Systematic Reviews

SYSTEMATIC REVIEW UPDATE

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Geospatial analysis of environmental atmospheric risk factors in neurodegenerative diseases: a systematic review update

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Abstract

Following up the previously published systematic review on the same topic and realizing that new studies and evidence had emerged on the matter, we conducted an update on the same research terms. With the objective of updating the information relating environmental risk factors on neurodegenerative diseases and the geographic approaches used to address them, we searched PubMed, Web of Science and Scopus for all scientific studies considering the following three domains: neurodegenerative disease, environmental atmospheric factor and geographical analysis, using the same keywords as in the previously published systematic review. From February 2020 to February 2023, 35 papers were included versus 34 in the previous period, with dementia (including Alzheimer's disease) being the most focused disease (60.0%) in this update, opposed to multiple sclerosis on the last review (55.9%). Also, environmental pollutants such as $PM_{2.5}$ and NO_2 have gained prominence, being represented in 65.7% and 42.9% of the new studies, opposed to 9.8% and 12.2% in the previous review, compared to environmental factors such as sun exposure (5.7% in the update vs 15.9% in the original). The mostly used geographic approach remained the patient's residence (82.9% in the update vs 21.2% in the original and 62.3% in total), and remote sensing was used in 45.7% of the new studies versus 19.7% in the original review, with 42.0% of studies using it globally, being the second most common approach, usually to compute the environmental variable. This review has been registered in PROSPERO with the number CRD42020196188.

Keywords Neurodegenerative, Environment, Geospatial, Epidemiology, Systematic review, Systematic review update

Introduction

The pathological changes suffered by the human brain during the ageing process lead to a range of neurodegenerative disorders [1], which are characterized by a progressive loss or damage of neuronal cell leading to compromised brain function. While the world's population over the age of 60 is expected to reach 22% until 2050, the concern about the future of neurodegenerative diseases arises, and the development of better suitable health systems for elder population is urged forward. Alzheimer's disease (AD) is the most prevalent of neurodegenerative pathologies worldwide and is responsible for an extensive cognitive damage which usually affects daily chores [2]. Parkinson's disease (PD) closely follows AD

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in prevalence and leads to both motor and non-motor symptoms due to dopaminergic neuronal loss. Affecting around 2.5 million people globally, multiple sclerosis (MS) is the third most prevalent neurodegenerative disease and is usually an autoimmune response causing an inflammatory demyelination of the brain [3].

Other risk factors are known in the development of neurodegenerative disorders, including gender, aggravated clinical history — hypertension, diabetes, cranial injury and tumours — and smoking and drinking [4]. Nevertheless, the knowledge on the development of these pathologies remains incomplete, and it is thought environmental factors may have a contribution [4]. With 91% of the world's population living under high pollution levels, with air quality levels above the established limits for health safety by the World Health Organization (WHO) [5], the urge for studying its implications on the population's health is rising. Recent studies have revealed that atmospheric pollution can trigger mechanisms responsible for neurodegenerative diseases [6–8].

A useful tool to both measure and analyse environmental exposure to air pollution is remote sensing data/techniques, and it has been increasingly used in epidemiological studies with the number publications featuring remote sensing applied to health increasing from 5.6 to 13.3% between 2007 and 2016 [9]. Geospatial analysis allows to integrate information on health, environmental data and socio-economic information at a local and global focus. Future research may then maximize the data used and establish future policies, which may be critical in preventing and progressing neurodegenerative diseases.

Following our previous systematic review [10], this systematic review update aims to identify new studies concerning neurodegenerative diseases and their environmental atmospheric risk factors through a geographical approach.

Materials and methods

The methods for this review are similar to the ones previously used in the original review [10].

Information sources and search strategy

We searched PubMed, Web of Science and Scopus databases from the 1st February 2020 until the 31st January 2023, using the keywords on Table 1. This review has been previously registered in PROSPERO with the number CRD42020196188 and has currently been set as updated. Duplicates were removed prior to abstract screening.

Eligibility criteria

Records were included if they contained all three domains considered in this review, neurodegenerative disease, atmospheric pollutant or factor and geographical approach, and were excluded otherwise. Inclusion criteria were as follows: (1) Studying a neurodegenerative disease, (2) accounting for atmospheric environmental factors or pollutants, (3) using geospatial analysis or tools and (4) include all previous criteria in the same study. All languages were considered.

Exclusion criteria encompassed studying mechanisms and biospecimen behind a neurodegenerative disease, soil and water pollutants and simply stating a geographical area without further comparing nor analysing it.

