BRUSSELS INSTITUTE FOR SOCIAL AND POPULATION STUDIES

BRISPO Working Paper No. 2025-1

Linking Social and Environmental Indicators to Neurodegenerative Disease Mortality in Belgian Municipalities Using Spatial Regression Analysis

Janna Dinneweth, Prof. Sylvie Gadeyne

12/02/2025

DOI: 10.5281/zenodo.14859170

Brussels Institute for Social and Population Studies, Vrije Universiteit Brussel,
Pleinlaan 5, 1050 Brussels, Belgium
Website: brispo.research.vub.be

1. Introduction

Dementias and Parkinson's Disease (PD) are becoming major public health concerns due to their growing prevalence and the significant strain they place on individuals, families, and healthcare systems (WHO, 2021, 2022). Understanding the mortality rates associated with these neurodegenerative diseases (NDDs) is key to shaping effective public health policies and allocating resources wisely. Despite the importance of studying mortality patterns for etiological research and healthcare planning, geographical and temporal analyses of NDD mortality remain underexplored, even though such studies could reveal potential risk factors and regional disparities, providing valuable insights for more targeted and equitable health interventions (Pedro-Cuesta et al., 2009; Xu & Wu, 2018). Building on our previous work (Dinneweth & Gadeyne, 2024b), which explored spatiotemporal trends in dementia and PD mortality across Belgium, this paper aims to further analyse these spatial patterns, using both bivariate and multivariate statistical methods, and incorporating key explanatory variables from the literature.

Socioeconomic variables have been consistently associated with NDD mortality. Most of these studies have focused on individual-level factors, showing that indicators such as educational attainment and income level are linked to higher NDD mortality (Dinneweth & Gadeyne, 2024a; Korhonen et al., 2020; Yang et al., 2016; Yoon et al., 2020). At the aggregated level, limited research has demonstrated similar associations. For example, mortality among people living with dementia was found higher in the most deprived areas of England (Watson et al., 2021). For PD, research is limited, but a Korean study found that regional deprivation was not related to PD mortality (Yoon et al., 2020).

There is also growing interest in the association between environmental pollutants and NDD mortality. A convincing body of literature exists on exposure to air pollution and the incidence of dementia and PD (Chen et al., 2017; Oudin et al., 2016; Shi et al., 2021; Wu et al., 2022; Yu et al., 2021). However, studies on exposure to air pollution and NDD mortality are relatively limited and inconclusive. Some studies found no associations between exposure to air pollution and NDD-related mortality (Andersen et al., 2022; Klompmaker et al., 2020), while others did find an association (Bowe et al., 2019; Cole-Hunter et al., 2023; Klompmaker et al., 2021; Rhew et al., 2021; Zhao et al., 2021).

Additionally, differences in mortality registration practices have been noted as a contributing factor to spatial variationsin NDD mortality. For instance, dementia mortality was higher in French regions with a greater number of specialised memory clinics, likely reflecting more accurate diagnoses (Brosselin et al., 2010). Studies from the United States (Akushevich et al., 2021; Lanska, 1997) and Australia (Jorm et al., 1989) have similarly shown geographical variation in the likelihood of reporting NDDs as contributing causes of death. Our previous study also suggested differences in the use of dementia classifications between Belgian regions (Dinneweth & Gadeyne, 2024b), which is why we will conduct seperate analyses for these regions in this study.

This study focuses on the period from 2017 to 2019, deliberately excluding the pandemic years to ensure that the analysis remains unaffected by the unprecedented impacts of COVID-19. Our research is motivated by the need to understand how social and environmental factors influence mortality rates from dementia and PD.

Belgium, with its diverse regions and comprehensive data availability, offers an ideal setting for this investigation. The country's distinct regional characteristics and well-documented social and environmental data enable a detailed examination of these factors' roles in shaping mortality outcomes. The primary objective of this study is twofold: first, to investigate the associations between mortality rates for dementia and PD and a range of social and environmental indicators at the aggregated level; and second, to assess regional differences within Belgium in these associations. By addressing these objectives, we aim to uncover patterns and determinants that could inform public health policies and interventions.

2. Methods

Data

Our analysis is based on cause-specific mortality data from 2017 to 2019, sourced from Statistics Belgium. These individual-level records encompass all Belgians and foreigners residing in Belgium and are aggregated at the municipal level. By focusing on the pre-pandemic period, we aimed to ensure that our analysis remained unaffected by the pandemic. Population size and structure were derived from the 2018 register data.

For the explanatory analyses, we incorporated data on social and environmental indicators from 2001, to address a time-lag. To account for deprivation at the municipal level, we used the Belgian Index of Multiple Deprivation of 2001 (excluding the health dimension) as described by Otavova et al. (2023). Environmental indicators, including air pollution metrics (PM10, NO2, and O3) in 2000, were obtained from the Belgian Interregional Environmental Agency (IRCEL-CELINE). Additionally, we controlled for the number of elderly residing in care homes and the population density, calculated using data form the 2001 Belgian census.

Variables

Our dependent variables were age-standardized mortality rates calculated for dementias (ICD10-F00-F03, G30) and Parkinson's Disease (ICD10-G20) at the municipality level for the population aged 45 or older. To ensure accurate comparisons, we used the mortality rates for the entire population of Belgium in 2019 as the reference standard for age-standardization. Given the small size of certain municipalities, we opted for the indirect standardization method. To account for fluctuations and the small number of deaths in some municipalities, we used the average deaths over a 3-year period (2017-2019).

