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Review

Climate Change, the Exposome and the Rising Burden of Neurodegenerative Diseases: A Review

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Abstract: Dynamic shifts in global temperatures have increased the intensity of extreme weather events over many decades, leading to an increase in wildfires, drought, floods, intense hurricanes, longer hurricane seasons, damaging dust storms, humidity changes, decreasing foliage canopy, and altering crop patterns. Accelerated environmental changes can cause negative impacts on everyday human activities and living conditions leading to an increase in the likelihood of human exposure to anthropogenic chemicals: i.e., microplastics; insecticides, fungicides, and herbicides; and biological chemicals: i.e., algal toxins, these exposures are defined collectively as the "*exposome*". Every human being is unique in their genetic makeup; therefore, individuals will respond differently to those chemical exposures. Intersecting with climate change is a global increase in neurodegenerative disorders. Exposure to specific compounds has been linked to various neurological diseases, such as dementia, Alzheimer's, and Parkinson's.

Keywords: microplastics; pesticides; algal toxins; Alzheimer's; Parkinson's; ALS; climate change

1. Introduction

Global temperatures have risen gradually since the mid-1800s and then more rapidly from the 1970s. The June 2025 Global Climate Monthly Report, published by the United States National Oceanic and Atmospheric Administration (US NOAA), charts that 2024 was the hottest year on record worldwide since global record keeping began in 1850 [1]. The report indicates that there was a significant upsurge in temperatures in 2024 when compared to the annual average temperatures from 1991 to 2020 [1]. A map of the chart data, presented in the report, better illustrates the overall global changes in temperatures Figure 1. These dynamic shifts in temperature have increased the intensity of extreme weather events, such as wildfires, droughts, floods, more intense hurricanes, longer hurricane seasons, and dust storms. These extreme weather events have led to changing humidity, decreasing foliage canopy, and altering crop patterns [2,3].

In April of 2025, the Centre for Research on the Epidemiology of Disasters (CRED) released their report on global disasters that occurred in 2024 [4]. There were 393 natural hazard-related disasters reported (i.e., extreme heat spells, floods, severe cold, tropical storms, and droughts), affecting 167.2 million people globally and creating 242 billion US dollars in economic damages [4]. Accelerated environmental changes, in contrast to historic long-term smaller environmental fluctuations, cause negative impacts on everyday human activities and living conditions, including, but not limited to, global food insecurity and increasing starvation; air pollution, causing exacerbation of asthma and other adverse respiratory conditions; spread of tropical diseases to former non-tropics

(i.e., dengue fever, malaria); and hotter, as well as, longer heat waves, resulting in increased adverse cardiovascular events [5–7].

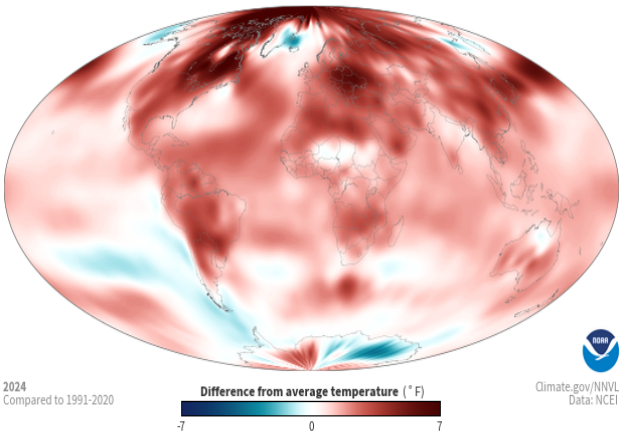

Figure 1. 2024 Global thermal map: Temperature—Global Yearly, Difference from Average. Color codes: Shades of red show where average annual temperature in 2024 was warmer than the average from 1991–2020. Shades of blue show where the annual average was cooler than the long-term average. The darker the color, the larger the difference from average temperature. White and very light areas were close to their long-term average temperature. Gray areas near the North and South Poles show where no data are available. https://www.climate.gov/maps-data/data-snapshots/data-source/temperature-global-yearly-difference-average; last accessed 8 August 2025.

In May 2025, the World Meteorological Organization (WMO) released their *Global Annual to Decadal Climate Update* for the period of 2025–2029 [8]. This report specified several key climate change indicators that had reached record levels in 2024. These indicators showed that the rate of sea-level rise has doubled since satellite measurements began, ocean warming will be irreversible for hundreds of years, record greenhouse gas concentrations are at the highest in 800,000 years which, when combined with the El Niño Southern Oscillation phenomenon, drove the 2024 heat records to be higher. These driving indicators led to stronger tropical cyclones in the South Pacific and more intense hurricanes in the North Atlantic in 2024 [4]. The impact from these unstable weather events in 2024 led to worldwide flooding, droughts, increased domestic food prices, the highest number of human displacements since 2008, as well as destruction of homes, critical infrastructure, and farmland [8]. Specifically, these high impact weather events were responsible for major economic and human losses in Southeast Asia and North America. The worst of the Southeast Asia typhoons was Typhoon Yagi. Typhoon Yagi was responsible for the deaths of more than 600 people and led to $20 billion (USD) in economic damages [4]. In the North Atlantic five major hurricanes impacted the United States and the Caribbean, from July-October 2024. These hurricanes caused $113 billion (USD) in economic damages and were attributable for the deaths of 314 people [9,10]. It is estimated that, in the US alone, extreme weather events will lead to an estimated 7000 to 11,000 excess deaths, particularly along the eastern coast of the United States [11].

Unraveling the connection between climate change, impacts on human populations, and increasing neurological disorders is complicated. In part, these rapid environmental fluctuations bring about a greater likelihood of human exposure to more contaminants, i.e., the *exposome*, of both anthropogenic sources, i.e., microplastics (MPs), pesticides, fungicides, herbicides, and natural sources, i.e., algal toxins.

The *exposome* is "the measure of all the exposures of an individual in a lifetime and how those exposures relate to health. An individual's exposure begins before birth and includes insults from environmental and occupational sources." [12,13]. Every living organism on Earth has a singular genetic design and therefore each organism may respond differently to chemical exposures. Exposure to specific contaminants has been linked to neurological diseases, such as dementia, Alzheimer's disease (AD), and Parkinson's disease (PD) [14,15]. Worldwide diagnoses of neurological disorders are on the rise, with high-income areas of the Asia-Pacific seeing the largest growth in Disability Adjusted Life Year (DALY) rates from AD and other forms of dementias Figure 2 [16]. We can only speculate as to why there is this dramatic increase in rates of DALY in the Asia-Pacific region. A couple of potential reasons could be from a broader adaptation of "Western-Eurocentric" diets into Asian cultures, increasing dramatic weather patterns in the Southern and Northern Pacific, i.e., El Niño/La Niña weather patterns, and a decrease in traditional indigenous farming methods to more "Western-Eurocentric" farming methods with their increased dependence upon pesticides.

