*European Journal of Neurology*

european journal of neurology
the official journal of the european academy of neurology

ORIGINAL ARTICLE OPEN ACCESS

# Impact of Marine Microplastics on Neurologic and Functional Disabilities: A Population-Level Study

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**Received:** 8 February 2025 | **Revised:** 21 March 2025 | **Accepted:** 25 March 2025

**Funding:** The authors received no specific funding for this work.

**Keywords:** cognitive dysfunction | environmental exposure | exposome | microplastics | persons with disabilities

## ABSTRACT

**Background:** Microplastics are emerging as environmental pollutants with potential neurotoxic effects, yet their association with neurological disabilities remains largely unexplored.

**Methods:** In this cross-sectional study comprising 218 coastal counties in the United States, we compared the self-reported prevalence of cognitive disability, mobility disability, self-care disability, and independent living disability in counties with very high and low marine microplastic levels (MMLs). Unadjusted and adjusted prevalence ratios (PRs) were computed using population-weighted quasi-Poisson regression across three different models to examine the relationship between disability prevalence and MMLs.

**Results:** Counties exposed to very high marine microplastic levels had a higher mean prevalence of self-reported cognitive disability (15.2% vs. 13.9%), mobility disability (14.1% vs. 12.3%), self-care disability (4.2% vs. 3.6%), and independent living disability (8.5% vs. 7.7%) compared to those exposed to low levels ($p < 0.001$). Regression analyses revealed significantly elevated adjusted prevalence ratios (PRs) for cognitive (PR: 1.09 [95% CI: 1.06–1.12], $p < 0.001$), mobility (PR: 1.06 [1.03–1.10], $p < 0.001$), self-care (PR: 1.16 [1.11–1.20], $p < 0.001$), and independent living disability (PR: 1.08 [1.05–1.12], $p < 0.001$) in counties with very high microplastic exposure compared to those with low exposure.

**Conclusions:** This study highlights a significant association between marine microplastic pollution and the self-reported prevalence of cognitive, mobility, self-care, and independent living disabilities at the county level. While merely associative, these findings emphasize the urgent need for further investigation into the individual-level health impacts of microplastic exposure and underscore the importance of environmental interventions to mitigate potential risks.

Bhargav Makwana and Brinda Desai have contributed equally.

## 1 | Introduction

Cognitive decline and dementia represent significant global health challenges, characterized by progressive impairment of cognitive abilities potentially resulting in difficulty in cognitive and executive function, mobility, and ability to care for self, among others. In 2020, more than 55 million people were living with dementia worldwide. This figure is projected to nearly double every 20 years, with an estimated 78 million cases in 2030 and 139 million in 2050 [1].

In recent years, growing attention has focused on the potential role of environmental pollutants in cognitive decline. Factors such as particulate matter, toxic heavy metals, electromagnetic fields, pesticides, sulfur dioxide ($SO_2$), neighborhood socioeconomic status, and rural living have been identified as possible risks [2]. Microplastics (MPs) have emerged as a particularly concerning contaminant.

Microplastics (MPs) are defined as plastic particles $<5$ mm in diameter. While microplastics are ubiquitous in the global environment and have been detected in food, soil, and air, marine microplastics can be a potential source of exposure to humans [3, 4].

Once in the circulatory system, MPs can induce oxidative stress, upregulate pro-inflammatory cytokines, decrease cell viability, and alter energy metabolism [3]. Of particular concern is the ability of MPs to cross the blood–brain barrier (BBB), potentially triggering neuroinflammation and contributing to neurodegenerative processes [5].

Although the full cognitive impact of microplastic exposure remains unclear, emerging evidence suggests a link to neurodegenerative disorders [6–12]. While the implications of different subtypes of microplastics on human health can be broad, this research article specifically explores marine microplastics' impact on vital neurological functions, including cognition, mobility, self-care, and independent living abilities.

## 2 | Methods

### 2.1 | Analytic Sample Collection and Assimilation

The National Centers for Environmental Information's (NCEI's) marine microplastics geodatabase was leveraged to obtain data on microplastic concentration in ocean water settings between January 1, 2015 and December 30, 2020. Microplastic concentration was measured at specific geo-coded locations using grab samples or plankton net tows [13, 14]. The data was filtered using ArcGIS Online to include geo-points within 200 nautical miles (equivalent to 230 miles) of the United States territorial sea margin. These limits correspond to the outer margin of the "Exclusive Economic Zone (EEZ)," defined by the United Nations Convention on the Law of Sea as an area of the ocean within which a coastal nation has sovereign rights to explore, exploit, conserve, and manage living and non-living resources [15]. Counties with their boundaries adjacent to the coastline were identified as "coastal counties" or "coastline counties" for our study. The list of coastline counties is publicly available from the United States Census Bureau resource library [16]. Two layers were created in ArcGIS, one consisting of coastal counties and another comprising the geo-points representing microplastic concentration measured in the ocean water sample from 2015 to 2020 within the EEZs. We used the built-in analysis tools in ArcGIS Online to first calculate the mean of geo-points and assign them to the adjacent coastal county.