Selection process

Abstracts were independently read by two authors to apply the inclusion and exclusion criteria explained above and select eligible papers for full-text screening. Rayyan was used to manage and perform all selection process in the abstracts phase. Abstracts were included if both reviewers agreed on the inclusion decision and excluded likewise. In abstracts with disagreement, reviewers discussed the individual cases until consensus was reached.

Data collection process

The review process was conducted independently by each of the two reviewers, who then convened to discuss their findings. Full texts were firstly screened for further selection. Rayyan kept being used in this phase to keep track of each reviewer's decisions. Included full texts' information was retrieved using semi-structured forms equal to the

Table 1 Keywords used to search databases by domain. Each domain's keywords were concatenated by an AND condition

Domain	*Keywords*
Neurodegenerative	(alzheimer*) OR (ataxia*) OR (Chorea Minor) OR (creutzfeldt*) OR (dementia*) OR (Frontotemporal) OR (Guillian-barre syndrome) OR (Huntington*) OR (kennedy* disease) OR (Lewy*) OR (motor neuron*) OR (Myotonic dystrophy) OR (neurodegen*) OR (parkinson*) OR (pick's) OR (Prion) OR (progressive AND palsy) OR (progressive muscular atrophy) OR (sclerosis*) OR (*senile) OR (Spinal Atrophy)
Environment	(atmospher*) OR (carbon) OR (environment*) OR (humidity) OR (meteorologic*) OR (nitrogen) OR (ozone) OR (particulate*) OR (PM2*) OR (pollut*) OR (sulphur*) OR (surface pressure) OR (temperature)
Geographic	(drone) OR (geograph*) OR (imagery) OR (landsat) OR (map) OR (mapping) OR (modis) OR (remote sens*) OR (satellite) OR (sentinel) OR (spatial) OR (topologic*)

ones used in the original review. The forms included free writing inputs such as the title, year, country, authors, DOI, participants, aims and key findings. Additionally, multiple-choice inputs were available for study design, statistical methods, outcome measurements, study limitations, neurodegenerative disease, environmental risk factors, geographic approach and type of geographical approach. Some level of simplification was made on categorizing the study limitations, as to better fit most studies on the main biases and issues encountered. However, new methodologies from the papers made it necessary to add fields such as Bayesian methods in the statistical methods, as well as PM_1 and black carbon (BC) as environmental factors. All respective options are listed in Table 2. Reviewers had the liberty to include supplementary free text comments when they felt it was necessary.

Study risk-of-bias assessment

To evaluate the risk of bias in individual studies, the study's limitations were categorized according to a set of predefined options. These options included the following: none given by the authors; conflict of interests (any conflict of interests stated by the authors); confounding factors (unassessed confounding factors); ecological bias (extrapolation of a conclusion from a population to a patient); exposure assessment (issues with assessing the patient's exposure to the environmental factor); interpolation (issues with spatially interpolating the environmental factor); memory bias (data collection relying on patient's memory); migration of patients (patients moving from one residence to another); referral bias (studies relying on the doctor's referring similar cases); sampling issues (under sampling; over sampling or non-representative sampling); statistical issues (lacking of more relevant statistical methods); study design issues (studies acknowledging inappropriate study design); survival bias (relying on a patient being alive over a period of time); time-related issues (inability to assess the amount of time a patient was exposed to the environmental factor); and unassessed patients (patients outside the databases not being considered). The risk of bias was retrieved from the paper itself, as assessed by the respective authors, and was not further analysed by the reviewers.

Effect measurements

Outcomes from studies were extracted using the same forms, in which each reviewer could select which measurement was used (prevalence, correlation, relative risk,

Table 2 Article forms' options regarding multiple-choice domains

Domain	*Options*		
Study limitations	None given by the authors	Interpolation	Statistical bias
	Conflict of interests	Memory bias	Study design issues
	Confounding factors	Migration of patients	Survival bias
	Ecological bias	Referral bias	Time-related bias
	Exposure assessment	Sampling bias	Unassessed patients
Study design	Case control	Cross-sectional	Methodological
	Cohort	Ecological	Review
Statistical methods	None	Chi-squared	Poisson regression
	Correlation	Linear regression	Spatial autoregressive
	T-test	Logistic regression	Clustering
	ANOVA	Cox regression	Sensitivity analysis
Measurements	Prevalence	Relative risk	Hazard ratio
	Correlation	Odds ratio	Coefficients
Neuro disease (NEURO)	Amyotrophic lateral sclerosis	Multiple sclerosis	Parkinson
	Paediatric multiple sclerosis	Motor neuron disease	Dementia
Environmental factor (ENV)	Sun exposure	Index	CO
	Temperature	PM_{10}	O_3
	Precipitation	$PM_{2.5}$	Cu
	Humidity	NO_x	Pb
	Pressure	SO_2	
Geographic approach (GEO)	Administrative	Latitude	Remote sensing
	Clustering	Longitude	Spatial interpolation
	GIS	Residence	
Type of GEO	Compare GEO	Compute ENV	Predict NEURO

