to a peak of 10.6 per 100,000 (95% CI: 10.5–10.7) in both 2020 and 2021, before declining to 10.1 per 100,000 (95% CI: 10.0–10.2) in 2024. Asian populations had the second-highest rates, rising from 5.3 per 100,000 (95% CI: 4.9–5.6) in 2018 to a peak of 6.1 per 100,000 (95% CI: 5.7–6.5) in 2021, followed by a decline to 5.6 per 100,000 (95% CI: 5.3–5.9) in 2024. PD mortality among Black or African American populations increased from 4.9 per 100,000 (95% CI: 4.6–5.1) in 2018 to 5.6 per 100,000 (95% CI: 5.3–5.8) in 2020, then gradually declined to 4.8 per 100,000 (95% CI: 4.6–5.0) in 2024. Lower and more stable mortality rates were observed among American Indian or Alaska Native populations, ranging from 3.8 (95% CI: 3.2–4.5) to 4.7 (95% CI: 3.9–5.7) per 100,000, and among individuals reporting more than one race, ranging from 2.5 (95% CI: 2.0–3.2) to 3.0 (95% CI: 2.4–3.7) per 100,000. Native Hawaiian or Other Pacific Islander populations had the most variable estimates across the study period, ranging from 2.6 (95% CI: 1.3–4.6) to 4.8 (95% CI: 3.0–7.3) per 100,000. Across most racial groups, there was a pattern of increased mortality during 2020–2021, followed by a decline or stabilization through 2024.

Spatial Analysis of County-Level PD Mortality in the United States

Local Moran's I (LISA) analysis identified 114 High-High clusters and 115 Low-Low clusters, with 16 High-Low and 43 Low-High spatial outliers, out of 2,344 counties analyzed (Fig. 4). High-High clusters, which were counties with higher-than-expected PD mortality surrounded by similarly high-mortality neighbors, were concentrated primarily in the central United States, particularly across Kansas, Nebraska, and parts of the South, including Kentucky, Mississippi, and Louisiana. Low-Low clusters, indicating counties with lower-than-expected mortality surrounded by similarly low-mortality neighbors, were most prominent in southern California, Arizona, southern Florida, and parts of the Northeast.

Getis-Ord Gi* analysis showed the geographic intensity of these clusters (Fig. 5). A total of 72 counties were classified as hot spots at the 99% confidence level, 126 at the 95% level, and 86 at the 90% level. Cold spots were similarly distributed, with 60 counties at the 99% level, 98 at the 95% level, and 97 at the 90% level. The most statistically significant hot spots were concentrated in counties in south-central Nebraska and north-central Kansas, with additional clusters in west Texas and parts of the South. The top county-level hot spots by Gi* z-score included Jefferson County, NE (SMR = 2.21; z = 5.31), Madison County, NE (SMR = 2.18; z = 3.78), Washington County, KS (SMR = 1.65; z = 6.36), and Lubbock County, TX (SMR = 1.44; z = 3.72), all classified as hot spots at the 99% confidence level. The Getis-Ord Gi* hot spots were spatially concordant with the LISA High-High clusters, both identifying the same high-mortality concentrations in Nebraska, Kansas, and west Texas, supporting the robustness of these findings to the choice of local statistic.

Global spatial autocorrelation analysis confirmed that county-level PD mortality was non-randomly distributed across the United States. The Global Moran's I statistic showed statistically significant positive spatial autocorrelation (Moran's I = 0.223; p = 0.001), suggesting that counties with higher-than-expected PD mortality tended to cluster geographically near other high-mortality counties, and vice versa (Fig. 6).

Discussion

This study examined county-level spatial patterns in PD mortality across the United States from 2018 to 2024, using CDC WONDER death certificate data. Our findings revealed several patterns which include; (1) a sustained increase in age-adjusted PD mortality over the study period, with a marked spike during the COVID-19 pandemic in 2020–2021 that hasn’t fully returned to pre-pandemic levels; (2) consistently higher mortality among males and White populations; (3) significant positive spatial autocorrelation in county-level PD mortality, indicating non-random geographic clustering; and (4) identifiable hotspots concentrated in the central United States, particularly in Nebraska, Kansas, west Texas, and parts of the South. Overall, the findings reveal marked geographic differences in PD mortality and emphasize the need for county-level spatial surveillance to support targeted public health planning.