After tabulating the geodata, we stratified coastal counties into four categories based on mean MMLs assigned to them: low/Q1 (0–0.005 pieces/$m^3$), medium/Q2 (0.005–1 pieces/$m^3$), high/Q3 (1–10 pieces/$m^3$) and very high/Q4 ($\geq 10$ pieces/$m^3$). This categorization was based on the classification used in the Marine Microplastics Map Portal [17].

The Centers for Disease Control and Prevention's PLACES 2023 dataset, containing Behavioral Risk Factor Surveillance System (BRFSS) 2021 data, Census Bureau 2021 county population estimates, and American Community Survey (ACS) 2016–2020 estimates were used to obtain the county-level demographic characteristics and self-reported prevalence estimates of cognitive, mobility, self-care, and independent living disabilities and investigate their association with county-assigned MMLs [18, 19]. A detailed outcome measures definition is provided in Table S1. As publicly available deidentified data was used, institutional review board approval from Lahey Hospital and Medical Center was not required per institutional policy.

### 2.2 | County-Level Predictive Variables

We adjusted for the prevalence of chronic diseases, including type II diabetes, drug-controlled hypertension, coronary artery disease, stroke, and depression. As land-based activities significantly contribute to coastal pollution [20–22], and rapid urbanization of coastal areas may increase levels of social and economic inequalities [23, 24], we accounted for the county-level estimates of poverty, education, unemployment, transport, criteria air pollutants, including PM 2.5, $NO_2$, and ozone, as well as land use determinants, among others (Table S5). The socioeconomic and environmental domains of the baseline vulnerability theme of the climate vulnerability index (CVI, Methods S1, Figure S1, and Table S2) were used as a surrogate measure for these influencing factors [25]. The number of active federal and non-federal physicians in a county per 10,000 population was also used as a covariate to adjust for county-level variation in health resources distribution that could be associated with the differences in outcomes [25].

### 2.3 | Statistical Analysis

We employed quasi-Poisson regression to examine the association between the county-level prevalence of cognitive, mobility, self-care, and independent living disability among individuals $\geq 18$ years of age (response variable) and the category of MMLs in the surrounding ocean water body assigned to these counties (exposure variable). The quasi-Poisson regression analysis was preferred because (1) Overdispersion was observed when running a Poisson regression model (Table S3) and (2) the absolute concentration of MMLs was non-normally distributed across coastal counties (Figure S2).

Our analysis comprised three models: Model A was unadjusted and depicted the crude association between MMLs and the prevalence of neurologic disabilities. Model B was adjusted for age. Model C accounted for the prevalence of five chronic diseases (drug-controlled hypertension, coronary artery disease, stroke, and depression) known to be associated with neurologic disabilities, the number of physicians available per 10,000 people, and CVI's baseline socioeconomic and environmental vulnerability domains as co-variates in addition to age. The baseline health vulnerability domain of CVI was not used due to the overlap of its components with the outcome variables. We did not adjust for race/ethnicity in our main model as CVI's baseline socioeconomic vulnerability domain accounts for minorities residing within a county (Table S2). The proportion of males and females was comparable between counties with low and very high marine microplastic levels (Table 1), indicating no significant differences. Consequently, sex was not included as an adjustment variable in our analysis. The differences in population characteristics among Q4 (very high MMLs) and Q1 (low MMLs) counties were estimated using quartile rate ratios computed by fitting a quasi-Poisson regression model with county-assigned MMLs as independent and individual demographic characteristics as a dependent variable (weighted quartile rate ratio; Table 1). The models were weighted for the total population of the corresponding county based on the estimates from the 2016–2020 American Community Survey. The goodness-of-fit of our final adjusted model was validated by comparing it to a null model using the chi-squared goodness-of-fit test (Table S4). Multicollinearity between the predictor variables in the fully adjusted model was measured using the variance inflation factor for each independent variable (Table S5). Statistical analysis was done using the R version 4.3.3 packages "tidyverse," "gtsummary," "AER," "car," and "jtools" (R Foundation for Statistical Computing, Vienna, Austria). The statistical analysis was conducted from June 2024 to September 2024.

## 3 | Results

### 3.1 | Baseline Characteristics

The baseline characteristics are presented in Table 1. Our analysis of 218 coastline counties showed that the mean age (SD) was 41.6 (6.3) years. Marine microplastic levels (MMLs) were categorized as low (Q1), medium(Q2), high (Q3), and very high (Q4) in 55, 86, 28, and 49 counties, respectively. The proportion of males and females was not significantly different across county categories. The mean percentile rank of CVI's baseline socioeconomic and environmental vulnerability domain was 51st (SD 17) and 48th (SD 23), respectively, across all the 218 counties studied. The overall mean prevalence of comorbidities in these counties, including hypertension on treatment, coronary artery disease (CAD), type II diabetes, stroke, and depression, was 58.1% (SD 4.6%), 5.4% (SD 0.8%), 10.2% (SD 2.2%), 2.9% (SD 0.5%), and 21.4% (SD 3.5%), respectively.

A higher proportion of Black adults resided in coastline counties with very high MML compared to coastline counties with low MML (quartile rate ratio Q4/Q1: 2.68 [1.87, 3.85]). The prevalence of comorbidities such as hypertension on treatment (Q4/Q1: 1.06 [95% CI: 1.04, 1.08]), coronary artery disease (Q4/Q1: 1.14 [1.06, 1.22]), type II diabetes (Q4/Q1: 1.12 [1.05, 1.20]), stroke (Q4/Q1: 1.14 [1.07, 1.21]), and depression (Q4/Q1:1.07 [1.00, 1.16]) were higher in counties with very high MMLs compared to low. The overall mean prevalence of cognitive disability, mobility disability, self-care disability, and independent living disability was 13.5%, 12.4%, 3.7%, and 7.6%, respectively.