CO carbon monoxide, *Cu* copper, NO_X nitrogen oxides, O_3 ozone, *Pb* lead, $PM_{2.5}$ particulate matter (diameter < 2.5 μm), PM_{10} particulate matter (diameter < 10 μm), SO_2 sulphur dioxide

odds ratio, hazard ratio and regression coefficients), as well as the obtained values with simple plus signs (+) for statistically significative positive associations, minus signs (−) for statistically significative negative associations and question marks (?) for statistically non-significative associations. All studies' measurements were considered, and only relative associations were noted to allow for more broad comparison. The strength of the association was not taken into account to simplify the relative comparison across different study types, population sizes and other variables that might influence the results.

Results

Identification, screening and assessment

Of the 3510 abstracts obtained, 2282 articles were initially screened after duplicates were removed, from which only 35 were included in the final study. The number of published papers on the scope of this review has clearly increased through the years, as visible in the graphic of Fig. 1. 2021 was the year with the most published articles in this scope, with 17 papers, while until 2015 only 15 had ever been published. The trend line presented in Fig. 1 is a fourth-degree polynomial line automatically obtained by fitting the number of studies over the years, and that shows the increasing trend in the amount of works published in the field. The selection process is summarized using PRISMA presented by a flow diagram (Fig. 2). The discrepancy in the total number of excluded studies and the sum of the exclusion reason categories are due to the overlapping of exclusion reasons. The full list with the studies results from the original review, and the present update is provided on Table S1 in the supplementary matterials.

Overall, as in Table 3, most papers studied multiple sclerosis (43.5%) and dementia — including AD — (34.8%) as neurodegenerative diseases and compared them with either $PM_{2.5}$, NO_X and PM_{10} (44.9%, 36.2% and 23.2%, respectively). Using the patient's residence as an estimator of exposure was used in 62.3% of the studies, and remote sensing was used in 42.0%. As categories from each domain are not mutually exclusive, the sum of all categories may be higher than the total number of articles. The graphics in Fig. 3 represent the number of articles in each domain with the corresponding categories.

The main methodological characteristics of the included studies are summarized on Table 4. A more detailed table with each paper's characteristics is included in supplementary materials in Table S1. The country of origin of the studies is represented in Fig. 4. The country with the most papers published was the USA, with 19 papers overall, 8 of which about dementia. It was also the country with the most variety of neurodegenerative diseases studied, which included dementia, MS, PD, amyotrophic lateral sclerosis (ALS) and paediatric multiple sclerosis (PMS). A list of all countries with their corresponding published papers is available on Table 5. As several times countries have joined their efforts to study a specific disease, the total number of studies included and the sum of the published papers by country do not match.

Qualitative synthesis

The following analysis was performed taking into account all included articles from the original and the updated