The independent variables include both social and environmental indicators. As our social indicator, we opted for a deprivation index due to the high correlation between separate social indicators at the municipal level. The Belgian Index of Multiple Deprivation (BIMD) is a combination of six domains of deprivation: income, employment, education, housing, crime, and health. We excluded the health indicator. The BIMDs scores were ranked and assigned to deciles from 1 (the most deprived) to 10 (the least deprived). The air pollution metrics PM10, NO2 and O3 were measured in $\mu g/m^3$. Our control variables included the number of elderly residing in care homes and the population density, using the 2001 census data. The first indicator was calculated by dividing the amount of people 65 or older residing in a care home by the total amount of people 65 or older and multiplying this number by 100. Population density was calculated by dividing the number of residents by the surface area of the municipality in hectares.

Statistical analyses

We conducted two preliminary steps. First, we mapped all variables at the municipality level. Second, we tested the spatial autocorrelation of the variables using Global Moran's I. As discussed thoroughly in our previous publication (Dinneweth & Gadeyne, 2024b), the maps reveal significant differences in NDD mortality between regions. Consequently, we performed the statistical analysis separately for municipalities in the three Belgian regions: Flanders (n = 300), the Walloon region (n = 262), and Brussels (n = 19).

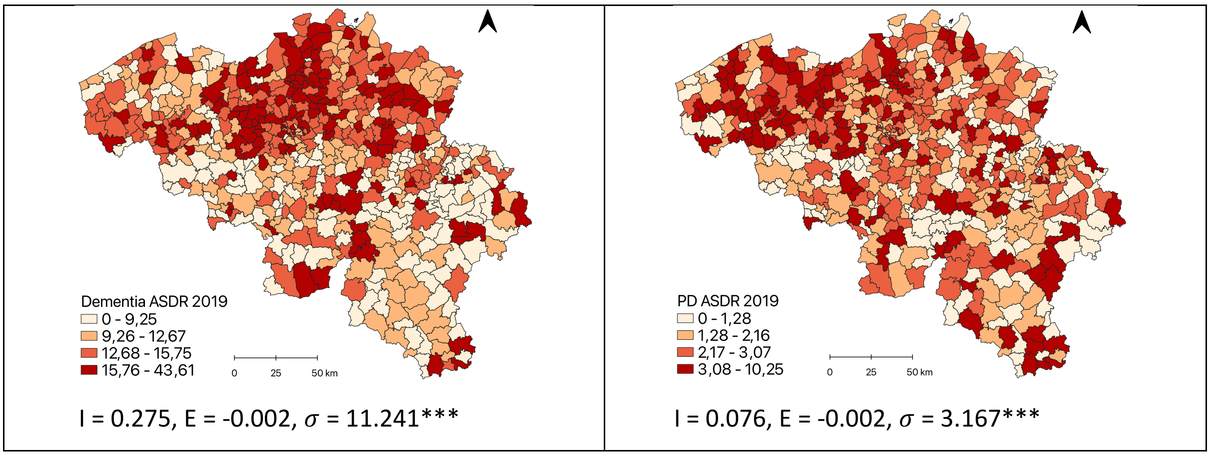
Next, we conducted a bivariate analysis using non-parametric Spearman correlation due to the non-normal distributions and heteroscedasticity of our study variables (Baró et al., 2019). Finally, we employed multivariate analysis to model the associations between NDD mortality and the social and environmental indicators. We compared an ordinary least squares (OLS) model, a spatial error model (SEM), and a spatial lag model (SLM) using R-squared and Akaike Information Criterion (AIC) values. The maps were created using QGIS software, and the analyses were performed using R software, both of which are open-source programs.

3. Results

Preliminary analyses

Figure 1 presents the dependent variables, specifically the standardized mortality rates for dementia and PD measured in 2019. Figure 2 illustrates the independent variables measured in 2000/2001. Initially, all variables were mapped at the municipality level using quantile classification. To evaluate spatial patterns, we calculated Global Moran's I statistics to assess spatial autocorrelation. Except for the proportion of elderly residents in care homes, which did not show significant autocorrelation, all variables exhibited a strong positive autocorrelation.