### 3.2 | Association Between Microplastic Concentration and Prevalence of Cognitive Disability

Counties with low MMLs had a significantly lower mean prevalence of cognitive disability (13,900 per 100,000 people; SD: 2300) than those with very high MMLs (15,200 per 100,000 people; SD: 2700; $p < 0.001$ using one-way ANOVA).

The unadjusted (Prevalence Ratio [PR] 1.15, 95% CI 1.08–1.22, $p < 0.001$), age-adjusted (PR 1.15, 95% CI 1.09–1.22, $p < 0.001$), and fully adjusted quasi-Poisson regression analysis (PR 1.09, 95% CI 1.06–1.12, $p < 0.001$) showed a significant association between counties potentially exposed to very high microplastic concentration and the prevalence of cognitive disability as compared to counties exposed to low microplastic concentration (Table 2).

### 3.3 | Association Between Microplastic Concentration and Prevalence of Mobility Disability

The mean prevalence of mobility disability was lower in counties with low MMLs (12,300 per 100,000 people; SD: 2700) compared to very high MMLs (14,100 per 100,000 people; SD: 2900; $p < 0.001$ using one-way ANOVA).

Counties potentially exposed to very high microplastic concentration had a significantly high prevalence of self-reported mobility disability as compared to low on unadjusted (PR 1.16, 95% CI 1.07–1.26, $p < 0.001$), age-adjusted (PR 1.18, 95% CI 1.09–1.28, $p < 0.001$), and fully adjusted quasi-Poisson regression analysis (PR 1.06, 95% CI 1.03–1.10, $p < 0.001$, Table 2).

### 3.4 | Association Between Microplastic Concentration and Prevalence of Self-Care Disability

Counties with very high MMLs had a significantly higher mean prevalence of self-care disability (4300 per 100,000; SD: 1100) compared to those with low MMLs (3600 per 100,000; SD: 900), highlighting the association between microplastic exposure and disability burden ($p < 0.001$, one-way ANOVA).

The unadjusted (PR 1.22, 95% CI 1.11–1, $p < 0.001$), age-adjusted (PR 1.23, 95% CI 1.12–1.36, $p < 0.001$), and fully adjusted quasi-Poisson regression analysis (PR 1.16, 95% CI 1.11–1.20, $p < 0.001$) showed a significant association between counties potentially exposed to very high microplastic concentration and the prevalence of self-care disability as compared to counties exposed to low microplastic concentration (Table 2).

**TABLE 1** | Demographic characteristics of the selected coastal counties stratified by marine microplastic levels (MMLs).