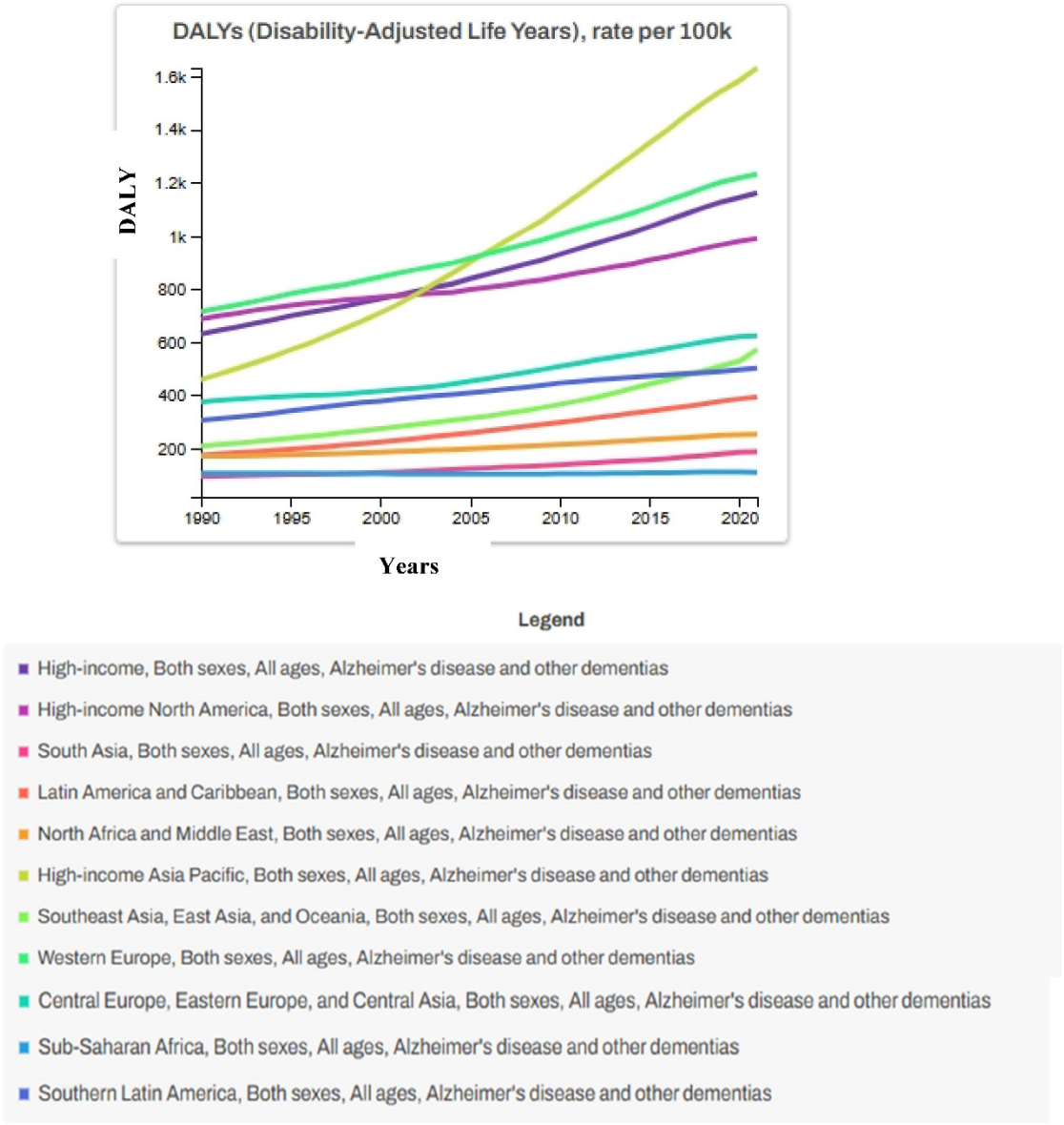

Figure 2. Global rates of DALY from AD and other neurological disorders. Graph built from data program: Institute for Health Metrics and Evaluation (IHME). Global Burden of Disease (GBD) results. Seattle, WA: IHME, University of Washington, 2024. Available from https://vizhub.healthdata.org/gbd-results?params=gbd-api-2021-permalink/cdbf2e3102349bb304a3283432de0438 (Data set built on 8 August 2025).

In 2024, approximately 7 million people in the United States (about 2% of the total population) have been diagnosed with AD, and that number is expected to double by 2060 [17]. In other countries, such as Vietnam, cases of dementia are expected to rise from an estimated 660,000 people (as diagnosed) in 2015 to 1.2 million people by 2030 [18]. Lee et al. undertook a detailed sampling study across India of over 60 community-based cohorts to establish a more comprehensive national database [19]. This study was larger than previous studies conducted by other researchers where their data had been limited to a few metropolitan areas of India. In this study Lee et. al. found that approximately 7.4% (8.8 million people) of India's population had dementia in 2023, higher than the previous models had predicted. Their newer model is now predicting that the number of people in India with dementia will climb to 16.9 million by 2036 [19]. The economic, social, and emotional toll on general and personal well-being will be strained by the increase in dementia cases.

We will briefly discuss different scenarios as they pertain to the three subject matters under review in this paper: harmful algal blooms (HABs); pesticides, fungicides, and herbicides; as well as MPs. Each of these areas will then be explored in greater detail in their respective sections.

In the first situation, climate change leads to increasing algal blooms in both freshwater and marine environments due to increasing water temperature and salinity. Under extreme warming temperatures and excess

nutrients, algal blooms can potentially become HABs, which are toxic [20,21]. Communities that border lakes and coastal communities have increased exposure to aerosolized algal toxins, and allergens, via the aerosolization during extreme weather events, such as windstorms, hurricanes, typhoons, and monsoon rains, thereby exposing these communities to toxic airborne particulates for hours and weeks after the weather event [22]. A review of evidence-based literature points to definitive links between algal toxins and neurodegenerative diseases, which will be detailed later in this review [23].

In the second situation, rising temperatures and increased humidity levels have led to increasing outbreaks of plant pathogens, such as fungi [24]. Rising fungal infections lead to an increased use of fungicides, such as triphenyltin (TPT), on susceptible crops (e.g., sweet potatoes and rice). TPT has been linked to neuroinflammation, oxidative stress (OS), and increases in α-synuclein aggregation, which are implicated in the onset of AD [25].

Finally, in the third scenario, increased flooding, more intense hurricanes, and overall extreme weather events lead to the widespread distribution of anthropogenic materials, such as plastics. Extreme weather events can cause disintegration of plastic materials into smaller particles, such as MPs, causing further dispersal throughout the environment [26,27]. Figure 3 displays an example of the weathering of a plastic bottle into smaller pieces and subsequent ingestion of those MPs into living organisms.

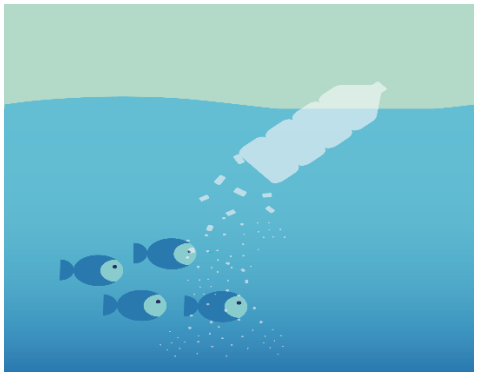

Figure 3. Breakdown of a plastic bottle into MPs. Used with permission by © European Union, 1998–2025, Attribution, https://commons.wikimedia.org/w/index.php?curid=116161052 (accessed on 2 September 2025).