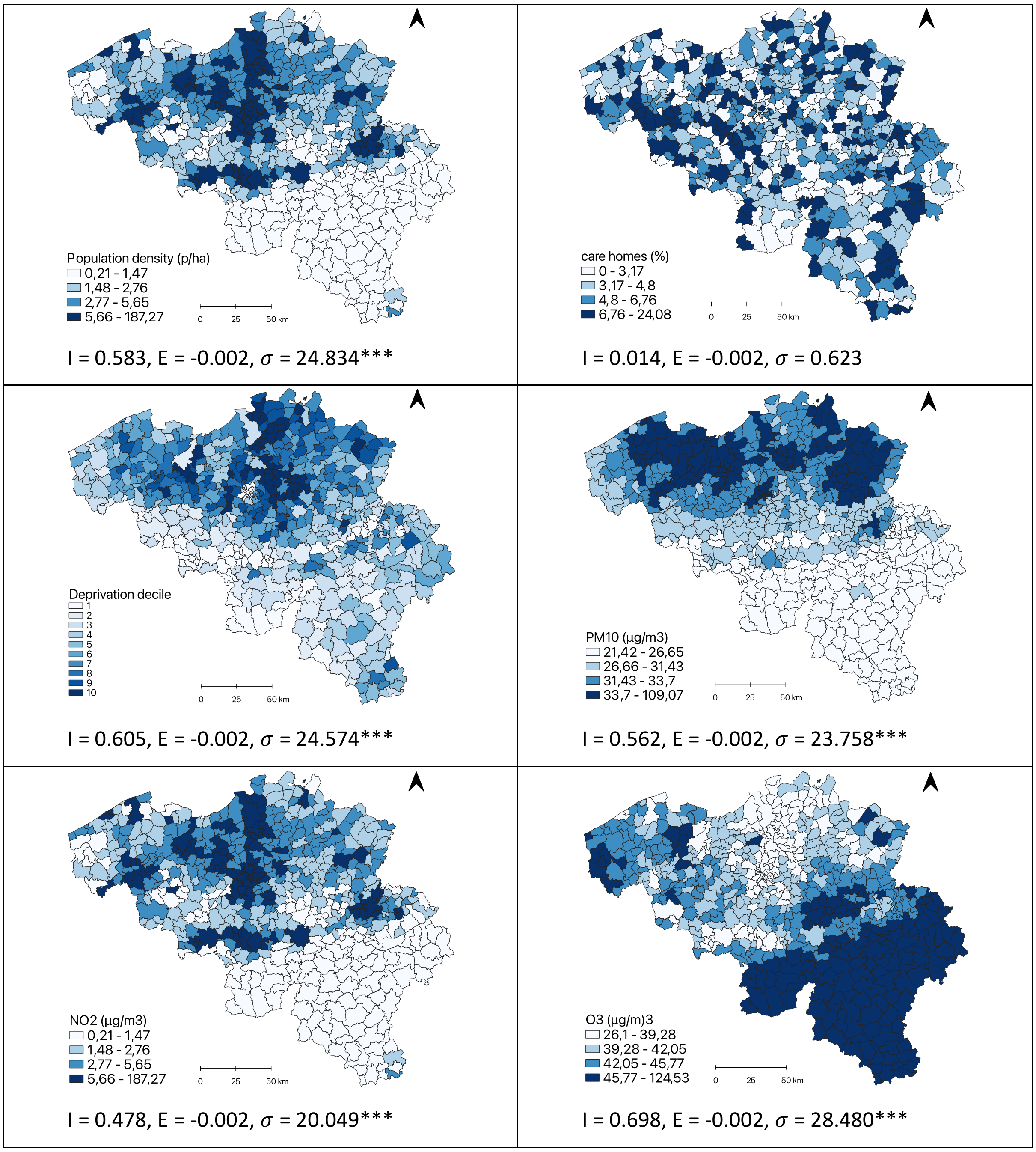
Figure 1 *Standardized dementia and Parkinson's mortality rates (per 10,000 population aged ≥ 45 years), Belgian municipalities 2017-2019*



*I = Moran's I statistic, E = Expected value, σ = Standard deviation, *** = p < 0.001*

Source: Statistics Belgium, calculations by author

Figure 2 *Independent variables, Belgian municipalities 2000/2001*



*I = Moran's I statistic, E = Expected value, σ = Standard deviation, *** = p < 0.001*

Source: Statistics Belgium, calculations by author

Bivariate analyses

Bivariate analyses indicate a strong positive correlation between population density and dementia mortality across all three Belgian regions. In the Walloon and Brussels-Capital regions, higher deprivation is significantly associated with higher dementia mortality. Regarding environmental indicators, higher PM10 levels are linked to increased dementia mortality, with this association reaching significance only in the Walloon region. Although dementia mortality shows a negative association with O3 levels and a positive association with NO2 levels, these associations are not significant in the Brussels-Capital region.

For PD mortality, the sole significant correlation is a positive association with PM10 levels in Flanders. Additionally, there are strong correlations between population density and air pollution indicators, as well as among air pollution indicators themselves. In the Walloon and Brussels-Capital regions, population density is correlated with deprivation, with the most deprived areas also being the most densely populated. Finally, there are correlations between the deprivation index and air pollution indicators, although the direction of these correlations varies across regions.

***Table 1** Spearman's correlation results between NDD mortality (2017-2019), social- and environmental variables (2000/2001) at the municipality level in Belgium by region*