The observed increase in PD mortality from 8.6 per 100,000 in 2018 to a peak of 9.8 per 100,000 in 2020–2021 is consistent with prior national studies from 1999 to 2020, which reported rising PD-related mortality in the United States.[13] The sharp increase observed during 2020–2021 coincides with the

onset of the COVID-19 pandemic. This could be explained by several mechanisms. First, individuals with PD are elderly and have multiple comorbidities, making them very vulnerable to severe COVID-19 disease and death. Second, pandemic-related disruptions to healthcare access, like foregone outpatient visits and disrupted medication refills management, may have worsened outcomes for people living with PD. Third, COVID-19 may have acted as a competing cause of death that influenced death certification patterns, potentially inflating deaths coded with PD as the underlying cause. Some studies found that PD-related mortality increased during the COVID-19 pandemic, with the largest rise occurring when PD was listed anywhere on the death certificate rather than as the only underlying cause of death.[33] Despite the post-pandemic decline to 9.3 per 100,000 in 2024, rates remained above pre-pandemic levels, consistent with an underlying long-term upward trajectory due to population aging and with global projections suggesting that PD deaths will continue to increase over the coming decades as the population ages.[12]

The finding that male PD mortality rates were approximately twice those of females throughout the study period is consistent with prior research and known epidemiology of PD. The risk of developing PD is approximately 1.5 to 2 times higher in men than in women. This pattern has been attributed to both biological and environmental factors. Studies have suggested that estrogens may offer neuroprotective effects, reducing dopaminergic neurodegeneration in women.[34] Additionally, greater oxidative stress in males may accelerate disease development.[35] Men are also more likely to be exposed to occupational and environmental neurotoxins, including pesticides, which are established risk factors for PD.[7,36] It is also important to note that both sexes exhibited parallel temporal trends, including the COVID-19 peak and the subsequent decline, suggesting that the pandemic's impact on PD mortality did not differ in direction between sexes.

White populations consistently experienced the highest mortality rates throughout the study period, followed by Asian populations, while Black or African American, American Indian or Alaska Native, Native Hawaiian or Other Pacific Islander, and multiracial populations had substantially lower mortality rates. The consistently higher PD mortality observed among white populations is consistent with previous research showing higher PD prevalence, incidence, and mortality among white individuals than other racial groups.[6] Several mechanisms have been proposed, including differences in disease incidence, genetic susceptibility, environmental exposures, healthcare utilization, and accurate diagnosis. White populations have historically been more likely to receive a diagnosis of PD and specialized neurological care, increasing the likelihood that PD is recorded on death certificates. On the other hand, lower mortality rates among minority populations should not be interpreted as evidence of a lower disease burden. Rather, they may reflect longstanding inequities in access to neurologic care, delayed diagnosis, under-recognition of PD symptoms, and differences in death certificate reporting. Literature suggests that racial disparities in PD extend beyond mortality. Black patients are less likely to be evaluated by neurologists or movement disorder specialists, receive antiparkinsonian medications, undergo advanced therapies such as deep brain stimulation, or participate in clinical research.[6,37] These disparities likely contribute to delayed diagnosis and differences in disease management, while also affecting the

accuracy of mortality surveillance.[38] Structural barriers like healthcare access, socioeconomic disadvantage, provider bias, and geographic availability of specialist services have been identified as important contributors to these inequities.[15,39] The Global Moran's I statistic of 0.223 (p = 0.001) indicated statistically significant positive spatial autocorrelation in county-level PD mortality, consistent with prior evidence of non-random geographic clustering of PD burden in the United States. In a study of Medicare beneficiaries, geographic clustering of higher PD incidence was identified in the Midwest and the Northeastern United States, and Lanska documented geographic variation in PD mortality across states in 1997.[14,15] Our findings extend this literature by applying Local Moran's I and Getis-Ord Gi* analyses at the county level to more recent mortality data, providing finer spatial resolution than prior state-level analyses.

The concentration of High-High mortality clusters and statistically significant hotspots in counties across Nebraska, Kansas, western Texas, and parts of the South is a particularly important finding. These regions are characterized by intensive agricultural activity and historically high use of pesticides and herbicides. Research has found significant associations between county-level PD incidence in Nebraska and exposure to specific pesticide ingredients.[40,40] These findings suggest that agricultural pesticide exposure may be an important environmental determinant of the elevated PD mortality observed in these counties.[41] The Low-Low clusters in southern California, Arizona, southern Florida, and parts of the Northeast may reflect demographic factors such as younger or more racially diverse populations, differences in agricultural land use, or differential access to neurological care that can influence survival and cause-of-death coding. Spatial outliers, the High-Low and Low-High counties, represent areas where mortality differs markedly from neighboring counties and may reflect localized demographic concentrations, specific occupational exposures, or healthcare access disparities that may need further research.