| Population characteristics | Overall | Marine microplastic levels (MMLs) | | | | Weighted quartile rate ratio (Q4/Q1) | *p* |
|---|---|---|---|---|---|---|---|
| | | Low, Q1 | Medium, Q2 | High, Q3 | Very high, Q4 | | |
| Total population | 6,21,51,867 | 1,96,91,272 | 1,73,43,473 | 1,67,13,520 | 84,03,602 | 0.41 (0.29, 0.56) | < 0.001 |
| Male (%) | 49.7 (2.8) | 51.6 (3.8) | 49.0 (2.3) | 48.4 (1.4) | 49.4 (1.7) | 0.99 (0.98, 1.00) | 0.2 |
| Female (%) | 50.3 (2.8) | 48.3 (3.8) | 50.9 (2.3) | 51.5 (1.4) | 50.6 (1.7) | 1.01 (1.00, 1.02) | 0.2 |
| Age | | | | | | | |
| Age (years) | 41.6 (6.3) | 41.4 (7.2) | 42.6 (6.1) | 41.7 (4.3) | 39.9 (6.2) | 0.97 (0.94, 1.01) | 0.13 |
| 18 to 44 years (%) | 33.3 (5.6) | 33.6 (5.8) | 32.6 (5.9) | 34.6 (5.1) | 33.6 (4.8) | 0.97 (0.92, 1.01) | 0.2 |
| 45 to 64 years (%) | 26.7 (3.4) | 26.5 (3.3) | 27.1 (2.6) | 27.8 (2.5) | 25.5 (4.4) | 0.95 (0.92, 0.99) | 0.005 |
| 65 years and over (%) | 18.8 (6.0) | 18.5 (7.4) | 19.6 (6.0) | 17.8 (3.7) | 17.9 (5.1) | 0.96 (0.88, 1.06) | 0.4 |
| Race and ethnicity | | | | | | | |
| One race (%) | 92.8 (4.4) | 91.5 (3.4) | 94.4 (2.3) | 93.8 (2.2) | 90.9 (6.9) | 0.98 (0.97, 1.00) | 0.016 |
| White (%) | 66.5 (19.3) | 64.2 (23.8) | 65.5 (15.5) | 71.5 (19.1) | 67.7 (19.5) | 0.98 (0.86, 1.11) | 0.7 |
| Black or African American (%) | 12.9 (13.9) | 3.4 (6.3) | 19.8 (14.7) | 9.7 (8.3) | 13.4 (14.3) | 2.68 (1.87, 3.85) | < 0.001 |
| American Indian and Alaska Native (%) | 4.0 (13.2) | 14.2 (23.4) | 0.3 (0.6) | 0.3 (0.2) | 1.0 (2.5) | 0.39 (0.11, 1.03) | 0.09 |
| Asian (%) | 5.0 (7.8) | 5.9 (8.0) | 4.5 (7.7) | 5.7 (5.6) | 4.5 (8.7) | 0.67 (0.46, 0.97) | 0.041 |
| Native Hawaiian and other Pacific Islander (%) | 0.43 (1.8) | 0.4 (0.6) | 0.1 (0.2) | 0.02 (0.04) | 1.2 (3.7) | 3.77 (2.10, 7.00) | < 0.001 |
| Hispanic or Latino (%) | 13.9 (16.0) | 10.6 (10.6) | 10.7 (9.7) | 15.5 (0.04) | 22.2 (25.8) | 0.94 (0.75, 1.17) | 0.6 |
| Not Hispanic or Latino (%) | 86.1 (16.0) | 89.3 (10.6) | 89.2 (9.7) | 84.4 (12.8) | 77.7 (25.8) | 1.03 (0.94, 1.13) | 0.5 |
| Socioeconomic parameters and comorbidities | | | | | | | |
| Baseline Socioeconomic Vulnerability Percentile Rank | 51 (17) | 56 (14) | 47 (17) | 40 (19) | 58 (15) | 0.95 (0.84, 1.07) | 0.4 |
| Baseline Environmental Vulnerability Percentile Rank | 48 (23) | 36 (28) | 51 (19) | 63 (19) | 50 (21) | 0.92 (0.84, 1.00) | 0.045 |
| Prevalence of cognitive disability (%) | 13.5 (2.5) | 13.9 (2.3) | 12.8 (2.1) | 11.5 (1.6) | 15.2 (2.6) | 1.15 (1.08, 1.22) | < 0.001 |
| Prevalence of mobility disability (%) | 12.4 (2.8) | 12.3 (2.7) | 12.0 (2.4) | 10.4 (2.3) | 14.1 (2.8) | 1.16 (1.07, 1.26) | < 0.001 |
| Prevalence of self-care disability (%) | 3.7 (1.0) | 3.6 (0.9) | 3.5 (0.9) | 3.0 (0.9) | 4.2 (1.1) | 1.22 (1.11, 1.33) | < 0.001 |

(Continues)

**TABLE 1** | (Continued)

| Population characteristics | Overall | Marine microplastic levels (MMLs) | | | | Weighted quartile rate ratio (Q4/Q1) | *p* |
|---|---|---|---|---|---|---|---|
| | | Low, Q1 | Medium, Q2 | High, Q3 | Very high, Q4 | | |
| Prevalence of independent living disability (%) | 7.6 (1.8) | 7.7 (1.8) | 7.2 (1.5) | 6.4 (1.3) | 8.5 (1.7) | 1.18 (1.09, 1.27) | <0.001 |
| Prevalence of hypertension on treatment (%) | 58.1 (4.6) | 53.2 (3.9) | 60.3 (3.5) | 58.1 (2.0) | 59.8 (3.6) | 1.06 (1.04, 1.08) | <0.001 |
| Prevalence of coronary artery disease (%) | 5.4 (0.8) | 5.5 (0.9) | 5.2 (0.6) | 4.7 (0.4) | 5.7 (0.6) | 1.14 (1.06, 1.22) | <0.001 |
| Prevalence of type II diabetes (%) | 10.2 (2.2) | 9.6 (1.9) | 10.3 (1.6) | 8.6 (1.9) | 11.3 (2.6) | 1.12 (1.05, 1.20) | <0.001 |
| Prevalence of stroke (%) | 2.9 (0.5) | 3.0 (0.6) | 2.9 (0.5) | 2.5 (0.3) | 3.1 (0.4) | 1.14 (1.07, 1.21) | <0.001 |
| Prevalence of depression (%) | 21.4 (3.5) | 22.3 (4.1) | 20.6 (2.5) | 20.9 (3.0) | 22.1 (4.2) | 1.07 (1.00, 1.16) | 0.056 |

*Note:* All population characteristics except total population are presented in the form of mean (SD). Total population is presented in the form of the sum of individual county population estimates from 2017 to 2021. Weighted quartile rate ratios along with p-values are computed by fitting a quasi-Poisson regression model with county-assigned MMLs as independent and individual demographic characteristics as a dependent variable. Statistical significance was defined as a $p$-value < 0.05.
Abbreviations: MML, marine microplastic levels; SD, standard deviation.

### 3.5 | Association Between Microplastic Concentration and Prevalence of Independent Living Disability

Counties with low MMLs had a significantly lower mean prevalence of independent living disability (7700 per 100,000 people; SD: 1800) than those with very high MMLs (8500 per 100,000 people; SD: 1800; $p < 0.001$ using one-way ANOVA).