With the discoveries of MPs in the environment, and subsequently in the tissues of living organisms, concerns over how these materials affect living organisms have been raised. MPs have been shown in human cell cultures to accelerate the aggregation of two amyloid-β (Aβ) peptides, (Aβ40 and Aβ42), which are implicated in the initiation of AD [28].

In this review, we will look in more detail at how climate change has increased exposure to algal toxins, pesticides, fungicides, herbicides, and MPs, and that these exposure associations are potentially linked to a rise in neurodegenerative disorders.

2. Algal Toxins

Cyanobacteria, the oldest known living organisms first appeared on the Earth around 2 to 3 billion years ago (according to the fossil record), and are photosynthetic microorganisms capable of thriving in diverse ecosystems and extreme environments [29]. Cyanobacteria played a critical role in developing an oxygenated atmosphere in the early Earth; they are still crucial in their ecological role of nitrogen fixation and solar energy utilization. Global climate change and increases in anthropogenic eutrophication have led to abundant growth of algal blooms, impacting fresh, marine and coastal environments [29,30]. These larger blooms can turn deadly with the right mixture of heat, fluctuating temperatures, nutrients, and biological stress [29,30]. Toxic algal blooms (e.g., cyanotoxins) pose significant risks to public health and ecosystems [29,30].

The connection between cyanotoxins and neurological diseases was first identified after World War II when US Army physicians documented an unusually high incidence of Amyotrophic Lateral Sclerosis/Parkinsonism-dementia complex (ALS/PDC) among the Chamorro people of Guam and Rota [31]. This condition occurred at rates 50 to 100 times higher than average, indicating a possible environmental cause. Research determined that ALS/PDC was associated with dietary exposure to β-*N*-methylamino-L-alanine, which was produced from cyanobacteria living symbiotically in cycad trees [32].

Likewise, higher ALS clusters have been observed in other geographical areas (i.e., Florida, New Hampshire, Wisconsin in the US, as well as Japan and France) near cyanobacteria-prone lakes and rivers, suggesting an environmental influence on disease prevalence [33]. As briefly mentioned in the introduction, routes of exposure can include food sources, dermal contact, and inhalation of aerosolized particulates containing the toxins [22].

Rogers and Stanley reported that when high winds agitate the surface of bodies of water they can release aerosols into the atmosphere, upwards of up to 6000 miles from the original HABs [22].

Some of the most researched algal-related neurotoxic compounds include microcystins (MCs) and anatoxin-a [23,34,35]. Drinking water advisories have been established for MCs by the US Environmental Protection Agency as 1.6 μg/L for children and adults and 0.3 μg/L for infants [36]. The World Health Organization sets a guideline of 1 μg/L for drinking water for adults and children, and they recommend that other sources of water be used for infants when the MC concentrations exceed 3 μg/L [37]. While the drinking water advisories are focused on acute toxicity and carcinogenicity endpoints, studies show that MCs can cross the blood-brain barrier via organ anion-transporting peptides [34]. This infiltration into the brain can cause neurostructural, functional, and behavioral changes through mechanisms such as OS, inhibition of phosphatases 1 and 2A, and impacts on neurotransmission, ion channels, signal transduction, and the cytoskeleton [34]. One toxic form of MC, microcystin-LR (MC-LR), primarily affects the liver; however, there is emerging evidence to suggest that MC-LR plays a role in neurodegenerative diseases, including ALS/PDC. A study by Yan et al. demonstrated that MC-LR, at drinking water doses of ≥15 μg/L, entered mouse brain tissues, such as the cortex, hippocampus, and substantia nigra (SN), leading to apoptosis of SN dopaminergic neurons [38]. Mouse studies by Wang et al. demonstrated that MC-LR, at higher doses of ≥30 μg/L in drinking water, accumulated in the hippocampus and the cortex [39]. At these doses, the mice exhibited memory and learning dysfunction, and upon sacrifice, the brain tissue exhibited neuronal cell apoptosis, accumulation of Aβ plaques (Aβ 1–42), and enhanced phosphorylation of p-tau, all implicated in AD [39]. Other studies have demonstrated that chronic exposure to MC-LR can disrupt the blood-brain barrier, inducing inflammation, damaging mitochondria, increasing glutamate release, inducing α-Syn aggregation, and worsening ALS/PDC progression [40–45].

Anatoxin-a, a cyanotoxin, is a potent neurotoxin that mimics acetylcholine, causing continuous stimulation of the muscles and leading to paralysis and respiratory failure [46]. Emerging evidence suggests anatoxin-a's link to neurodegenerative diseases, such as ALS/PDC, is due to its neurotoxic effects and interactions with the motor system. Anatoxin-a binds irreversibly to the nicotinic acetylcholine receptor, which mimics acetylcholine but cannot be degraded by acetylcholinesterase (AChE). This results in prolonged neuronal excitation, which leads to calcium overload and excitotoxicity [47,48]. Over time, excitotoxicity kills motor neurons, which is a hallmark of ALS. Anatoxin-a stimulates excess glutamate release, leading to *N*-methyl-D-aspartate receptor overactivation [49]. This in turn induces OS and mitochondrial dysfunction, a mechanism well-documented in ALS pathology.

Anatoxin-a(S), also called guanitoxin, is a cholinesterase inhibitor which prevents the breakdown of acetylcholine at synaptic junctions [50]. Anatoxin-a(S) is activated through oxidative metabolism and binds to AChE, the enzyme that is critical for hydrolyzing acetylcholine and terminating its activity at nicotinic and muscarinic receptor sites. The inhibition of AChE leads to the accumulation of acetylcholine, resulting in excessive stimulation of these receptors [51]. Over stimulation of the AChE receptors leads to a decrease in acetylcholine, which can cause degeneration of the cholinergic system potentially leading to AD [52].

Another algal toxin is saxitoxin. Saxitoxins (STXs) block sodium channels in nerve and muscle cells, inhibiting nerve transmission. This algal toxin is responsible for Paralytic Shellfish Poisoning (PSP). Mass mortality events have been documented regarding STX, such as the die-off of endemic sponges in Lake Baikal, Russia [53], as well as massive fish mortality in Lake Vistonis, Greece [54]. In early 2013, Sabah, Malaysia, experienced six outbreaks of PSP, resulting in 58 cases (24 males and 34 females) and four fatalities. These incidents were linked to red tide events, with many of the victims consuming shellfish sourced from local markets or collected from local beaches [55]. It has been suggested that even exposure to low doses of STXs can induce a decrease in voltage-dependent anion-selective channel 1 (VDAC1). VDAC1 is a multifunctional protein expressed by mitochondria and regulates metabolic functions of cells. It represents one of the main docking sites of misfolded proteins, such as Aβ and Tau. It was reported that concentrations of VDAC1 were over expressed in the post-mortem tissue of AD brains, which ironically suggests that STXs could potentially be used in the treatment of AD [23].