FLANDERS REGION								
	Dementia ASDR	Parkinson ASDR	Population density	Care homes	Deprivation	PM10	O3	NO2
Dementia	1							
Parkinson	**0.155	1						
Population density	***0.415	0.104	1					
Care homes	0.097	-0.024	-0.034	1				
Deprivation	0.098	0.113	0.092	-0.045	1			
PM10	0.055	*0.129	**0.218	-0.083	-0.019	1		
O3	***-0.424	-0.029	***-0.715	0.024	***-0.332	***-0.248	1	
NO2	***0.386	0.059	***0.702	-0.053	***0.301	***0.395	***-0.726	1
WALLOON REGION								
	Dementia ASDR	Parkinson ASDR	Population density	Care homes	Deprivation	PM10	O3	NO2
Dementia	1							
Parkinson	***0.222	1						
Population density	***0.284	0.060	1					
Care homes	0.028	0.079	0.018	1				
Deprivation	**-0.187	0.010	**-0.164	-0.05	1			
PM10	***0.216	0.017	***0.742	0.041	0.012	1		
O3	**-0.197	-0.028	***-0.853	-0.020	**0.181	***-0.756	1	
NO2	***0.203	0.067	***0.876	0.038	-0.042	***0.795	***-0.868	1
BRUSSELS CAPITAL REGION								
	Dementia ASDR	Parkinson ASDR	Population density	Care homes	Deprivation	PM10	O3	NO2
Dementia	1							
Parkinson	-0.158	1						
Population density	**0.674	-0.284	1					
Care homes	0.144	-0.192	0.189	1				
Deprivation	*-0.560	0.183	**-0.619	-0.274	1			
PM10	0.316	-0.451	**0.619	0.418	**-0.763	1		
O3	-0.312	0.418	*-0.563	*-0.487	*0.518	***-0.781	1	
NO2	0.288	-0.386	**0.593	0.423	***-0.810	***0.979	***-0.783	1

**p<0.05, **p<0.01, ***p<0.001*

Source: Statistics Belgium, calculations by author

Multivariate analyses

The multivariate regression results can be found in Table 2 for dementia mortality and in Table 3 for PD mortality. The results are split into three models, one for each air pollution indicator because of the high variance inflation factor (VIF) of these variables when putting them all in the same model (see: Appendix). We further checked the VIF for each multivariate model, confirming that all VIF values are under 2, indicating that multicollinearity is not a significant issue. Based on the AIC and (pseudo) R-squared values, the OLS models have the best fit in the Walloon and Brussels capital region. In Flanders, the spatial regression models have the best fit, indicating that spatial dependencies play a significant role in explaining the variations in dementia mortality.

For dementia mortality, we see that many of the bivariate associations disappear when running multivariate models. In Flanders, population density is the only variable that has a significant positive association with dementia mortality. In the Walloon region, there is a significant negative association with the deprivation index, indicating that dementia mortality is lower when there is less deprivation (considering that 1 is the most deprived decile and 10 is the least deprived decile). In the Brussels capital region, we found a significant positive association with population density, as well as a significant negative association with NO2 levels.

Similar to the bivariate associations, there are barely any associations found for PD mortality. The only significant finding is a positive association between the amount of elderly in care homes and PD mortality in the Walloon region. Models for both dementia and PD mortality have fairly low (pseudo) R-squared values, indicating that even when we found some significant associations, the overall explanatory power of the models is rather limited. For the Brussels capital region, we did find high (pseudo) R-squared values, possibly explained by the fact that the Brussels capital region only has 19 municipalities, which results in a more homogeneous dataset and potentially overfits the model.

To conclude, the results should be interpreted with care. Although some significant associations were identified, the overall model fits suggest that other unobserved factors may be important in explaining dementia and PD mortality.

Table 2 *Ordinary least squares (OLS), spatial error model (SEM) and spatial lag model (SLM) results for dementia mortality and social-and environmental variables*

	FLANDERS REGION			WALLOON REGION			BRUSSELS CAPITAL REGION		
	OLS	SEM	SLM	OLS	SEM	SLM	OLS	SEM	SLM
MODEL 1									
Pop. density	***0.37	***0.35	***0.29	0.07	0.06	0.06	**0.06	***0.07	***0.06
Care homes	0.11	0.09	0.10	0.06	-0.02	-0.04	0.18	0.29	0.12
Deprivation	0.09	-0.07	-0.05	**-0.38	-0.41	*-0.38	-0.49	-0.57	-0.43
PM10	-0.05	-0.04	-0.04	0.20	0.22	0.20	-0.79	-0.92	-0.83
R-squared	0.16	0.25	0.25	0.06	0.07	0.06	0.57	0.62	0.60
AIC	1683.1	1661.3	1661.6	1589.7	1590.6	1591.2	102.4	103.39	103.3
Lag coef.	NA	NA	0.38	NA	NA	0.07	NA	NA	0.38
MODEL 2									
Pop. density	***0.33	***0.33	***0.27	0.10	0.10	0.10	**0.05	***0.06	***0.05
Care homes	0.12	0.09	0.10	-0.04	-0.02	-0.03	0.35	0.43	0.29
Deprivation	0.06	-0.08	-0.07	*-0.34	-0.37	-0.34	-0.48	-0.45	-0.41
O3	-0.07	-0.04	-0.05	-0.08	-0.09	-0.08	0.69	0.66	0.69
R-squared	0.17	0.25	0.25	0.05	0.06	0.06	0.60	0.62	0.63
AIC	1680.4	1660.4	1660	1591.4	1592.4	1593	100.99	102.56	101.93
Lag coeff.	NA	NA	0.37	NA	NA	0.07	NA	NA	0.36
MODEL 3									
Pop. density	***0.37	***0.35	***0.29	0.05	0.05	0.05	**0.07	***0.07	***0.06
Care homes	0.12	0.09	0.10	-0.05	-0.03	-0.04	0.15	0.23	0.10
Deprivation	0.08	-0.08	-0.06	**-0.38	**-0.40	**-0.38	-0.79	*-0.90	-0.72
NO2	0.02	0.00	0.01	0.11	0.11	0.11	*-0.55	**-0.56	**-0.54
R-squared	0.15	0.25	0.24	0.06	0.06	0.06	0.64	0.68	0.67
AIC	1685.4	1662.4	1663.1	1590.3	1591.5	1592	98.79	99.96	99.64
Lag coeff.	NA	NA	0.39	NA	NA	0.06	NA	NA	0.37