Counties potentially exposed to very high microplastic concentration had a significantly high prevalence of self-reported independent living disability as compared to low concentration on unadjusted (PR 1.18, 95% CI 1.09–1.27, $p < 0.001$), age-adjusted (PR 1.19, 95% CI 1.10–1.29, $p < 0.001$), and fully adjusted quasi-Poisson regression analysis (PR 1.08, 95% CI 1.05–1.12, $p < 0.001$, Table 2).

Figure 1 shows the prevalence of cognitive and mobility disabilities, and Figure 2 shows the prevalence of self-care and independent living disabilities corresponding to the MMLs in the adjacent ocean surface water.

### 3.6 | Racial and Ethnic Majority-Based Subgroup Analyses

We performed a subgroup analysis to assess the association between MMLs and neurological disabilities among counties with above-median proportions of Whites, Blacks, Asians, and Hispanics. We observed similar results for all our selected outcomes based on race, albeit with wider confidence intervals in all racial and ethnic subgroups except Blacks (Table S6).

## 4 | Discussion

Our study analyzed 218 coastal counties in the United States, focusing on the correlation between microplastic levels in nearby ocean waters and functional neurologic disability among residents. Using ocean water samples collected between 2015 and 2020, we observed that counties exposed to high MMLs had increased rates of cognitive, mobility, self-care, and independent living disabilities after adjustment for age, physician access, comorbidities, and socioeconomic and environmental vulnerabilities of the communities residing in these counties.

This is one of the first studies investigating the population-level impact of microplastics on the potential downstream consequences of neurodegenerative diseases. Emerging evidence supports the interaction between marine microplastics in ocean water surface and the communities living in coastal areas. Seawater intrusion, defined as a phenomenon of mixing of seawater with groundwater, is well-documented in coastal areas [26–29]. Evidence shows this intrusion leads to contaminants, including microplastics, in coastal groundwater aquifers [30–33]. 35% of US drinking water comes from groundwater, potentially allowing microplastics to enter human bodies [34]. Moreover, microplastic contamination in seafood is widespread, as evidenced by a global review, which revealed that microplastics were detected in roughly 45% of fish consumed worldwide, averaging 5.93 microplastic particles per fish species [35]. The "Eat Like a Fish" project assessed the retail market's reflection of local marine ecosystems and showed the geographic differences in the variety of seafood. A decline was noted in seafood variety from coastal

**TABLE 2** | Prevalence ratios and confidence intervals for study outcomes.

| | Neurologic outcomes | Model type (A, B, or C) | Prevalence ratio (95% CI) | *p* |
|---|---|---|---|---|
| Marine microplastic level: very high | Cognitive disability | A | 1.15 (1.08, 1.22) | < 0.001 |
| | | B | 1.15 (1.09, 1.22) | < 0.001 |
| | | C | 1.09 (1.06, 1.12) | < 0.001 |
| | Mobility disability | A | 1.16 (1.07, 1.26) | < 0.001 |
| | | B | 1.18 (1.09, 1.28) | < 0.001 |
| | | C | 1.06 (1.03, 1.10) | < 0.001 |
| | Self-care disability | A | 1.22 (1.11, 1.33) | < 0.001 |
| | | B | 1.23 (1.12, 1.36) | < 0.001 |
| | | C | 1.16 (1.11, 1.20) | < 0.001 |
| | Independent living disability | A | 1.18 (1.09, 1.27) | < 0.001 |
| | | B | 1.19 (1.10, 1.29) | < 0.001 |
| | | C | 1.08 (1.05, 1.12) | < 0.001 |

*Note:* Model A is unadjusted and shows the raw association between coastal microplastic levels and neurologic outcomes. Model B shows the age-adjusted association between marine microplastic levels and neurologic outcomes. Model C is adjusted for the self-reported prevalence of five chronic diseases (type II diabetes, treatment-controlled hypertension, stroke, coronary artery disease, depression), number of physicians in the county per 10,000 people, as well as the baseline socioeconomic and environmental vulnerability domain of the US climate vulnerability index (CVI). Prevalence ratio depicts the prevalence of outcome in counties potentially exposed to very high marine microplastic levels as compared to low marine microplastic levels. Statistical significance was defined as a $p$-value $< 0.05$.

to inland areas [36]. After accounting for species, state, and market type, the number of seafood species with at least a 50% chance of being found decreased from 11 at coastal locations to just three at sites 100 miles inland [36]. Additionally, states with more extended coastlines generally offered a greater variety of local seafood [36]. This may suggest higher seafood consumption in coastal markets, assuming that availability loosely correlates with sales volume [36, 37]. While our findings suggest an association, causation cannot be inferred, as microplastic exposure may also result from migration, other sources like air and food, and local marine pollution.

One potential pathway for ingested microplastics to enter the bloodstream involves gut microbiome disruption, leading to intestinal barrier dysfunction and alteration in gastrointestinal absorption [38]. This allows microplastics to enter the bloodstream via paracellular transport or by being internalized by intestinal cells through epithelial villi [39, 40].