Implications for Public Health

The identification of statistically significant PD mortality hotspots in agricultural regions of the United States has important implications for public health surveillance, healthcare planning, and environmental policy. Counties in Nebraska, Kansas, and west Texas with SMRs exceeding 2.0 represent areas where PD mortality burden is more than double that expected based on national age-specific rates. These findings provide a basis for prioritizing neurological care resources, expanding access to movement disorder specialists, promoting earlier diagnosis, and strengthening community-based support services in high-burden areas. They also highlight geographic areas where enhanced environmental health surveillance and epidemiologic investigations may help identify potentially modifiable risk factors. Although our study is ecological and cannot establish causality, the geographic overlap between PD mortality hotspots and regions of intensive agricultural activity supports continued investigation into the potential contribution of environmental exposures, including agricultural pesticides. The sustained elevation of PD mortality above pre-pandemic levels through 2024 highlights the importance of continued surveillance of neurodegenerative disease outcomes post-COVID. Continued monitoring will

be essential to distinguish temporary pandemic-related effects from longer-term changes in PD mortality patterns and to inform future healthcare planning for aging populations.

Study Limitations

Estimates of mortality were based on death certificate data and may be subject to underreporting or misclassification of PD as the underlying cause of death. Because the study was based on PD mortality rather than disease incidence or prevalence, the findings should be interpreted in terms of disease burden and mortality patterns, not disease occurrence. Our study period also overlapped with the COVID-19 pandemic, which may have affected mortality patterns and death-certification practices. Factors which may affect geographic variation in PD mortality, such as environmental exposures, occupational risks, access to health care, quality of care, or diagnostic practices, were not assessed in the study. The analysis was designed to describe geographic patterns and spatial clustering of PD and cannot prove causal relationships. County-level analyses may mask important within-county heterogeneity, particularly in large and demographically diverse counties.

Counties with PD death counts below the CDC WONDER suppression threshold (fewer than ten deaths) were excluded. These are mostly rural, low-population counties; thus, the analytic sample may be spatially structured and underrepresent such counties. County SMRs are less stable in counties with small populations, which could influence local cluster and hotspot designations. Expected deaths were estimated by multiplying the 2024 ACS population by seven study years, assuming a stable population over the 2018–2024 period. However, county boundaries are administrative units, so results may be sensitive to the modifiable areal unit problem and to edge effects.

Conclusion

PD mortality in the United States shows significant county-level geographic clustering at county level. Our study identified areas of elevated burden concentrated in parts of the Midwest and South. These findings demonstrate that PD mortality is not uniformly distributed across the country. The findings also highlight the value of spatial analyses for identifying communities disproportionately affected by the disease. By mapping mortality patterns and hotspots, this study provides information that may help guide future research. In addition, the study may help with public health planning and resource allocation. Further research is needed to better understand the factors underlying these geographic patterns and their implications for the burden of PD.

Abbreviations

AAMR
Age-Adjusted Mortality Rate
ACS
American Community Survey
CDC

Centers for Disease Control and Prevention
CI
Confidence Interval
CMR
Crude Mortality Rate
GIS
Geographic Information System
ICD-10
International Classification of Diseases, Tenth Revision
LISA
Local Indicators of Spatial Association
PD
Parkinson Disease
SD
Standard Deviation
SMR
Standardized Mortality Ratio
WONDER
Wide-ranging Online Data for Epidemiologic Research

Declarations

Ethics approval

The study is a secondary analysis of deidentified data. Mortality data were from the CDC WONDER Underlying Cause of Death database. This is a public-use mortality database maintained by the National Center for Health Statistics (NCHS). County-level socioeconomic variables such as poverty and median household income were obtained from the U.S. Census Bureau's American Community Survey (ACS) 5-year estimates. Geographic boundary files were downloaded from the U.S. Census Bureau's TIGER/Line Shapefiles. This study was exempt from Institutional Review Board review and informed consent requirements because all data were publicly available and de-identified.

Consent to publish

All authors have approved the publication of this manuscript.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable

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This study received no funding.

Author Contribution

EWNC, EN, BFB: Conceptualization of the study, study methodology, design, drafting of the manuscript, manuscript writing, reviewing, and editing. EWNC, BFB: Data acquisition. EWNC, BFB, EDM, PK: Data management, Data analysis, results writing. PK, EDM, and ERF: editing the manuscript. ERF: approval of the manuscript. ERF: Study supervision and project oversight.

Data Availability

All datasets used in this study are publicly available from their respective sources. Mortality data are available from the CDC WONDER Underlying Cause of Death database (https://wonder.cdc.gov/ucd-icd10-expanded.html). We obtained county-level socioeconomic data from the U.S. Census Bureau American Community Survey (ACS) 5-year estimates (https://www.census.gov/programs-surveys/acs and https://data.census.gov/). Finally, our geographic boundary files for spatial analyses and mapping were downloaded from the U.S. Census Bureau TIGER/Line Shapefiles (https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html).