**p<0.05, **p<0.01, ***p<0.001, Source: Statistics Belgium, calculations by author*

Table 3 *Ordinary least squares (OLS), spatial error model (SEM) and spatial lag model (SLM) results for PD mortality and social-and environmental variables*

	FLANDERS REGION			WALLOON REGION			BRUSSELS CAPITAL REGION		
	OLS	SEM	SLM	OLS	SEM	SLM	OLS	SEM	SLM
MODEL 1									
Pop. density	0.02	0.02	0.02	-0.06	-0.00	-0.01	-0.00	-0.00	-0.00
Care homes	0.01	0.00	0.01	*0.07	*0.07	*0.07	-0.05	-0.06	-0.05
Deprivation	0.06	0.06	0.05	0.02	0.03	0.02	-0.07	-0.06	-0.07
PM10	0.01	0.01	0.01	0.00	-0.00	0.00	-0.22	-0.22	-0.22
R-squared	0.02	0.05	0.05	0.02	0.02	0.02	0.28	0.29	0.28
AIC	1002.2	998.5	998.23	964.87	966.7	966.65	49.12	50.96	51.11
Lag coef.	NA	NA	0.21	NA	NA	-0.05	NA	NA	-0.04
MODEL 2									
Pop. density	0.03	0.02	0.02	-0.00	-0.00	-0.00	-0.01	-0.01	-0.01
Care homes	0.01	0.00	0.01	*0.07	*0.07	*0.07	-0.06	-0.07	-0.06
Deprivation	0.06	0.06	0.06	0.02	0.03	0.03	-0.01	-0.00	-0.01
O3	0.01	0.01	0.01	0.00	0.01	0.01	0.04	0.04	0.04
R-squared	0.02	0.05	0.05	0.02	0.02	0.02	0.19	0.21	0.19
AIC	1002.4	998.64	998.31	964.86	966.66	966.62	51.26	53.04	53.25
Lag coeff.	NA	NA	0.22	NA	NA	-0.05	NA	NA	0.05
MODEL 3									
Pop. density	0.02	0.02	0.02	-0.03	-0.02	-0.03	-0.00	-0.00	-0.00
Care homes	0.01	0.00	0.01	*0.07	*0.06	*0.06	-0.07	-0.07	-0.07
Deprivation	0.06	0.06	0.05	0.01	0.02	0.02	-0.08	-0.07	-0.08
NO2	-0.00	0.00	0.00	0.02	0.02	0.02	-0.08	-0.08	-0.08
R-squared	0.02	0.05	0.05	0.02	0.02	0.02	0.25	0.26	0.25
AIC	1003.6	999.51	999.4	964.02	965.91	965.82	49.72	51.63	51.72
Lag coeff.	NA	NA	0.22	NA	NA	-0.05	NA	NA	0.003

**p<0.05, **p<0.01, ***p<0.001, Source: Statistics Belgium, calculations by author*

4. Discussion

This study aimed to investigate the spatial association between air pollution, socioeconomic factors, and mortality due to dementia and PD at the municipality level in Belgium. Our preliminary analysis involved mapping all relevant variables and testing their spatial autocorrelation using Global Moran's I. Notably, all variables exhibited strong positive autocorrelation, except for the proportion of elderly residents in care homes, which did not show significant clustering. This result emphasizes the importance of considering geographic clustering in epidemiological studies of mortality, as such clustering can reveal critical insights into patterns of health outcomes.

The bivariate analyses indicated a significant correlation between population density and dementia mortality across all regions, suggesting that municipalities with higher population densities experience higher rates of dementia-related deaths. However, this relationship did not persist in the multivariate analyses for the Walloon region, where population density was no longer a significant predictor. This shift may be attributed to our control for the deprivation index, which revealed a significant negative association; specifically, less deprived areas tended to have lower dementia mortality. This findings aligns with similar results from England (Watson et al., 2021), indicating that socioeconomic factors may play a critical role in explaining dementia mortality patterns in the Walloon region.

While air pollution has been linked to both dementia incidence and mortality in previous research (Bowe et al., 2019; Klompmaker et al., 2021; Oudin et al., 2016; Rhew et al., 2021; Shi et al., 2021), our analysis found no significant associations between air pollution levels and dementia mortality, except for an unexpected negative relationship with NO2 levels in the Brussels-Capital region. This finding contrasts with existing literature that typically associates higher NO2 levels with adverse health outcomes (Klompmaker et al., 2021; Oudin et al., 2016; Shi et al., 2021). One potential explanation for the lack of associations between air pollution indicators and dementia mortality could be related to the geographical level of analysis. Using average municipality concentrations to assess air pollution exposure may underestimate the health risks associated with elevated pollution levels near specific sources (Hoek et al., 2002; Jerrett et al., 2005), which calls for more refined methodologies in future studies.