The downregulation of blood–brain-barrier (BBB) tight junction proteins, such as zoludin and occludin, seen in murine and in vitro models exposed to polystyrene nanoplastics, may be responsible for the dose-dependent deposition of microplastics and subsequent microglial activation in the hippocampus, hypothalamus, and cerebral cortex [9–11]. In Alzheimer's disease (AD) mice models, microplastic exposure increased neuronal inflammation and microglial pyroptosis compared to unexposed AD mice [7]. Additionally, in a nematode model of Parkinson's Disease (PD), exposure to microplastics induced the degeneration of dopaminergic neurons [8]. Researchers found significantly lower acetylcholine esterase (AChE) activity in wild fish species (*Dicentrarchus labrax*) with microplastics (MPs) in the brain compared to those without, negatively impacting neurodevelopmental events like cell migration, neurite outgrowth, and synaptogenesis [12]. Since the brain is highly susceptible to foreign substances, the transport of microplastics across the blood–brain barrier may lead to neuroinflammatory cellular changes [9, 12, 38, 41–45]. Microglial cells, which phagocytose microplastic particles deposited in the neurons, transition into a pro-inflammatory phenotype and release pro-inflammatory cytokines such as TNF-α, IL-1β, IL-6, and chemokines like CXCL10 and MCP-1 [9, 38, 41]. Alteration in the BBB permeability and neuroinflammation is further amplified by peripheral inflammation and increased levels of LPS, both caused by intestinal disruption [42–44]. Microplastics significantly alter the levels and functions of key neurotransmitters such as dopamine, glutamate, serotonin, gamma-aminobutyric acid (GABA), and acetylcholine and enzymes crucial for cholinergic transmission like acetylcholinesterase and acetylcholine transferase [38].

A key factor proving microplastic's direct correlation with proteinopathies and neurodegenerative diseases is the presence of α-synuclein aggregation induced by microplastics. In vitro, fibril formation and acceleration of fibril growth were directly triggered by the interaction of microplastics with α-synuclein [5]. Similarly, microplastics increased the number of α-synuclein aggregates per cell and the overall aggregate area in dopaminergic neurons in a PD model [8]. Microplastics co-injected with α-synuclein fibrils showed notably increased dispersion within cultured neurons [5]. In addition, nanoplastics accelerated the nucleation rate of Amyloid β subtypes—a key hallmark of AD. They facilitated the production of protein oligomers rather than fibrils linked to neuronal membrane damage [46]. Combining evidence from neurodegenerative disease models suggests that microplastics play a role in the development of Alzheimer's disease (AD) and Parkinson's disease (PD), leading to a decline in cognitive function, mobility,