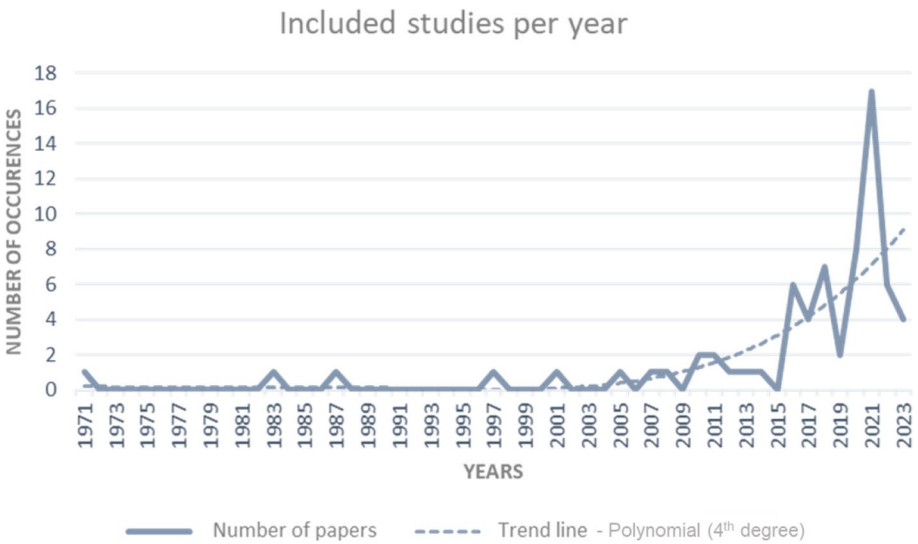

Fig. 1 Number of published articles on this review's scope throughout the years

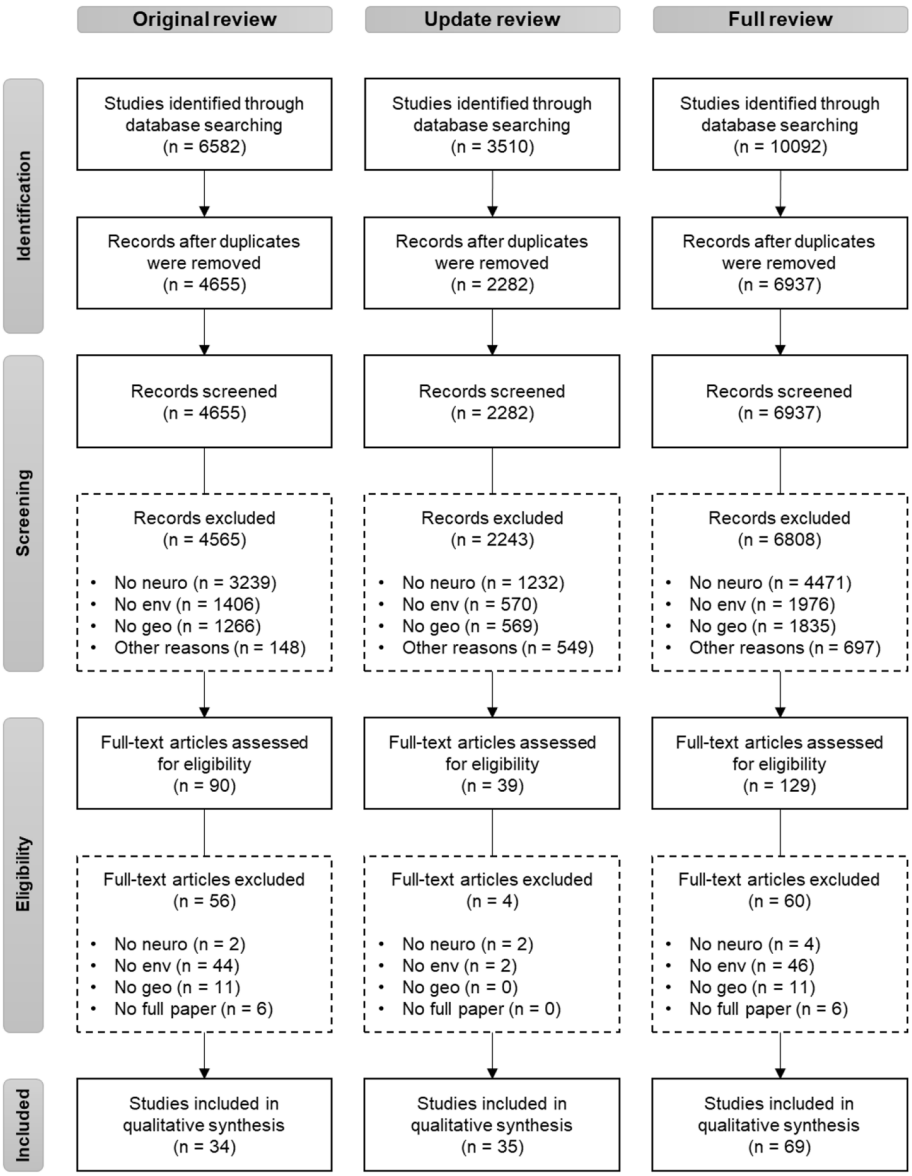

Fig. 2 Systematic review PRISMA flowchart, including original and update reviews and their junction. Neuro, neurodegenerative disease; env, environmental factor or pollutant; geo, geographic approach

systematic review. Further, detailed information regarding the results presented in each study is presented on in the supplementary materials.

- *Amyotrophic lateral sclerosis*: ALS was approached on four studies [11–14]. Of these, three studied its interaction with PM_{10} [12–14], and two analysed $PM_{2.5}$ [12, 14]. Both pollutants generally showed a negative but not significant association. A study [11] identified a significant negative association between ALS and sun exposure and significant positive association with precipitation and humidity, while no significant associations were identified with both temperature and pressure. Another study [12] found a positive significant association with NO_x, with an odds ratio (OR) between 1.872 and 2.703. This study found no more significant associations with the remaining pollutants studied: SO_2, CO, O_3 and Pb.
- *Dementia*: Dementia, including AD, was studied 24 times [15–38], 18 of which focused on $PM_{2.5}$, with

Table 3 Number and percentage of papers included in the update for each domain categories