In examining PD mortality, associations were notably sparse. The only significant bivariate finding was a positive association with PM10 levels in Flanders, indicating a potential environmental risk factor for PD in this region, which is consistent with prior literature linking PM10 exposure to increased PD incidence (Chen et al., 2017; Yu et al., 2021). Additionally, in the multivariate models, the positive association between the number of elderly in care homes and PD mortality in the Walloon region suggests that institutional settings may play a role in PD mortality, possibly due to the concentration of vulnerable populations or differences in care practices.

Our findings have several important implications. First, they highlight the complex interplay between environmental factors, socioeconomic deprivation, and health outcomes. The significant associations between population density, air pollution, and dementia mortality emphasize the need for targeted public health interventions in densely populated and polluted areas. Moreover, the regional differences observed suggest that local context matters, and interventions should be tailored accordingly.

The study also has significant limitations. The relatively low (pseudo) R-squared values in most models indicate that results should be interpreted with caution. Several factors could underlie these low values. First, unobserved factors could be influencing dementia and PD mortality. Second, the geographical level of municipalities could be too small or too large to observe patterns; environmental indicator studies, such as those on air pollution, are generally conducted at a smaller geographical scale. Lastly, a lack of associations with NDD mortality could be due to limitations related to using mortality data for NDD definitions, such as underestimation of true NDD mortality (Benito-León et al., 2014; Rizzuto et al., 2018; Romero et al., 2014) and differences in registration practices of NDDs between areas (Akushevich et al., 2021; Jorm et al., 1989).

In conclusion, this study contributes to a deeper understanding of the spatial dynamics of mortality related to dementia and PD in Belgium. Further research is necessary to refine our methodologies and address the limitations identified, thereby enhancing our understanding of the multifaceted factors influencing these critical public health issues.

5. Conclusion

In conclusion, this study highlights the spatial association between air pollution, socioeconomic factors, and mortality due to dementia and PD at the municipality level in Belgium. Our findings underscore the geographic clustering of these variables and emphasize the importance of considering spatial dependencies in epidemiological research. Significance correlations between population density and dementia mortality, and the nuanced role of air pollution, suggest the need for targeted public health interventions in densely populated and polluted areas. However, the study's limitations, including low explanatory power and potential unobserved influencing factors, indicate that results should be interpreted with caution. Further research at different geographical scales and incorporating more comprehensive data is necessary to fully understand the environmental and social determinants of NDDs.

6. References

Akushevich, I., Yashkin, A. P., Yashin, A. I., & Kravchenko, J. (2021). Geographic disparities in mortality from Alzheimer's disease and related dementias. *Journal of the American Geriatrics Society*, *69*, 2306 - 2315.

Andersen, Z. J., Zhang, J., Jørgensen, J. T., Samoli, E., Liu, S., Chen, J., Strak, M., Wolf, K., Weinmayr, G., Rodopolou, S., Remfry, E., de Hoogh, K., Bellander, T., Brandt, J., Concin, H., Zitt, E., Fecht, D., Forastiere, F., Gulliver, J., . . . Lim, Y.-H. (2022). Long-term exposure to air pollution and mortality from dementia, psychiatric disorders, and suicide in a large pooled European cohort: ELAPSE study. *Environment international*, *170*, 107581. https://doi.org/https://doi.org/10.1016/j.envint.2022.107581

Baró, F., Calderón-Argelich, A., Langemeyer, J., & Connolly, J. J. (2019). Under one canopy? Assessing the distributional environmental justice implications of street tree benefits in Barcelona. *Environmental Science & Policy*, *102*, 54-64.

Benito-León, J., Louis, E. D., Villarejo-Galende, A., Romero, J. P., & Bermejo-Pareja, F. (2014). Under-reporting of Parkinson's disease on death certificates: A population-based study (NEDICES). *Journal of the Neurological Sciences*, *347*(1-2), 188-192.

Bowe, B., Xie, Y., Yan, Y., & Al-Aly, Z. (2019). Burden of cause-specific mortality associated with PM2. 5 air pollution in the United States. *JAMA network open*, *2*(11), e1915834-e1915834.

Brosselin, P., Duport, N., & Bloch, J. (2010). Mortality with Alzheimer's disease and dementia in France, 2006. *Revue d'épidémiologie et de santé publique*, *58*(4), 269-276.

Chen, C.-Y., Hung, H.-J., Chang, K.-H., Hsu, C. Y., Muo, C.-H., Tsai, C.-H., & Wu, T.-N. (2017). Long-term exposure to air pollution and the incidence of Parkinson's disease: A nested case-control study. *PLoS ONE*, *12*(8), e0182834.