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Figures

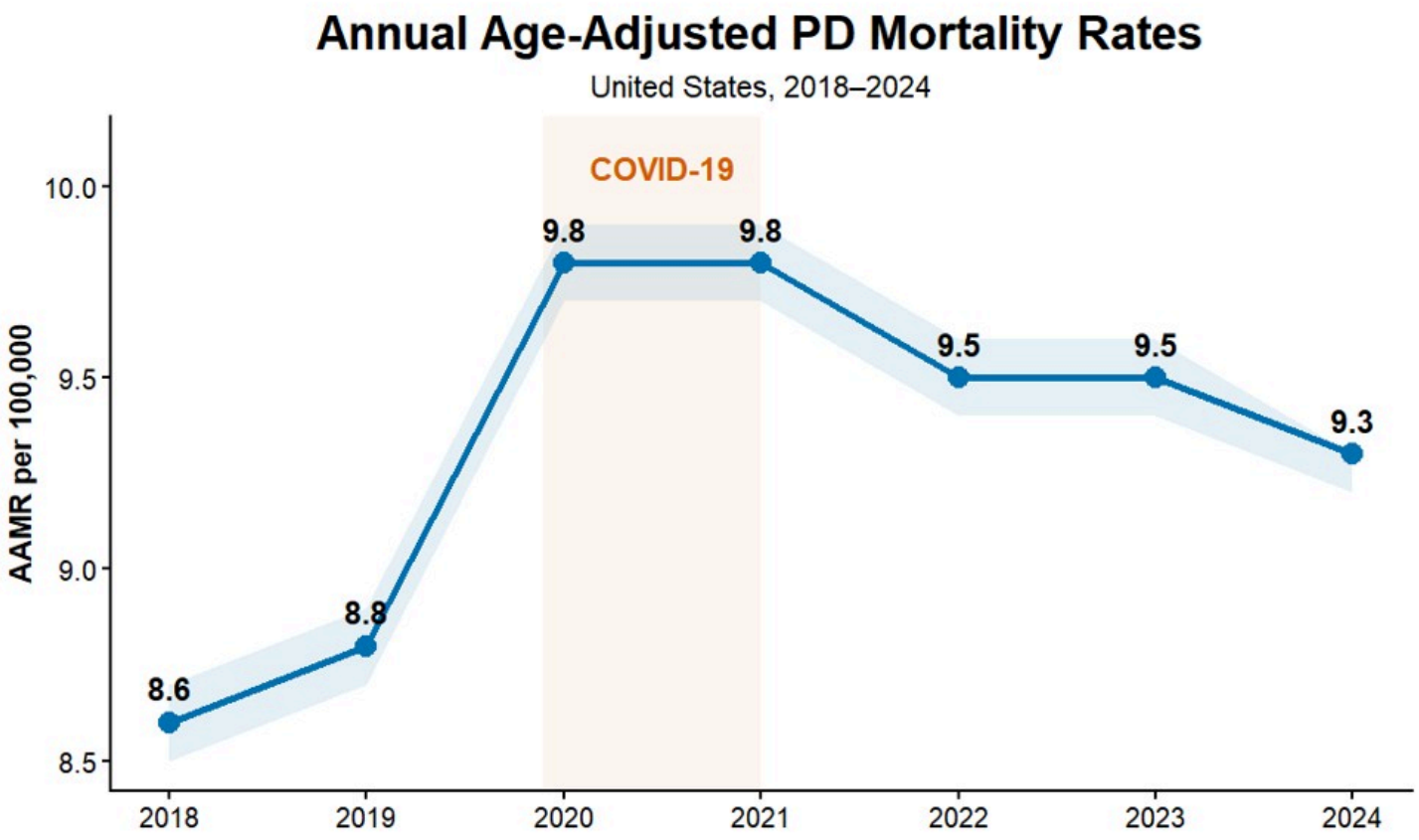

Figure 1

Annual Age- Adjusted PD Mortality Rates in the United States, 2018-2024