Interestingly, Botelho et al. review the links between exposure to marine dinoflagellate toxins and decreases in Aβ plaques and tau hyperphosphorylation, both of which are known to be potential precursor initiates of AD [56]. They propose that various marine dinoflagellate toxins (i.e., yessotoxin, gymnodiine, 13-desmethyl spirolide-C, and gambierol) can attenuate kinase thereby preventing overexpression of Aβ and the hyperphosphorylation tau proteins, which may lead to potential treatments for AD [56]. However, they point out that one marine dinoflagellate, okadaic acid (OA), has a different cellular mechanism compared to the other marine toxins. OA mediates the inhibition of phosphatase activity leading to hyperphosphorylation of tau proteins, which causes neuronal and synaptic dysfunction and cellular death [56].

3. Insecticides, Fungicides, and Herbicides

The changing climate, characterized by rising temperatures and increased pest outbreaks, has led to a greater reliance on insecticides, fungicides, and herbicides in sustaining agriculture practices [57]. These shifts, coupled with changes in farming regions, have heightened human and environmental exposure to agricultural chemicals, raising concerns about their health and ecological impacts. Climate change exacerbates environmental exposures to pesticides, fungicides, and herbicides, which increases the risk of neurological diseases through complex interactions in the exposome [58].

Plant protection products (PPPs), including insecticides, herbicides, and fungicides, offer significant benefits for agriculture, but they pose risks, including driving pest resistance, secondary pest outbreaks, environmental contamination, and human health concerns [59–61].

While pesticides target harmful pests, they can harm non-target biota. A review by Kamel and Hoppin discusses how the detection of higher concentrations of organochlorine pesticides were found in the post-mortem brains of Parkinson's disease patients, compared to a baseline population [62]. A study by Li et al. showed that exposure to the once commonly used pesticide dichlorodiphenyltrichloroethane (DDT) increased levels of Aβ precursor, which affected the Aβ synthesis pathways. DDT also impaired the clearance and extracellular degradation of Aβ peptides [63]. In 2014 a study, published by Richardson et al., measured levels of dichlorodiphenyldichloroethylene (DDE), the metabolite of DDT, in human serum (peri-mortem) and temporal cortex samples (post-mortem) and compared these levels to the apolipoprotein E (APOE) genotype [64]. In that study they found that a there was an increased risk of AD for those patients that had elevated DDE levels in their serum (supported by levels detected in brain tissue samples) and that were also carriers of the APOE ε4 allele [64]. Parrales-Macias et al., in 2023, published a study of chlordecone (CLD), another organochlorine pesticide, showed that chronic, low-level exposure could potentially lead to Parkinson-like neurodegeneration [65]. Both mouse midbrain cell cultures and *Caenorhabditis elegans* (*C. elegans*) worms were exposed to varying levels, and durations, of CLD. The data indicated progressive losses of dopamine neurons in *C. elegans* worms after exposure [65]. CLD also caused the phosphorylation of protein tau in both the mouse midbrain cell cultures and in the *C. elegans* worms [65]. Another study looked at organochlorine pesticides (OCPs) and two herbicides trifluralin and triallate (fluorinated and thiocarbamate herbicides, respectively) and their effect on human neuroblastoma cells viability [66]. This study concluded that the OCPs caused cell death via mitochondrial dysfunction and dysregulation of cellular processes, while the two herbicides were more likely to cause cellular death through mitophagy and inhibition of proliferation. These cellular disruptions and dysregulation are implicated in the development of neurodegenerative disorders, such as AD, PD, and multiple sclerosis [66].

As mentioned in the introduction, TPT, an organometallic compound, is a widely used fungicide that has connections to neurodegenerative disease. TPT, after application to crops, can be released into the surrounding environment via waterways or potentially during dust storms and carried along with airborne soil particulates, thus increasing exposure to people living or working near TPT-applied crops. TPT exposure can lead to an increase in α-synuclein aggregation, implicated in neurodegenerative disease, in human nerve cells [25]. A review by Ferraz de Silva et al. discusses links between TPT, as well as other organotins, and how they can cross the blood-brain barrier to initiate neurotoxic effects, such as neuroinflammation and OS [67].

Pesticides such as organophosphates and carbamates inhibit acetylcholinesterase, a key enzyme for nerve function, causing neurotoxicity and increasing the risk of disorders such as PD, AD, and cognitive decline with chronic exposure [68–71]. Herbicides such as glyphosate and paraquat contribute to OS and mitochondrial dysfunction, which are linked to neurodegenerative diseases, such as PD [68,72]. Fungicides, including dithiocarbamates, can disrupt neurotransmitter balance and induce OS, potentially aggravating neurological conditions causing PDC (Parkinsonism-dementia complex) [73]. Long-term exposure, even at sub-lethal doses, can accumulate in the body and trigger chronic neuroinflammation and neurodegeneration, which is particularly concerning for communities living in, and near, agricultural regions, and especially for farm workers who apply PPPs and work in the fields after application [68,74,75]. Prenatal exposure to PPPs has been linked to neurodevelopmental disorders, including autism spectrum disorder and attention-deficit hyperactivity disorder, due to disruptions in brain development during critical periods [76,77].

The potential mechanistic effects of pesticides, fungicides, and herbicides of neurodegenerative diseases such as ALS and PDC are excitotoxicity, OS, endocrine disruption, and gut-brain axis disruption. Glutamate-induced excitotoxicity is a key mechanism in the pathogenesis of ALS, leading to selective motor neuron degeneration [78]. Due to their high calcium influx and limited buffering capacity, motor neurons are particularly susceptible to degeneration [78,79]. Exposure to pesticides, particularly organochlorine insecticides, has been linked to an increased risk of ALS [80]. Fortunately, advances in induced pluripotent stem cell technology now allow for

human cell-based models that study ALS-related excitotoxicity, accelerating research on gene-environment interactions and disease mechanisms [81]. These models are especially valuable for investigating how pesticides and cyanotoxins affect neuronal excitability [81]. A deeper understanding of excitotoxicity in ALS is essential for developing targeted treatments, as demonstrated by riluzole—the only FDA-approved ALS drug—which is believed to exert its effects by reducing excitotoxic damage [78,79].

4. Microplastics

Climate change and MPs are an interconnected phenomenon. Climate change can increase the abundance and distribution of MPs throughout the environment due to the rise of ocean temperatures, melting ice caps, and extreme weather events, all of which redistribute the flow of waters [82]. Rising temperatures have increased the rate of plastic degradation through enhanced chemical, biological and physical means, creating an abundance of MPs [82].

Small particles of plastic that are 0.1 μm to 5 mm in diameter have been categorized as "microplastics," and those plastic particles with diameters less than 100 nm are "nanoplastics" [83]. There are two categories of MPs based on the method of their production. Primary MPs are intentionally manufactured, for items such as toothpaste, cosmetics, and sunscreen. Secondary MPs are created through the breakdown of plastic debris, particularly MPs, over time due to physical, biological, or chemical processes [82,84]. This profusion of MPs into the environment can indirectly affect the carbon cycle by damaging marine life that is essential to carbon fixation [85]. Higher temperatures also increase the distribution of MPs into ocean currents due to the influx of fresh water into the oceans from the melting ice caps, disrupting oceanic circulations [86]. Extreme weather events, such as typhoons and flooding, can cause additional movement of MPs throughout the environment. Samples of surface water and sediment after such events have indicated increased levels of MPs [83,87–90].