Cole-Hunter, T., Zhang, J., So, R., Samoli, E., Liu, S., Chen, J., Strak, M., Wolf, K., Weinmayr, G., Rodopolou, S., Remfry, E., de Hoogh, K., Bellander, T., Brandt, J., Concin, H., Zitt, E., Fecht, D., Forastiere, F., Gulliver, J., . . . Andersen, Z. J. (2023). Long-term air pollution exposure and Parkinson's disease mortality in a large pooled European cohort: An ELAPSE study. *Environment international*, *171*, 107667. https://doi.org/https://doi.org/10.1016/j.envint.2022.107667

Dinneweth, J., & Gadeyne, S. (2024a). Socioeconomic Disparities in Neurodegenerative Disease Mortality: A Population-Based Study among Belgian Men and Women Aged 65 or Older. *INQUIRY*, *61*, 469580241237113. https://doi.org/10.1177/00469580241237113

Dinneweth, J., & Gadeyne, S. (2024b). Unravelling the Evolution of Neurodegenerative Disease Mortality: Insights from 50 Years of Belgian Data. *Espace populations sociétés*, *2023/3-2024/1*. https://doi.org/https://doi.org/10.4000/12tpx

Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P., & van den Brandt, P. A. (2002). Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. *The Lancet*, *360*(9341), 1203-1209.

Jerrett, M., Burnett, R. T., Ma, R., Pope III, C. A., Krewski, D., Newbold, K. B., Thurston, G., Shi, Y., Finkelstein, N., & Calle, E. E. (2005). Spatial analysis of air pollution and mortality in Los Angeles. *Epidemiology*, *16*(6), 727-736.

Jorm, A. F., Henderson, A. S., & Jacomb, P. A. (1989). Regional differences in mortality from dementia in Australia: an analysis of death certificate data. *Acta Psychiatrica Scandinavica*, *79*.

Klompmaker, J. O., Hoek, G., Bloemsma, L. D., Marra, M., Wijga, A. H., van den Brink, C., Brunekreef, B., Lebret, E., Gehring, U., & Janssen, N. A. (2020). Surrounding green, air pollution, traffic noise exposure and non-accidental and cause-specific mortality. *Environment international*, *134*, 105341.

Klompmaker, J. O., Janssen, N. A., Bloemsma, L. D., Marra, M., Lebret, E., Gehring, U., & Hoek, G. (2021). Effects of exposure to surrounding green, air pollution and traffic noise with non-accidental and cause-specific mortality in the Dutch national cohort. *Environmental Health*, *20*, 1-16.

Korhonen, K., Einiö, E., Leinonen, T., Tarkiainen, L., & Martikainen, P. (2020). Midlife socioeconomic position and old-age dementia mortality: a large prospective register-based study from Finland. *BMJ open*, *10*(1), e033234.

Lanska, D. J. (1997). The geographic distribution of Parkinson's disease mortality in the United States. *Journal of the Neurological Sciences*, *150*, 63-70.

Otavova, M., Masquelier, B., Faes, C., Van den Borre, L., Bouland, C., De Clercq, E., Vandeninden, B., De Bleser, A., & Devleesschauwer, B. (2023). Measuring small-area level deprivation in Belgium: The Belgian

Index of Multiple Deprivation. *Spatial and spatio-temporal epidemiology*, *45*, 100587. https://doi.org/https://doi.org/10.1016/j.sste.2023.100587

Oudin, A., Forsberg, B., Adolfsson Annelie, N., Lind, N., Modig, L., Nordin, M., Nordin, S., Adolfsson, R., & Nilsson, L.-G. (2016). Traffic-Related Air Pollution and Dementia Incidence in Northern Sweden: A Longitudinal Study. *Environmental health perspectives*, *124*(3), 306-312. https://doi.org/10.1289/ehp.1408322

Pedro-Cuesta, J. d., Rodríguez-Farré, E., & López-Abente, G. (2009). Spatial distribution of Parkinson's disease mortality in Spain, 1989-1998, as a guide for focused aetiological research or health-care intervention. *BMC public health*, *9*, 445 - 445.

Rhew, S. H., Kravchenko, J., & Lyerly, H. K. (2021). Exposure to low-dose ambient fine particulate matter PM2. 5 and Alzheimer's disease, non-Alzheimer's dementia, and Parkinson's disease in North Carolina. *PLoS ONE*, *16*(7), e0253253.

Rizzuto, D., Feldman, A. L., Karlsson, I. K., Dahl Aslan, A. K., Gatz, M., & Pedersen, N. L. (2018). Detection of dementia cases in two Swedish health registers: a validation study. *Journal of Alzheimer's Disease*, *61*(4), 1301-1310.

Romero, J. P., Benito-León, J., Mitchell, A. J., Trincado, R., & Bermejo-Pareja, F. (2014). Under reporting of dementia deaths on death certificates using data from a population-based study (NEDICES). *Journal of Alzheimer's Disease*, *39*(4), 741-748.

Shi, L., Steenland, K., Li, H., Liu, P., Zhang, Y., Lyles, R. H., Requia, W. J., Ilango, S. D., Chang, H. H., Wingo, T., Weber, R. J., & Schwartz, J. (2021). A national cohort study (2000–2018) of long-term air pollution exposure and incident dementia in older adults in the United States. *Nature Communications*, *12*(1), 6754. https://doi.org/10.1038/s41467-021-27049-2

Watson, J., Darlington-Pollock, F., Green, M., Giebel, C., & Akpan, A. (2021). The Impact of Demographic, Socio-Economic and Geographic Factors on Mortality Risk among People Living with Dementia in England (2002–2016). *International journal of environmental research and public health*, *18*(24), 13405.

WHO. (2021). Global status report on the public health response to dementia.