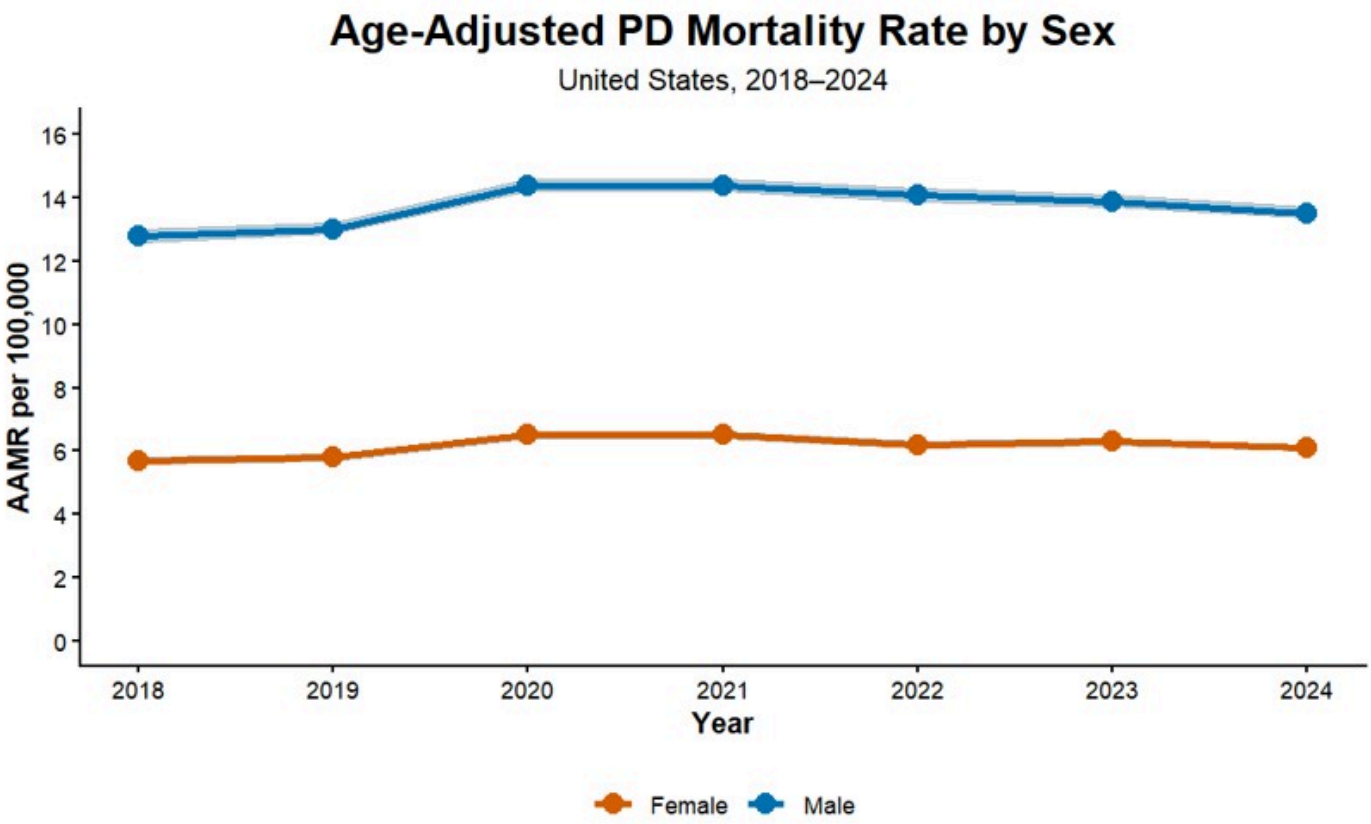

Figure 2

Age- Adjusted PD Mortality rates by sex in the United States, 2018-2024

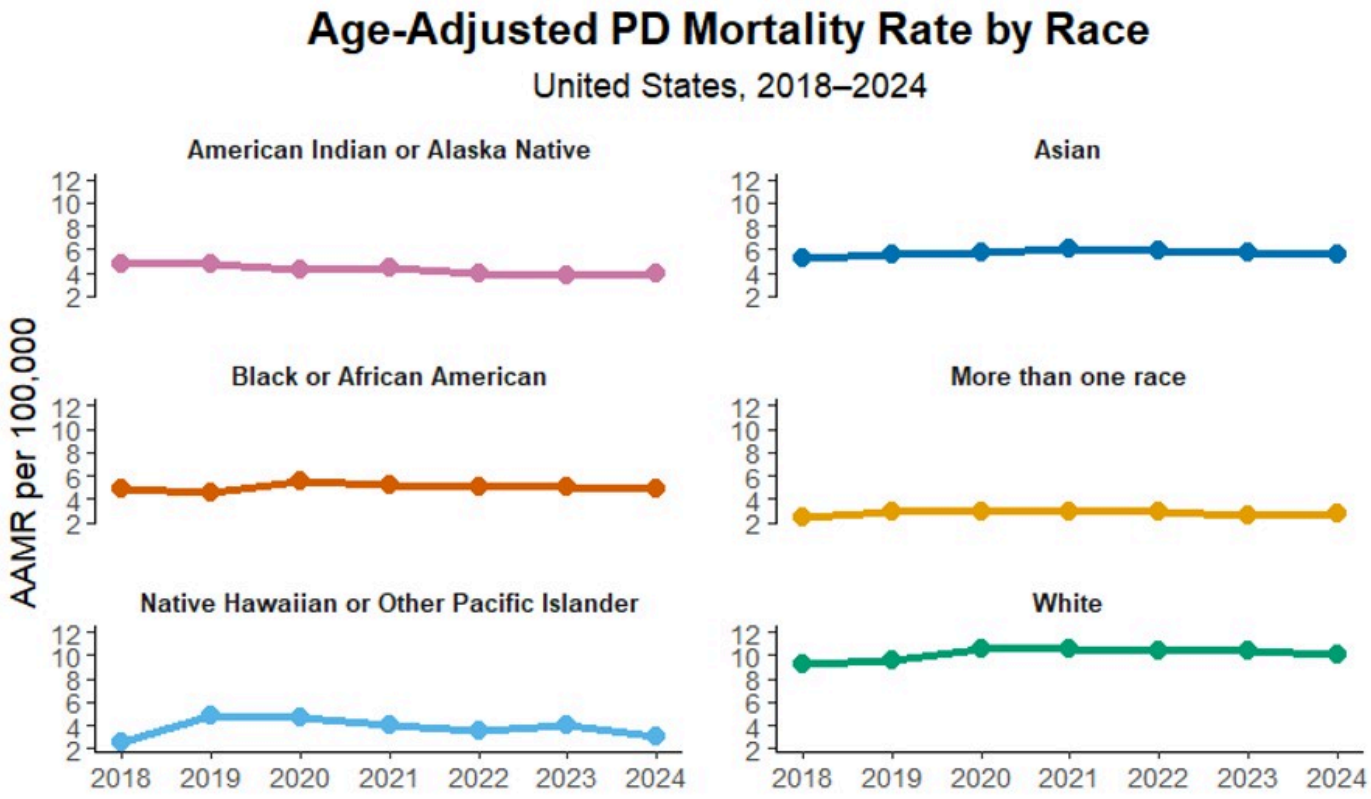

Figure 3