	Update		*Total*	
	N	**%**	***N***	**%**
NEURO				
Amyotrophic lateral sclerosis	2	5.7	3	4.3
Dementia	21	60.0	24	34.8
Motor neuron disease	0	0.0	1	1.4
Multiple sclerosis	11	31.4	30	43.5
Paediatric multiple sclerosis	0	0.0	2	2.9
Parkinson	5	14.3	12	17.4
ENV				
BC	4	11.4	4	5.8
CO	1	2.9	7	10.1
Cu	0	0.0	1	1.4
Humidity	2	5.7	5	7.2
Index	3	8.6	5	7.2
Mg	0	0.0	2	2.9
Mn	0	0.0	1	1.4
No_x	15	42.9	25	36.2
O_3	8	22.9	12	17.4
Pb	0	0.0	5	7.2
PM_1	1	2.9	1	1.4
PM_{10}	10	28.6	16	23.2
PM_{25}	23	65.7	31	44.9
Precipitation	0	0.0	6	8.7
Pressure	0	0.0	1	1.4
Rn	0	0.0	1	1.4
SO_2	2	5.7	8	11.6
Sun exposure	2	5.7	15	21.7
Temperature	4	11.4	12	17.4
GEO				
Administrative	3	8.6	19	27.5
Clustering	2	5.7	4	5.8
GIS	7	20.0	21	30.4
Latitude	3	8.6	8	11.6
Longitude	2	5.7	3	4.3
Remote sensing	16	45.7	29	42.0
Residence	29	82.9	43	62.3
Spatial interpolation	6	17.1	7	10.1

NEURO, ENV and GEO represent the three domains, respectively, neurodegenerative diseases, environmental risk factors and geographic approach. *BC*, black carbon; *CO*, carbon monoxide; *Cu*, copper; *Mg*, magnesium; *Mn*, manganese; NO_X, nitrogen oxides; O_3, ozone; *Pb*, lead; PM_1, ultrafine particulate matter (diameter < 1 μm); PM_{10}, particulate matter (diameter < 10 μm); $PM_{2.5}$, particulate matter (diameter < 2.5 μm); *Rn*, radon; SO_2, sulphur dioxide

13 finding a significant positive association between dementia and $PM_{2.5}$ [15, 19, 21, 22, 26–32, 36, 37], with hazard ratios ranging from 1.02 [36] to 1.67 [30] and the remaining not finding a significant association [23, 33, 34, 38]. No association was ever found between dementia and temperature [16, 20], humidity [20] nor black carbon [23, 26, 33]. The outcomes concerning NO_x and NO_2 were controversial, with six papers finding a positive association [15, 25, 35, 39–41], two finding a negative association [20] (in particular with Alzheimer [23]) and five finding no significant association [22, 23, 26, 33, 34]. Furthermore, a study [35] approached several air pollutants (PM_{10}, NO_2, SO_2, CO and O_3) and found a significant positive association with all of them.

- *Motor neuron disease*: Only one study focused on motor neuron disease (MND) [42], and it positively related the disease to lead (Pb), with a correlation coefficient of 0.824.
- *Multiple sclerosis*: MS was studied 30 times [23, 43–71], 13 of which in relation to sun exposure, where half the studies found a significant negative association [43–45, 47, 50, 51], half found no significant association [52, 55, 56, 58, 60, 70] and 1 found a positive association [62]. Other environmental factors such as temperature and precipitation brought up further conflicts: some studies found a negative relation to temperature [43, 44, 49, 66], opposing others [45, 47, 49], and precipitation was mostly inconclusive [43, 47]. Concerning the air pollutants, the results were more in line with each other, with most studies finding at least one significant positive association [23, 48, 53, 57, 59, 61, 67–69, 71].
- *Paediatric multiple sclerosis*: Two studies focused on PMS [72, 73]: one positively relating an air quality index to the disease [72] and another one studying several pollutants, positively associating the disease with $PM_{2.5}$, SO_2, CO and Pb, and not finding significative association with PM_{10}, NO_X and O_3 [73].
- *Parkinson's disease*: Finally, PD was studied 12 times [23, 29, 32, 74–82], mostly related to air pollutants, where significant positive relations were found between the disease and PM_{10} [81], $PM_{2.5}$ [23, 32, 82], NO_X/NO_2 [23, 77, 81] and CO [77]. No associations were found with either black carbon [23, 82], copper [75], lead [75] and manganese [74]. Negative associations were also found in relation to sun exposure [78] and O_3 [82].