WHO. (2022). Parkinson disease: a public health approach: technical brief.

Wu, J., Grande, G., Stafoggia, M., Ljungman, P., Laukka, E. J., Eneroth, K., Bellander, T., & Rizzuto, D. (2022). Air pollution as a risk factor for Cognitive Impairment no Dementia (CIND) and its progression to dementia: A longitudinal study. *Environment international*, *160*, 107067. https://doi.org/https://doi.org/10.1016/j.envint.2021.107067

Xu, W. X., & Wu, C. (2018). Detecting spatiotemporal clusters of dementia mortality in the United States, 2000-2010. *Spatial and spatio-temporal epidemiology*, *27*, 11-20.

Yang, F., Johansson, A. L. V., Pedersen, N. L., Fang, F., Gatz, M., & Wirdefeldt, K. (2016). Socioeconomic status in relation to Parkinson's disease risk and mortality: A population-based prospective study. *Medicine (Baltimore)*, *95*(30), e4337. https://doi.org/10.1097/md.0000000000004337

Yoon, S. Y., Shin, J., Chang, J. S., Lee, S. C., & Kim, Y. W. (2020). Effects of socioeconomic status on mortality after Parkinson's disease: A nationwide population-based matched cohort study in Korean populations. *Parkinsonism & Related Disorders*, *80*, 206-211. https://doi.org/https://doi.org/10.1016/j.parkreldis.2020.10.017

Yu, Z., Wei, F., Zhang, X., Wu, M., Lin, H., Shui, L., Jin, M., Wang, J., Tang, M., & Chen, K. (2021). Air pollution, surrounding green, road proximity and Parkinson's disease: A prospective cohort study. *Environmental Research*, *197*, 111170.

Zhao, N., Pinault, L., Toyib, O., Vanos, J., Tjepkema, M., & Cakmak, S. (2021). Long-term ozone exposure and mortality from neurological diseases in Canada. *Environment international*, *157*, 106817.

7. Appendix

Table S1 *Ordinary least squares (OLS), spatial error model (SEM) and spatial lag model (SLM) results for dementia mortality and social-and environmental variables*

	FLANDERS REGION				WALLOON REGION				BRUSSELS CAPITAL REGION			
	OLS	SEM	SLM	VIF	OLS	SEM	SLM	VIF	OLS	SEM	SLM	VIF
Population density	*0.16	*0.21	0.14	2.33	0.04	0.04	0.04	2.14	*0.05	***0.06	***0.05	2.14
Care homes	0.12	0.09	0.10	1.01	-0.05	-0.03	-0.04	1.01	0.15	0.18	0.11	1.58
Deprivation	-0.05	-0.11	-0.14	1.15	**-0.41	*-0.42	*-0.40	1.20	-0.89	*-0.97	*-0.81	2.54
PM10	-0.17	-0.17	-0.13	11.82	0.16	0.19	0.17	2.77	1.93	1.76	1.76	12.65
O3	-0.17	-0.17	-0.13	6.69	0.16	0.19	0.17	4.50	1.93	1.76	1.76	3.19
NO2	-0.07	-0.03	-0.05	5.87	0.06	0.05	0.06	6.44	0.33	0.31	0.32	13.78
R-squared	0.19	0.26	0.26		0.06	0.07	0.06		0.70	0.71	0.72	
AIC	1674.3	1659.7	1658		1593.3	1594.3	1594.9		99.52	101.26	100.69	
Lag coeffient	NA	NA	0.34		NA	NA	0.07		NA	NA	0.31	

**p<0.05, **p<0.01, ***p<0.001*

Source: Statistics Belgium, calculations by author

Table S2 *Ordinary least squares (OLS), spatial error model (SEM) and spatial lag model (SLM) results for PD mortality and social-and environmental variables*

	FLANDERS REGION				WALLOON REGION				BRUSSELS CAPITAL REGION			
	OLS	SEM	SLM	VIF	OLS	SEM	SLM	VIF	OLS	SEM	SLM	VIF
Population density	*0.06	0.05	0.05	2.33	-0.03	-0.02	-0.03	2.14	-0.00	-0.00	-0.00	2.14
Care homes	0.01	0.00	0.01	1.01	*0.06	0.06	*0.06	1.01	-0.08	-0.09	-0.08	1.58
Deprivation	*0.08	0.07	*0.07	1.15	-0.00	0.01	0.00	1.20	-0.07	-0.05	-0.07	2.54
PM10	0.07	0.06	0.06	11.82	-0.02	-0.03	-0.03	2.77	-0.28	-0.30	-0.28	12.65
O3	-0.01	-0.01	-0.01	6.69	0.06	0.06	0.06	4.50	-0.09	-0.10	-0.08	3.19
NO2	*-0.08	-0.07	-0.07	5.87	0.08	0.08	0.08	6.44	-0.01	-0.01	-0.01	13.78
R-squared	0.04	0.05	0.06		0.03	0.03	0.03		0.29	0.31	0.29	
AIC	1001.3	999.71	998.71		967.24	965.65	967.2		52.64	54.37	54.63	
Lag coeffient	NA	NA	0.189		NA	NA	-0.07		NA	NA	-0.03	

**p<0.05, **p<0.01, ***p<0.001*

Source: Statistics Belgium, calculations by author