Age-adjusted PD mortality rate by race in the United States, 2018-2024

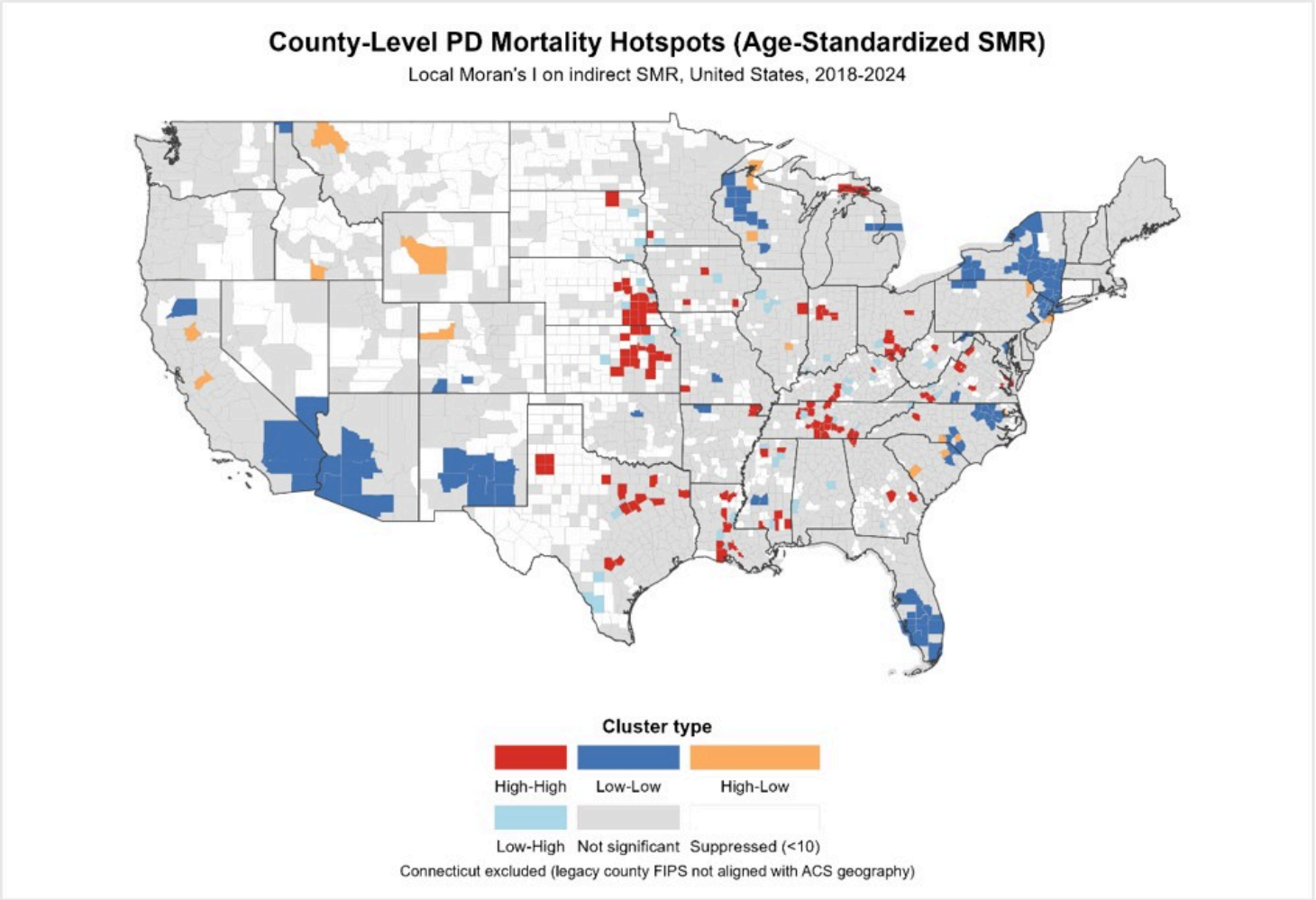

Figure 4

Local Moran's I spatial clusters of county-level Parkinson's disease