MPs are an environmental concern due to marine and mammalian uptake of MPs; these MPs can cross the blood-brain barrier potentially leading to neurotoxicity or having a role in neurodegeneration [28,83]. MPs harm aquatic ecosystems as they are small enough to be ingested, or absorbed, by living organisms. Once ingested, or absorbed, a variety of complications can occur including OS, clogging of the digestive tract, and reduced growth rate [26]. The chemical additives within MPs, when inhaled or ingested, can result in neurotoxic effects within the brain. In addition, MPs may contribute to the imbalance between antioxidants and free radicals in the body, resulting in OS, which can lead to the cellular damage and neuroinflammation commonly associated with diseases, such as AD and PD [83].

MPs may also trigger an immune response when they enter the brain, causing chronic activation of microglia, the immune cells of the brain, leading to neuroinflammation [91]. They can directly affect synaptic function, affecting neurotransmitter release which would inhibit the ability of efficient neuronal transmission [83]. Additionally, the inhibition of AChE is one of the most reported effects of the neurotoxic MPs [83]. The inhibition of AChE results in the lack of acetylcholine being broken down and its accumulation in the synaptic cleft, causing continuous stimulation of the postsynaptic neuron.

Additionally, MPs can absorb organic pollutants which can be introduced to the food chain [84]. A recent study demonstrated that polyfluoroalkyl substances were bonded to MPs during wastewater treatment. The MPs collected from the wastewater were categorized as smaller MPs, whereby 99.8% of the MPs collected were < 1mm [92]. These smaller MPs have higher sorption capacities, allowing for a diversity of other chemicals to be sorbed onto them. Another recent study has shown that TPT binds onto the surface of an agglomeration of MPs [93]. This study demonstrated that the fungicide TPT was carried along with the MPs across the blood-brain barrier (MPs < 50 nm). The two chemicals together formed a unit that displayed a synergistic effect in enhancing neurotoxicity, as compared to when they were introduced individually [93].

5. Conclusions

Throughout this review we have tried to show the links between neurodegenerative diseases and a subset of chemical classes. Algal toxins, pesticides, fungicides, herbicides, MPs, and NPs are just a few of the contaminants, out of potentially millions, which have been implicated in neurodegenerative disorders. Table 1 and Figure 4 summarize the various pathological mechanisms that are common across the chemical classes discussed in the three sections of this review.

Table 1. Summary of mechanisms leading to neurological degeneration.

Mechanism	Algal Toxins	Pesticides	Microplastics	Notes
Oxidative stress	MC induces OS, mitochondrial damage; anatoxin-a excitotoxic Ca^{2+} overload	Paraquat causes OS via mitochondrial inhibition; glyphosate includes oxidative stress; TPT and OCPs also linked	MPs and NPs increase OS, disrupt antioxidant balance, mitochondrial impairment	Universal mechanism; central to all exposures.
Neuroinflammation	MC disrupts BBB → microglial activation; anatoxin-a excitotoxicity drives inflammation	TPT triggers neuroinflammation; OCPs. Fungicides and herbicides promote chronic glial activation	MPs activate microglia inflammasome	Common downstream drive of degeneration
Protein aggregation	MC promotes Aβ plaques, tau phosphorylation, α-syn aggregation; OA promotes tau hyperphosphorylation	TPT promotes α-syn aggregation; CLD promotes tau phosphorylation; DDT/DDE enhances Aβ accumulation	MPs accelerate Aβ40/42 aggregation; synergize with TPT to worsen protein misfolding	Converges on AD/PD hallmarks (Aβ, tau, α-syn)
Blood-Brain barrier disruption	MC crosses BBB via OATPs, damages tight junctions	Organotin (e.g., TPT) and other PPPs disrupt barrier integrity	MPs (<50 nm) crosses BBB; NPs can carry pesticides across, synergizing toxicity	Shared entry route enhancing CNS exposure.
Excitotoxicity/synaptic dysfunction	Anatoxin-a mimics acetylcholine → persistent receptor stimulation; glutamate dysregulation	Organophosphates & carbamates inhibit AChE → express acetylcholine; glutamate excitotoxicity in ALS	MPs inhibit AChE, alter neurotransmitter release, disrupt synaptic function	Direct convergence on synaptic loss
Mitochondrial dysfunction	MC and anatoxin-a cause mitochondrial swelling and dysfunction; STX modulates VDAC1	Paraquat inhibits complex I; herbicides include mitophagy failure; OCPs impair energy metabolism	MPs impair mitochondrial function, energy failure	Energy failure

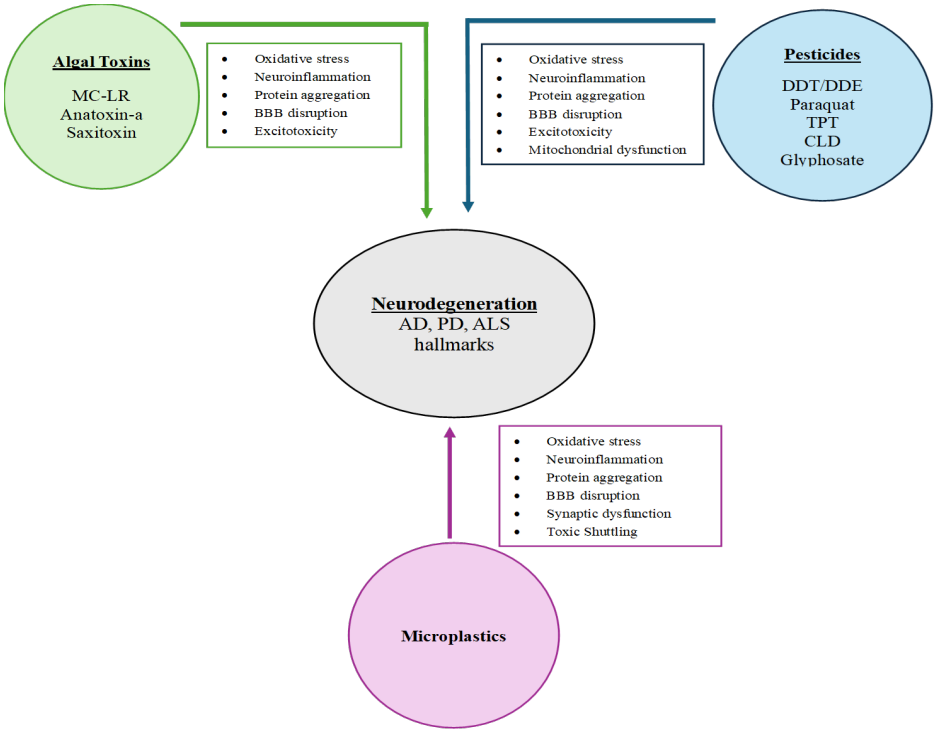

Figure 4. Pathological mechanisms across algal toxins, pesticides and microplastics.