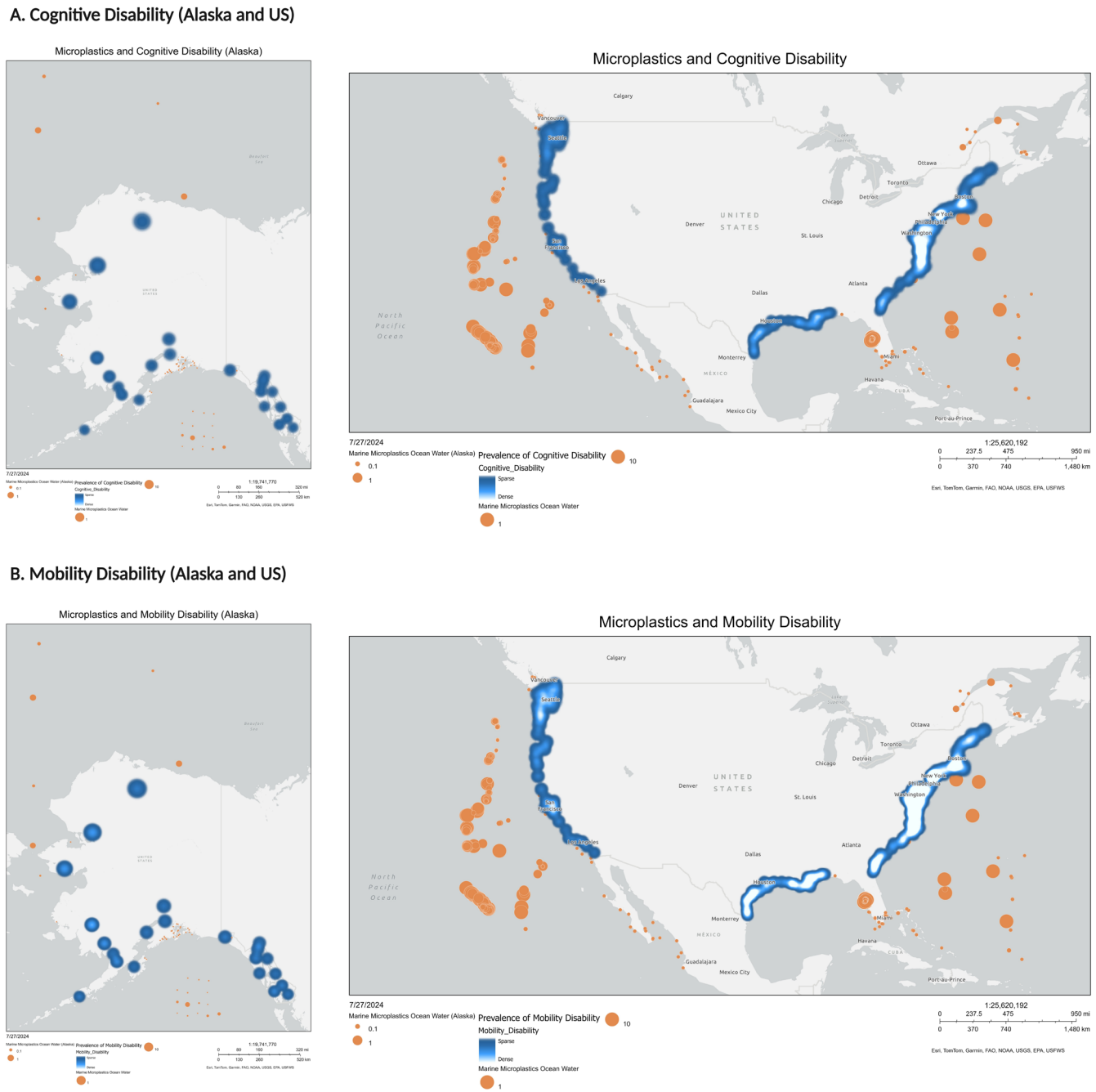


**FIGURE 1** | Marine microplastic levels and cognitive and mobility disability. Choropleth maps showing the prevalence of cognitive disability(A), mobility disability (B), as well as the marine microplastic levels in the adjacent ocean water in the US coastal counties (including Alaska). The blue fluorescent areas along the coastline represent the prevalence of disability, with higher fluorescence corresponding to a higher prevalence. The diameter of the orange bubble in the ocean is proportional to the absolute concentration of microplastic detected in the sample of ocean water collected at that site between 2015 and 2020.

self-care, and independence. These findings were further solidified when Nihart et al. [47] observed that the concentration of microplastics was significantly higher in post-mortem samples of the human brain compared to those in the liver and kidney. Additionally, decedents with diagnosed dementia had a significantly greater microplastic concentration in their frontal cortex compared to those without dementia [47]. The results, while merely associative and limited by analytic techniques, suggest the need to understand microplastics' role in neurological disorders at a granular level.

Although no study directly assessed the impact of microplastics on functional neurologic status, accentuating the progression of Alzheimer's disease (AD) and Parkinson's disease (PD) is known to impair cognition, physical function, and the ability to live independently, which corresponds with the results observed in our study [48, 49]. Furthermore, micro- and nanoplastics within human carotid plaque were associated with a higher incidence of stroke, which may result in cognitive impairment [50]. Hence, we have robustly adjusted for the prevalence of stroke and CAD to delineate their superimposing effects on neurologic disabilities.