mortality, United States, 2018–2024

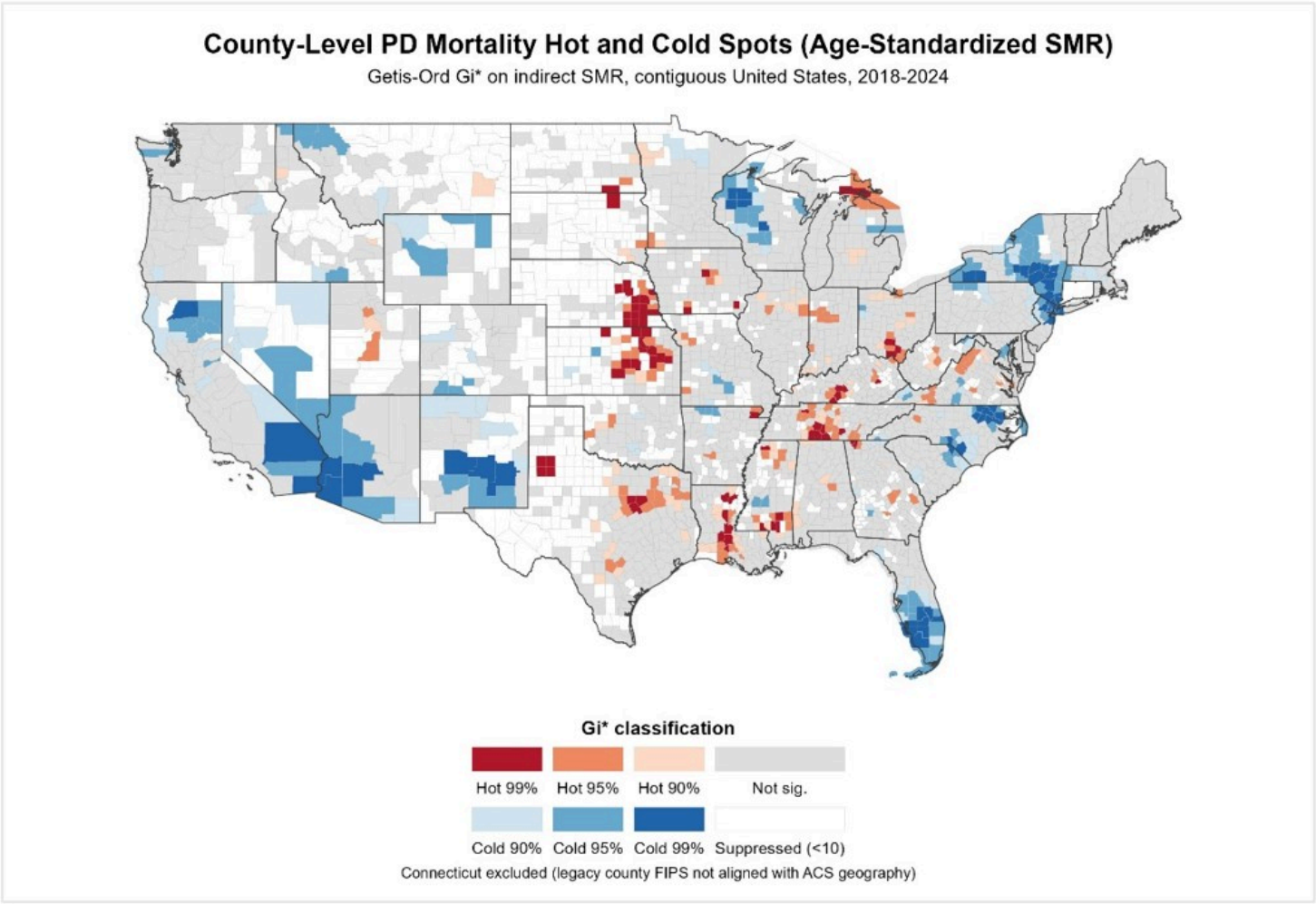

Figure 5

Getis-Ord Gi* hot and cold spots of county-level Parkinson's disease mortality, United States, 2018–2024