Discussion

Overview

This systematic review has retrieved as many studies in this update, concerning 2020 to 2023 as in the original

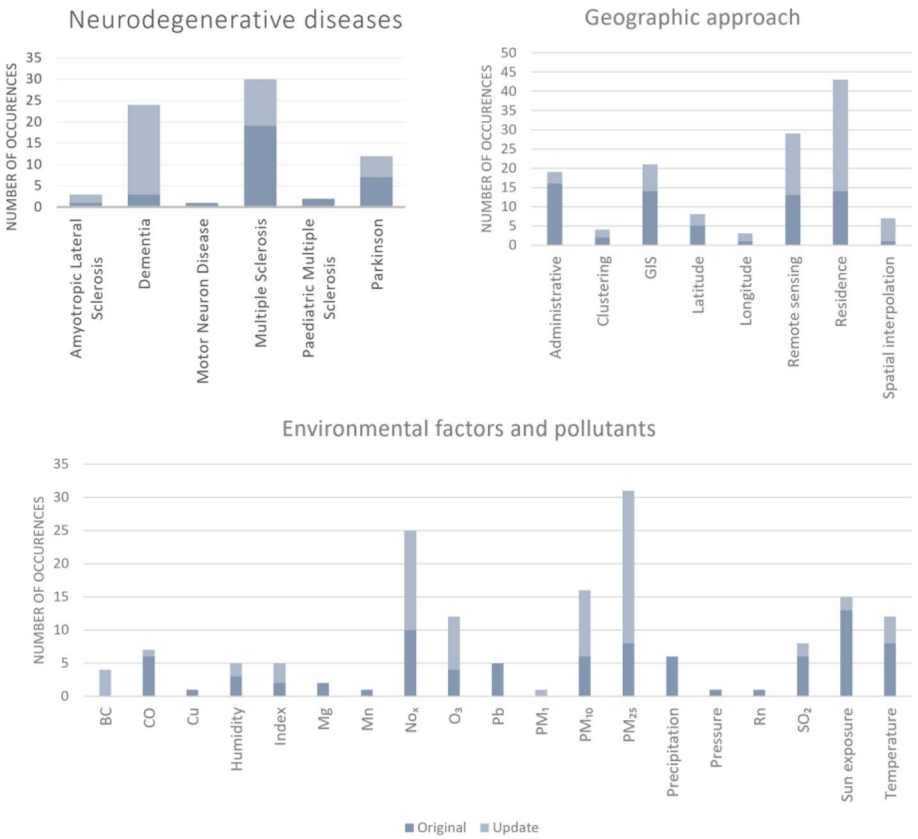

Fig. 3 Studies in each category by domain: neurodegenerative diseases, geographic approach and environmental factors and pollutants

review, from inception to 2020, using the same methods, suggesting an increased concern in relating neurodegenerative diseases to, primarily, air pollution. Also, an increasing trend of studying dementia opposed to MS was clearly observed, which could indicate a new focus on less studied diseases. This updated version of the systematic review has hence brought new insights on the subject.

ALS studies are scarce, as well as MND and PMS ones, probably due to the low incidence of these diseases, and gaps addressing the related environmental risk factors have been found [83]. Considering the three most prevalent diseases, dementia (including AD) has nearly come level with MS in terms of the number of studies (24 versus 28), and PD, the second most prevalent neurodegenerative disease worldwide, has been studied not even half the times (10). Overall, all neurodegenerative diseases were positively related to air pollutants such as PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO [12, 15, 17, 19–23, 26–32, 35–38, 48, 53, 59, 61, 67–69, 71, 73, 75, 77, 81, 82].

In the studies reviewed, various environmental factors were analysed for their associations with neurological conditions, yielding mixed results across different diseases. For ALS, significant associations were noted with NO_X, but not with PM_{10} or $PM_{2.5}$. Dementia studies predominantly identified a positive link with $PM_{2.5}$, while findings regarding NO_X and NO_2 were inconsistent. MND research indicated a positive correlation with lead. MS studies showed a divided stance on sun exposure, with air pollutants generally associated positively. Paediatric MS research also found positive associations with $PM_{2.5}$, SO_2, CO and lead. PD research demonstrated significant associations with PM_{10}, $PM_{2.5}$, NO_X/NO_2 and CO, but not with other pollutants like black carbon or heavy metals. These results underscore the varied impact of environmental factors on neurological conditions, with certain pollutants, as is the case of PM_{10} and $PM_{2.5}$, consistently appearing as risk factors. The lack of studies in South America and Africa rises the concern of whether this group of diseases is being overlooked in these areas. Although Africa has the lowest rates of neurodegenerative diseases in the world, the same cannot be said about South America, and so further research on this region is advised.