The studies presented in this review implicate that post-industrial climate change is causing increasing temperatures and humidity, rising CO_2 levels, and stronger cyclones, tornadoes, and hurricanes. This disturbance of the natural order by anthropogenic changes has increased the production of HABs, led to greater use of plant

protection products to keep the world fed, and has created a new category of contaminants, MPs, which are potentially a health concern, especially as they are now known to transport other chemicals into living organisms.

Overall, the need is urgent to reduce our reliance on greenhouse gas-producing chemicals and plastics. It has been suggested by Cheng [94], that our most urgent mission is turning our knowledge into action. It remains an ongoing challenge to promote science and take steps to form a civil movement for a global effort towards decarbonization. As individuals who are concerned about the environment, especially those of us in industrialized countries, we can do our part to encourage science studies, reduce our dependence on plastics, and bridge the gap between science and communities. Shen et al. sound the alarm on how our dependence on plastics contributes to not only greenhouse gas emissions but also increasing degradation of said plastics into the environment as MPs and NPs, where their interactions with other chemicals can occur [85].

While this is an abbreviated review, we encourage readers to explore further these connections between climate change, the exposome and neurological diseases. New data and discoveries are continually adding to our knowledge and hopefully redirecting our efforts towards a more sustainable future. There are gaps in our knowledge that can be further explored, such as, studying synergistic effects of contaminant microplastics and chemical mixtures. Ideally, getting away from animal research models to ones that incorporate induced pluripotent stem cell technology, or potentially developing human organelles for more accurate modeling would be better for understanding the mechanistic pathways of exposure to neuro-cellular degeneration.

Ultimately, future research should prioritize longitudinal human cohort studies that integrate climate modeling with detailed exposomic and biomarker analysis to untangle the complex interactions driving neurodegeneration.

Author Contributions

H.H.: Writing original draft, writing review & editing; T.J.-L.: Conceptualization, writing original draft, writing review & editing, supervision; M.N.M.: writing original draft, writing review & editing, visualization; K.W.: writing original draft, writing review & editing; E.K.: writing review & editing, supervision; E.J.M.: writing review & editing, supervision; J.W.K.: writing review & editing, supervision, funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. NOAA National Centers for Environmental Information (2025). Global Climate Report June 2025. Available online: https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/202506/2025-year-to-date-temperatures-versus-previous-years (accessed on 8 August 2025).
2. Abbass, K.; Qasim, M.Z.; Song, H.; et al. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environ. Sci. Pollut. Res.* **2022**, *29*, 42539–42559. https://doi.org/10.1007/s11356-022-19718-6.
3. Chen, W.; Liu, L.; Liu, D.; et al. Droughts and windstorms due to climate change increase variability in species and trait composition of a subtropical monsoon evergreen broadleaf forest in China. *For. Ecosyst.* **2025**, *12*, 100253. https://doi.org/10.1016/j.fecs.2024.100253.
4. Centre for Research on the Epidemiology of Disasters (CRED). *2024 Disasters in Numbers*; CRED: Brussels, Belgium, 2024. Available online: https://files.emdat.be/reports/2024_EMDAT_report.pdf (accessed on 14 August 2025).
5. Rocque, R.J.; Beaudoin, C.; Ndjaboue, R.; et al. Health effects of climate change: An overview of systematic reviews. *BMJ Open* **2021**, *11*, e046333. https://doi.org/10.1136/bmjopen-2020-046333.
6. Franchini, M.; Mannucci, P.M. Impact on human health of climate changes. *Eur. J. Intern. Med.* **2014**, *26*, 1–5. https://doi.org/10.1016/j.ejim.2014.12.008.
7. Watts, N.; Amann, M.; Arnell, N.; et al. The 2020 report of the *Lancet* Countdown on health and climate change: Responding to converging crises. *Lancet* **2021**, *397*, 129–170. https://doi.org/10.1016/S0140-6736(20)32290-X.

8. World Meteorological Organization (WMO). *Global Annual to Decadal Climate Update 2025–2029*; WMO: Geneva, Switzerland, 2025. Available online: https://wmo.int/sites/default/files/2025-05/WMO_GADCU_2025-2029_Final.pdf (accessed on 14 August 2025).
9. Available online: https://coast.noaa.gov/states/fast-facts/hurricane-costs.html (accessed on 14 August 2025).
10. Available online: https://www.ncei.noaa.gov/access/billions/events/US/1980-2024/?disasters[]=tropical-cyclone (accessed on 14 August 2025).
11. Young, R., Hsiang, S. Mortality caused by tropical cyclones in the United States. *Nature* **2024**, *635*, 121–128. https://doi.org/10.1038/s41586-024-07945-5.
12. Available online: https://archive.cdc.gov/www_cdc_gov/niosh/topics/exposome/default (accessed on 14 August 2025).
13. Vineis, P.; Robinson, O.; Chadeau-Hyam, M.; et al. What is new in the exposome? *Environ. Int.* **2020**, *143*, 105887. https://doi.org/10.1016/j.envint.2020.105887.
14. Nabi, M.; Tabassum, N. Role of environmental toxicants on neurodegenerative disorders. *Front. Toxicol.* **2022**, *4*, 837579. https://doi.org/10.3389/ftox.2022.837579.
15. Lefèvre-Arbogast, S.; Chaker, J.; Mercier, F.; et al. Assessing the contribution of the chemical exposome to neurodegenerative disease. *Nat. Neurosci.* **2024**, *27*, 812–821. https://doi.org/10.1038/s41593-024-01627-1.
16. Huang, Y.; Li, Y.; Pan, H.; et al. Global, regional, and national burden of neurological disorders in 204 countries and territories worldwide. *J. Glob. Health.* **2023**, *13*, 04160. https://doi.org/10.7189/jogh.13.04160.
17. Available online: https://www.alz.org/getmedia/ef8f48f9-ad36-48ea-87f9-b74034635c1e/alzheimers-facts-and-figures.pdf (accessed on 14 August 2025).
18. Nguyen, T.A.; Pham, T.; Dang, T.H.; et al. Towards the development of Vietnam's national dementia plan-the first step of action. *Australas J. Ageing* **2020**, *39*, 137–141. https://doi.org/10.1111/ajag.12755.
19. Lee, J.; Meijer, E.; Langa, K.M.; et al. Prevalence of dementia in India: National and state estimates from a nationwide study. *Alzheimer's Dement*. **2023**, *19*, 2898–2912. https://doi.org/10.1002/alz.12928.
20. Gobler, C.J. Climate change and harmful algal blooms: Insights and perspective. *Harmful Algae* **2020**, *91*, 101731. https://doi.org/10.1016/j.hal.2019.101731.
21. Moore, S.K.; Trainer, V.L.; Mantua, N.J.; et al. Impacts of climate variability and future climate change on harmful algal blooms and human health. *Environ. Health* **2008**, *7*, 1–12. https://doi.org/10.1186/1476-069X-7-S2-S4.
22. Rogers, M.M.; Stanley, R.K. Airborne Algae: A Rising Public Health Risk. *Environ. Sci. Technol.* **2023**, *57*, 5501–5503. https://doi.org/10.1021/acs.est.3c01158.
23. Sini, P.; Dang, T.B.C.; Fais, M.; et al. Cyanobacteria, Cyanotoxins, and Neurodegenerative Diseases: Dangerous Liaisons. *Int. J. Mol. Sci.* **2021**, *22*, 8726. https://doi.org/10.3390/ijms22168726.
24. Singh, B.K.; Delgado-Baquerizo, M.; Egidi, E.; et al. Climate change impacts on plant pathogens, food security and paths forward. *Nat. Rev. Microbiol.* **2023**, *21*, 640–656. https://doi.org/10.1038/s41579-023-00900-7.
25. Chen, X.; Shi, G.; Zhong, G.; et al. Triphenyltin inhibition of the proteasome activity and its influence on substrate protein levels in nerve cells. *Chin. Sci. Bull.* **2010**, *55*, 22–26. https://doi.org/10.1007/s11434-009-0678-1.
26. Hu, D.; Shen, M.; Zhang, Y.; et al. Microplastics and nanoplastics: Would they affect global biodiversity change? *Environ. Sci. Pollut. Res.* **2019**, *26*, 19997–20002. https://doi.org/10.1007/s11356-019-05414-5.
27. Shi, W.; Wu, N.; Zhang, Z.; et al. A global review on the abundance and threats of microplastics in soils to terrestrial ecosystem and human health. *Sci. Tot. Environ*. **2024**, *912*, 169469. https://doi.org/10.1016/j.scitotenv.2023.169469.
28. Gou, X.; Fu, Y.; Li, J.; et al. Impact of nanoplastics on Alzheimer's disease: Enhanced amyloid-β peptide aggregation and augmented neurotoxicity. *J. Hazard. Mater.* **2024**, *465*, 133518. https://doi.org/10.1016/j.jhazmat.2024.133518.
29. Aráoz, R.; Molgó, J.; Tandeau de Marsac, N. Neurotoxic cyanobacterial toxins. *Toxicon* **2010**, *56*, 813–828. https://doi.org/10.1016/j.toxicon.2009.07.036.
30. Rastogi, R.P.; Madamwar, D.; Incharoensakdi, A. Bloom dynamics of cyanobacteria and their toxins: Environmental health impacts and mitigation strategies. *Front. Microbiol.* **2015**, *6*, 1254. https://doi.org/10.3389/fmicb.2015.01254.
31. Rodgers, K.J.; Main, B.J.; Samardzic, K. Cyanobacterial neurotoxins: Their occurrence and mechanisms of toxicity. *Neurotox. Res.* **2018**, *33*, 168–177. https://doi.org/10.1007/s12640-017-9757-2.
32. Jonasson, S.; Eriksson, L.E.; Berntzon, L.; et al. A novel cyanobacterial toxin (BMAA) with potential neurodegenerative effects. *Plant Biotechnol*. **2008**, *25*, 227–232. https://doi.org/10.5511/plantbiotechnology.25.227.
33. Torbick, N.; Hession, S.; Stommel, E.; et al. Mapping amyotrophic lateral sclerosis lake risk factors across northern New England. *Int. J. Health Geogr*. **2014**, *13*, 1. https://doi.org/10.1186/1476-072X-13-1.
34. Hu, Y.; Chen, J.; Fan, H.; et al. A review of neurotoxicity of microcystins. *Environ. Sci. Pollut. Res.* **2016**, *23*, 7211–7219. https://doi.org/10.1007/s11356-016-6073-y.
35. Mokoena, M.M. Microcystins in water containers used in the home: A review of their potential health effects. *Ecotoxicol. Environ. Saf*. **2024**, *269*, 115787. https://doi.org/10.1016/j.ecoenv.2023.115787.