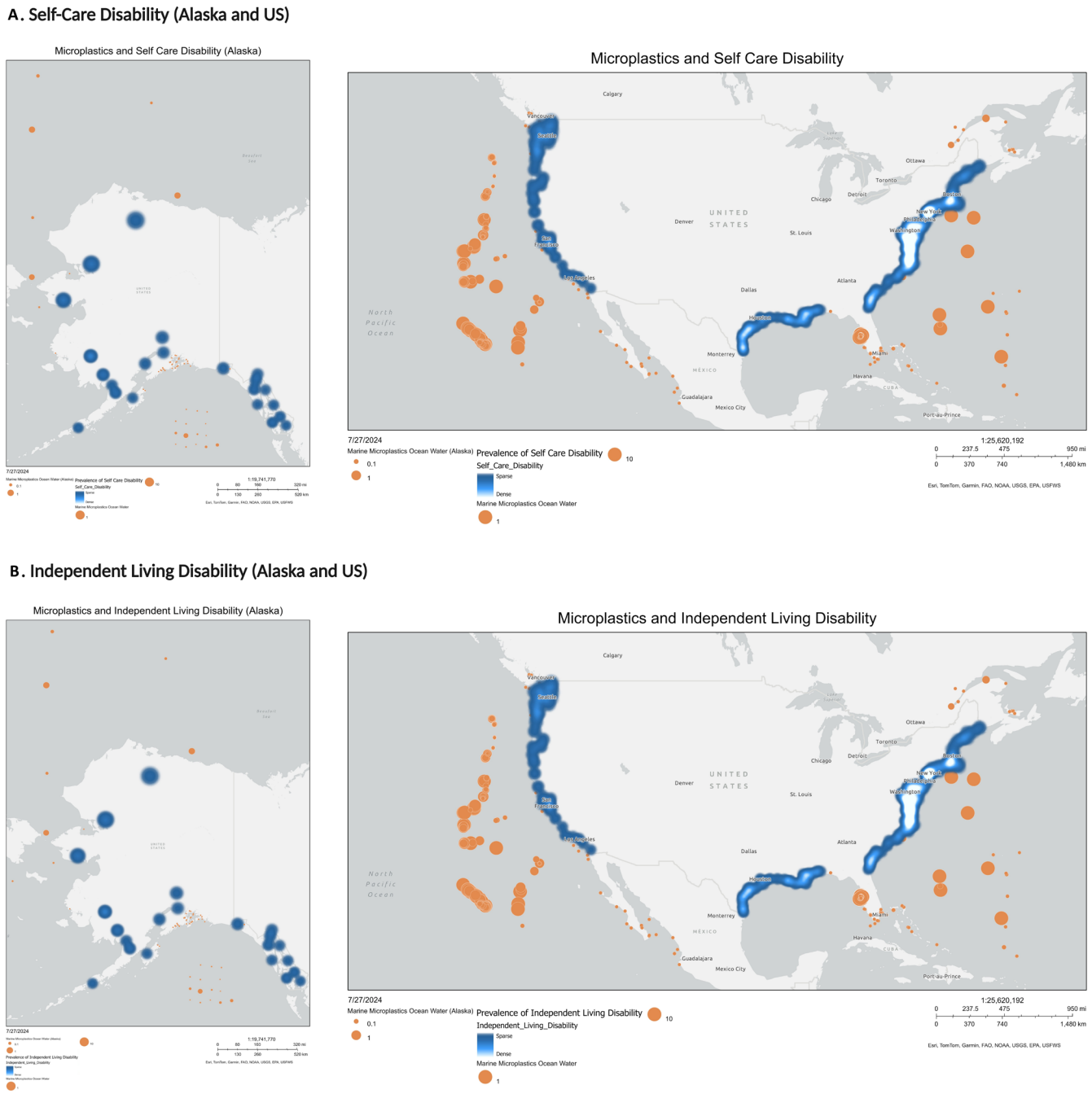


**FIGURE 2** | Marine microplastic levels and self-care and independent living disability. Choropleth maps showing the prevalence of self-care disability (A), independent living disability (B), as well as the marine microplastic levels in the adjacent ocean water in the US coastal counties (including Alaska). The blue fluorescent areas along the coastline represent the disability prevalence, with higher fluorescence corresponding to a higher prevalence. The diameter of the orange bubble in the ocean is proportional to the absolute concentration of microplastic detected in the sample of ocean water collected at that particular site between 2015 and 2020.

As we advance, translational research will clarify how microplastics harm human tissues at a cellular and molecular levels. The link between microplastics and human health should be explored at an individual level to support evidence-based decisions and enhance government regulations on plastic production, use, treatment, and disposal. The aim is to reduce microplastic pollution and develop interventions for current environmental levels.

## 5 | Limitations

Our study has several limitations. Firstly, it only considers the concentration of microplastics in the marine ecosystem, measured explicitly on the ocean surface. However, data on microplastics in the ocean subsurface and ocean water sediment were unavailable in the confinement of exclusive economic zones within the pre-selected time period (2015–2020). Microplastics

can also be detected in terrestrial ecosystems and ingested and accumulated by animals. They can be propagated in the food chain, ultimately affecting humans. Data on the concentration of nanoplastics, which are defined as synthetic polymers with dimensions ranging from 1 nm to 1 μm, were unavailable [51]. Although consuming groundwater or seafood containing microplastics may lead to human exposure, it is difficult to quantify the amount of microplastics entering and accumulating in human tissues.

Our study cannot determine the temporality of association. The population migration across the counties is unknown and unaccounted for during the study period. Genetic and epigenetic factors, which may influence neurological disabilities, were not accounted for in this study. Our study assumes potential microplastic exposure through locally caught fish and groundwater; however, we acknowledge that the sources of natively available seafood and local fish consumption may vary, which may not necessarily reflect their contribution to overall exposure. The interaction of other unknown confounders and risk factors that directly or indirectly impact the study outcomes may have been missed.

Counties not located along the coastline have not been assessed. Due to database restrictions, we could not explore the individual impacts of different types of microplastics on disability outcomes. Neurological disability data in this study is derived from self-reported surveys or censuses, which may be subject to reporting biases and misclassification. Considering the study's cross-sectional and ecological design and given the multifaceted nature of microplastic exposure and the chronic, complex pathophysiological processes underlying neurocognitive disorders, our findings indicate an association but do not establish a causal relationship.

Even with inherent limitations, our findings may be, at best, the underestimation of the hazard posed by microplastics and raise the need to investigate further and intervene to address this emerging environmental hazard.

## 6 | Conclusion

Coastal counties with higher marine microplastic levels in adjacent ocean water showed a higher adjusted prevalence of cognitive disability, mobility disability, self-care disability, and independent living disability compared to those with lower concentrations. While our findings indicate an association, additional studies investigating the health impacts of microplastics at an individual level should be undertaken to establish causality and support a policy-level change to mitigate microplastic exposure and reduce marine water pollution.

### Author Contributions

**Bhargav Makwana:** conceptualization, investigation, writing – original draft, formal analysis, visualization. **Brinda Desai:** conceptualization, investigation, writing – original draft. **Jayashri Srinivasan:** data curation, resources, supervision. **Diana Apetauerova:** validation. **Sourbha S. Dani:** conceptualization, investigation, writing – original draft, supervision. **Siddharth Sehgal:** data curation, resources. **Oleg Yerstein:** validation. **Sumanth Khadke:** formal analysis. **Ashish Kumar:** writing – review and editing. **Khurram Nasir:** writing – review and editing. **Rishi Wadhera:** writing – review and editing. **Yixin Kong:** formal analysis. **Ana Navas-Acien:** writing – review and editing. **Gary Adamkiewicz:** writing – review and editing. **Sanjay Rajagopalan:** writing – review and editing. **Sadeer Al-Kindi:** writing – review and editing. **Susan Moffatt-Bruce:** writing – review and editing. **Sarju Ganatra:** conceptualization, investigation, writing – original draft, supervision.

### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The data that support the findings of this study will be made available on a case-by-case basis. Requests for access should be directed to the corresponding author via the email address provided in the manuscript.

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**Supporting Information**

Additional supporting information can be found online in the Supporting Information section.