Table 4 Study methodological characteristics summary: limitations, study design, statistical methods and effect measures

	Original		*Update*		*Overall*	
	N	**%**	***N***	**%**	***N***	**%**
Limitations						
None given by the authors	5	14.7	2	5.7	7	10.1
Conflict of interests	1	2.9	0	0.0	1	1.4
Confounding factors	15	44.1	18	51.4	33	47.8
Ecological bias	3	8.8	4	11.4	7	10.1
Exposure assessment	18	52.9	29	82.9	47	68.1
Interpolation	3	8.8	0	0.0	3	4.3
Memory bias	3	8.8	1	2.9	4	5.8
Migration of patients	4	11.8	2	5.7	6	8.7
Referral bias	2	5.9	0	0.0	2	2.9
Sampling bias	7	20.6	17	48.6	24	34.8
Statistical bias	13	38.2	6	17.1	19	27.5
Study design issues	3	8.8	2	5.7	5	7.2
Survival bias	1	2.9	1	2.9	2	2.9
Time-related bias	9	26.5	7	20.0	16	23.2
Unassessed patients	6	17.6	11	31.4	17	24.6
Study design						
Case control	9	26.5	6	17.1	15	21.7
Case crossover	0	0.0	4	11.4	4	5.8
Cohort	4	11.8	21	60.0	25	36.2
Cross-sectional	12	35.3	1	2.9	13	18.8
Ecological	6	17.6	2	5.7	8	11.6
Methodological	2	5.9	0	0.0	2	2.9
Review	1	2.9	1	2.9	2	2.9
Statistical methods						
None	2	5.9	1	2.9	3	4.3
ANOVA	2	5.9	1	2.9	3	4.3
Bayesian	0	0.0	2	5.7	2	2.9
Chi-squared	5	14.7	1	2.9	6	8.7
Clustering	2	5.9	2	5.7	4	5.8
Correlation	22	64.7	2	5.7	24	34.8
Cox regression	4	11.8	11	31.4	15	21.7
Linear regression	12	35.3	8	22.9	20	29.0
Logistic regression	10	29.4	13	37.1	23	33.3
Poisson regression	3	8.8	1	2.9	4	5.8
Sensitivity analysis	10	29.4	8	22.9	18	26.1
Spatial autoregressive	1	2.9	0	0.0	1	1.4
T-test	5	14.7	2	5.7	7	10.1
Effect measurements						
None	2	5.9	0	0.0	2	5.9
Coefficients	14	41.2	5	14.3	14	41.2
Correlation	20	58.8	3	8.6	20	58.8
Hazard ratio	3	8.8	4	11.4	3	8.8
Odds ratio	11	32.4	11	31.4	11	32.4
Prevalence	4	11.8	13	37.1	4	11.8
Relative risk	4	11.8	5	14.3	4	11.8