36. US EPA, Drinking Water Health Advisory for Microcystins-June 2015, Document EPA-820R15100. Available online: https://www.epa.gov/sites/default/files/2017-06/documents/microcystins-report-2015.pdf (accessed on 14 August 2025).
37. *Cyanobacterial Toxins: Microcystins. Background Document for Development of WHO Guidelines for Drinking-Water Quality and Guidelines for Safe Recreational Water Environments*; World Health Organization: Geneva, Switzerland, 2020. (WHO/HEP/ECH/WSH/2020.6). Available online: https://iris.who.int/bitstream/handle/10665/338066/WHO-HEP-ECH-WSH-2020.6-eng.pdf (accessed on 14 August 2025).
38. Yan, M.; Jin, H.; Pan, C.; et al. Movement disorder and neurotoxicity induced by chronic exposure to microcystin-LR in mice. *Mol. Neurobiol.* **2022**, *59*, 5516–5531. https://doi.org/10.1007/s12035-022-02919-y.
39. Wang, J.; Chen, Y.; Zhang, C.; et al. Learning and memory deficits and alzheimer's disease-like changes in mice after chronic exposure to microcystin-LR. *J. Haz. Mater*. **2019**, *373*, 504–518. https://doi.org/10.1016/j.jhazmat.2019.03.106.
40. Wang, J.; Zhang, C.; Zhu, J.; et al. Blood-brain barrier disruption and inflammation reaction in mice after chronic exposure to Microcystin-LR. *Sci. Total Environ.* **2019**, *689*, 662–678. https://doi.org/10.1016/j.scitotenv.2019.06.387.
41. Martin, R.M.; Bereman, M.S.; Marsden, K.C. BMAA and MCLR interact to modulate behavior and exacerbate molecular changes related to neurodegeneration in Larval Zebrafish. *Toxicol. Sci*. **2020**, *179*, 251. https://doi.org/10.1093/toxsci/kfaa178.
42. Zhao, S.; Xu, J.; Zhang, W.; et al. Paternal exposure to microcystin-LR triggers developmental neurotoxicity in zebrafish offspring via an epigenetic mechanism involving MAPK pathway. *Sci. Total Environ.* **2021**, *792*, 148437. https://doi.org/10.1016/j.scitotenv.2021.148437.
43. Zhao, S.; Yuan, C.; Tuo, X.; et al. MCLR induces dysregulation of calcium homeostasis and endoplasmic reticulum stress resulting in apoptosis in Sertoli cells. *Chemosphere* **2021**, *263*, 127868. https://doi.org/10.1016/j.chemosphere.2020.127868.
44. Yan, M.; Wu, H.; Wu, T.; et al. Microcystin-LR Exposure Damages Neurons by Inducing α-Syn Aggregation via MAPK4/GATA2/*SNCA* and PP2A/GRKs Pathways. *Mol. Neurobiol.* **2025**, *62*, 6195–6211. https://doi.org/10.1007/s12035-024-04683-7.
45. Lee, S.E. Guam dementia syndrome revisited in 2011. *Curr. Opin. Neurol*. **2011**, *24*, 517–524. https://doi.org/10.1097/WCO.0b013e32834cd50a.
46. Colas, S.; Marie, B.; Lance, E.; et al. Anatoxin-a: Overview on a harmful cyanobacterial neurotoxin from the environmental scale to the molecular target. *Environ. Res.* **2021**, *193*, 110590. https://doi.org/10.1016/j.envres.2020.110590.
47. Kumar, N.; Garg, A. Structural optimization and docking studies of anatoxin-a: A potent neurotoxin. *African J. Biotechnol.* **2014**, *13*, 3092–3100. https://doi.org/10.5897/ajb2014.13671.
48. Bezprozvanny, I.B. Calcium signaling and neurodegeneration. *Acta Naturae* **2010**, *2*, 72–80. https://doi.org/10.32607/20758251-2010-2-1-72-80.
49. Campos, F.; Alfonso, M.; Vidal, L.; et al. Mediation of glutamatergic receptors and nitric oxide on striatal dopamine release evoked by anatoxin-a. An in vivo microdialysis study. *Eur. J. Pharmacol*. **2006**, *548*, 90–98. https://doi.org/10.1016/j.ejphar.2006.07.044.
50. Fernandes, K.A.; Fadul, J.C.; Fiore, M.F.; et al. A systematic review on guanitoxin: General characteristics and ecological risks. *Chemosphere* **2024**, *352*, 141277. https://doi.org/10.1016/j.chemosphere.2024.141277.
51. Patocka, J.; Gupta, R.C.; Kamil, K. Anatoxin-A(S): Natural organophosphorus anticholinesterase agent. *Mil. Med. Sci. Lett.* **2011**, *80*, 129–139. https://doi.org/10.31482/mmsl.2011.019.
52. Walczak-Nowicka, Ł.J.; Herbet, M. Acetylcholinesterase Inhibitors in the Treatment of Neurodegenerative Diseases and the Role of Acetylcholinesterase in their Pathogenesis. *Int. J. Mol. Sci.* **2021**, *22*, 9290. https://doi.org/10.3390/ijms22179290.
53. Belykh, O.I.; Tikhonova, I.V.; Kuzmin, A.V.; et al. First detection of benthic cyanobacteria in Lake Baikal producing paralytic shellfish toxins. *Toxicon*. **2016**, *121*, 36–40. https://doi.org/10.1016/j.toxicon.2016.08.015.
54. Moustaka-Gouni, M.; Hiskia, A.; Genitsaris, S.; et al. First report of *Aphanizomenon favaloroi* occurrence in Europe associated with saxitoxins and a massive fish kill in Lake Vistonis, Greece. *Mar. Freshw. Res.* **2017**, *68*, 793–800. https://doi.org/10.1071/MF16029.
55. Suleiman, M.; Jelip, J.; Rundi, C.; et al. Case Report: Paralytic Shellfish Poisoning in Sabah, Malaysia. *Am. J. Trop. Med. Hyg*. **2017**, *97*, 1731–1736. https://doi.org/10.4269/ajtmh.17-0589.
56. Botelho, M.J.; Milinovic, J.; Bandarra, N.M.; et al. Alzheimer's Disease and Toxins Produced by Marine Dinoflagellates: An Issue to Explore. *Mar. Drugs* **2022**, *20*, 253. https://doi.org/10.3390/md20040253.
57. Rhodes, L.A.; McCarl, B.A. An analysis of climate impacts on herbicide, insecticide, and fungicide expenditures. *Agron*. **2020**, *10*, 745. https://doi.org/10.3390/AGRONOMY10050745.
58. Noyes, P.D.; McElwee, M.K.; Miller, H.D.; et al. The toxicology of climate change: Environmental contaminants in a warming world. *Environ. Int*. **2009**, *35*, 971–986. https://doi.org/10.1016/J.ENVINT.2009.02.006.
59. Damalas, C.A. Understanding benefits and risks of pesticide use. *Sci. Res. Essays* **2009**, *4*, 945–949.
60. Pogacean, M.O.; Gavrilescu, M. Plant protection products and their sustainable and environmentally friendly use. *Environ. Eng. Manag. J*. **2009**, *8*, 607–627. https://doi.org/10.30638/eemj.2009.084.