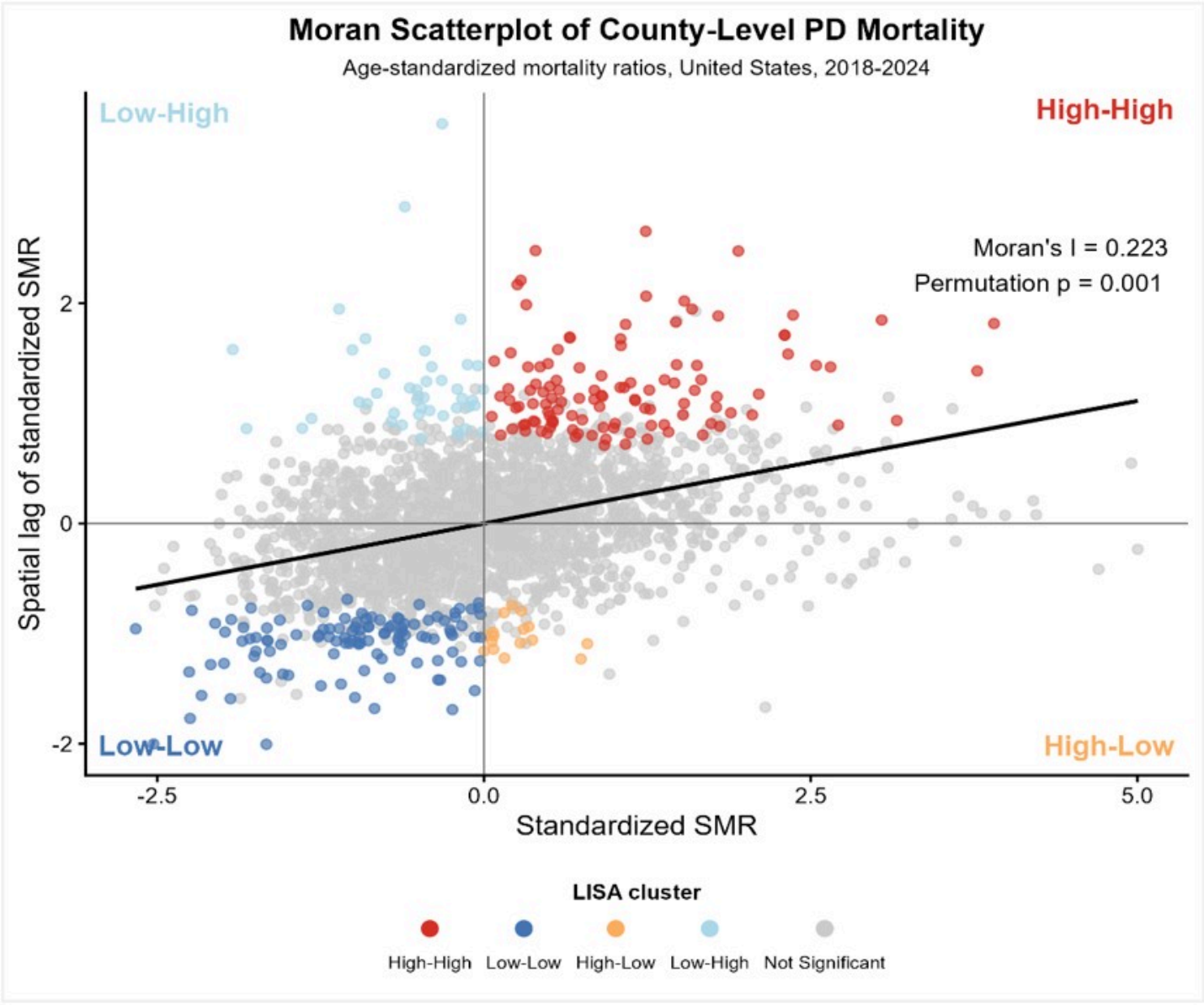

Figure 6

Global Moran's I scatter plot of county-level Parkinson's disease standardized mortality ratios, United States, 2018–2024

Supplementary Files

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- TableS1.docx