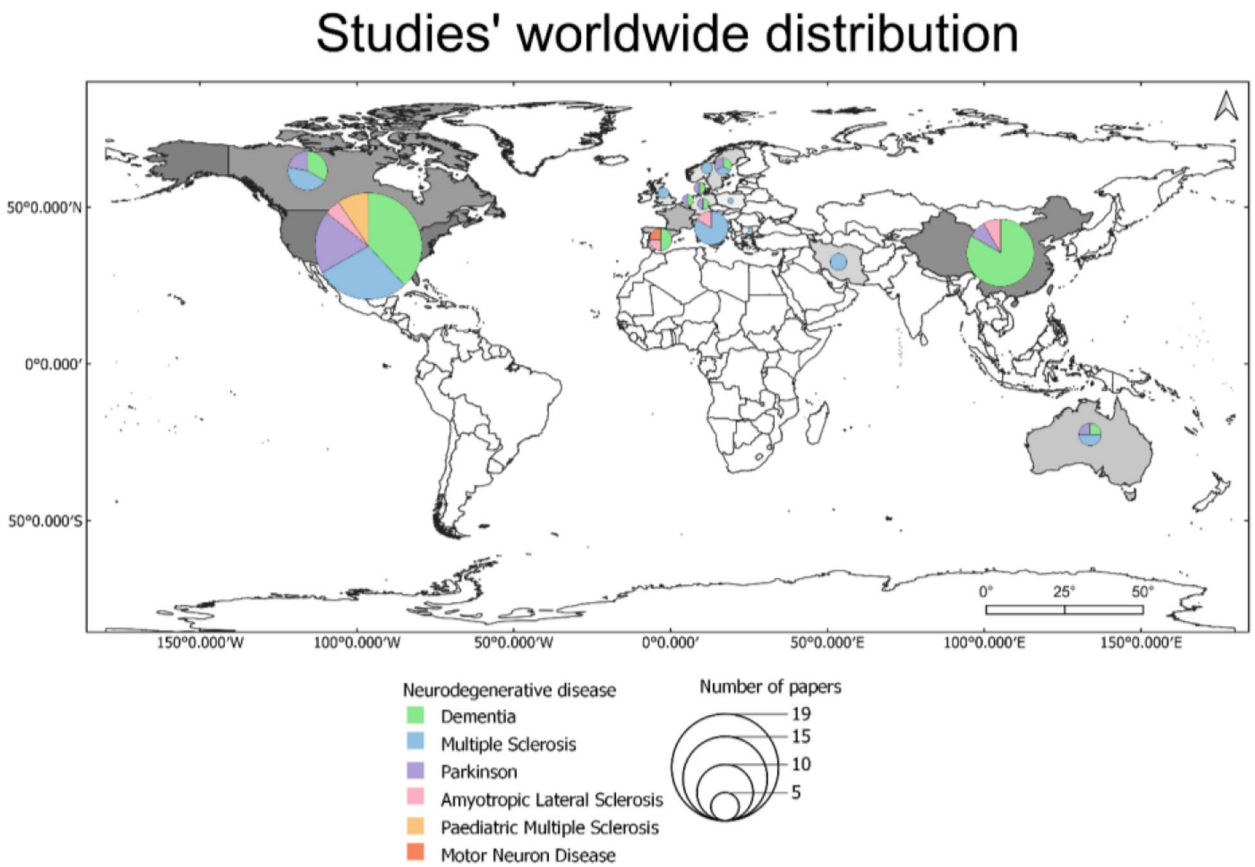

Fig. 4 Country of origin of the studies and the diseases studied in each country. Different diseases are represented by different colours in the pie charts showing the diseases' proportions, while the chart sizes represent the absolute number of studies issued in the respective country

Study limitations

Our study has some limitations. For instance, despite this being an update, rarer diseases such as Creutzfeldt-Jakob and Huntington's are still unstudied in the domains of this review. It is thus identified as a potential future study case to focus on the diseases not yet found. Also, despite not having excluded any study based on its language, and having scanned three different relevant databases in the scientific field, no grey literature was analysed, and it could potentially provide further studies of interest. Also, no particular tool was used to assess the risk of bias from the included studies. It is relevant to refer that the studies included in this review focus on association and not causality; thus, no causal inference can be taken from the results collected.

Study implications

Future works on the field of neurodegenerative diseases and their relation to environmental factors might refer to this review as a starting point to identify studies in the area, along with which diseases have been studied and those which still lack analysis, and which environmental factors have they been related to, hypothesizing environmental factors relatable to unstudied diseases or related environmental factors yet to analyse. The geographic approaches also present diverse methods that can be used to add the geographical dimension to the studies, as well as exposures assessment.

Conclusions

The most studied neurodegenerative diseases were in line with the most prevalent ones worldwide. It is mostly unanimous that environmental pollutants significantly influence the incidence of these pathologies, increasing their rates. Particulate matter and nitric oxides were the most studied pollutants and have mostly contributed positively to the rates of neurodegenerative diseases. The present systematic review update provides an insight of the evidence being made

Table 5 Country of origin with the number of studies published (N) and the respectively studied diseases. Some studies have investigators or focus on data from more than one country

Country (N)	*Amyotrophic lateral sclerosis*	*Dementia*	*Motor neuron disease*	*Multiple sclerosis*	*Paediatric multiple sclerosis*	*Parkinson*
USA (19)	1	8		6	2	4
China (12)	1	10				1
Canada (7)		3		4		2
Italy (6)	1			5		
France (5)		2		1		2
Australia (4)		1		2		1
Spain (4)	1	2	1			
Austria (3)		1		1		1
Iran (3)				3		
Sweden (3)		1		1		1
Denmark (2)		1				1
Germany (2)		1				1
Israel (2)				2		
Netherlands (2)		1				1
Norway (2)				2		
UK (2)				2		
Bulgaria (1)				1		
Poland (1)				1		
Switzerland (1)						1

regarding the association between environmental factors and neurodegenerative diseases using geospatial analysis. As with the original systematic review, the ever-increasing amount of data support the development of further research on this topic. Less prevalent diseases such as ALS, MND and PMS have been targeted as less studied, as well as the regions of South America and Africa, and are an interesting starting point for future works.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13643-024-02637-7.

Supplementary Material 1. Supplementary tables: Table S1. Detailed characteristics of each included study. ALS: amyotrophic lateral sclerosis; GIS: geographic information system; MS: multiple sclerosis. Table S2. Study results summary. +: positive statistically significative association, -: negative statistically significative association; ?: no statistically significative association found.

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Authors' contributions
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Data availability
All data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare that they have no competing interests.

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