61. Żak, A. Plant protection products versus changes in the natural environment and their impact on the human health. *Probl. Agric. Econ*. **2016**, *346*, 155–166. https://doi.org/10.30858/zer/83045.
62. Kamel, F.; Hoppin, J.A. Association of pesticide exposure with neurologic dysfunction and disease. *Environ. Health Perspect*. **2004**, *112*, 950–958. https://doi.org/10.1289/ehp.7135.
63. Li, G.; Kim, C.; Kim, J.; et al. Common Pesticide, Dichlorodiphenyltrichloroethane (DDT), Increases Amyloid-β Levels by Impairing the Function of ABCA1 and IDE: Implication for Alzheimer's Disease. *J. Alzheimer's Dis*. **2015**, *46*, 109–122. https://doi.org/10.3233/JAD-150024.
64. Richardson, J.R.; Roy, A.; Shalat, S.L.; et al. Elevated Serum Pesticide Levels and Risk for Alzheimer Disease. *JAMA Neurol.* **2014**, *71*, 284–290. https://doi.org/10.1001/jamaneurol.2013.6030.
65. Parrales-Macias, V.; Michel, P.P.; Tourville, A.; et al. The Pesticide Chlordecone Promotes Parkinsonism-like Neurodegeneration with Tau Lesions in Midbrain Cultures and *C. elegans* Worms. *Cells* **2023**, *12*, 1336. https://doi.org/10.3390/cells12091336.
66. Alehashem, M.; Alcaraz, A.J.; Hogan, N.; et al. Linking pesticide exposure to neurodegenerative diseases: An in vitro investigation with human neuroblastoma cells. *Sci. Tot. Environ.* **2024**, *933*, 173041. https://doi.org/10.1016/j.scitotenv.2024.173041.
67. Ferraz da Silva, I.; Freitas-Lima, L.C.; Graceli, J.B.; et al. Organotins in neuronal damage, brain function, and behavior: A short review. *Front. Endocrinol*. **2018**, *8*, 366. https://doi.org/10.3389/fendo.2017.00366.
68. Baltazar, M.T.; Dinis-Oliveira, R.J.; de Lourdes Bastos, M.; et al. Pesticides exposure as etiological factors of Parkinson's disease and other neurodegenerative diseases—A mechanistic approach. *Toxicol. Lett.* **2014**, *230*, 85–103. https://doi.org/10.1016/j.toxlet.2014.01.039.
69. Mostafalou, S.; Abdollahi, M. The link of organophosphorus pesticides with neurodegenerative and neurodevelopmental diseases based on evidence and mechanisms. *Toxicology* **2018**, *409*, 44–52. https://doi.org/10.1016/J.TOX.2018.07.014.
70. Sánchez-Santed, F.; Colomina, M.T.; Hernández, E.H. Organophosphate pesticide exposure and neurodegeneration. *Cortex* **2016**, *74*, 417–426. https://doi.org/10.1016/j.cortex.2015.10.003.
71. Zaganas, I.; Kapetanaki, S.; Mastorodemos, V.; et al. Linking pesticide exposure and dementia: What is the evidence? *Toxicology* **2013**, *307*, 3–11. https://doi.org/10.1016/J.TOX.2013.02.002.
72. Tanner, C.M.; Kame, F.; Ross, G.W.; et al. Rotenone, paraquat, and Parkinson's disease. *Environ. Health Perspect*. **2011**, *119*, 866–872. https://doi.org/10.1289/ehp.1002839.
73. Lini, R.S.; Scanferla, D.T.P.; de Oliveira, N.G.; et al. Fungicides as a risk factor for the development of neurological diseases and disorders in humans: A systematic review. *Crit. Rev. Toxicol.* **2024**, *54*, 35–54. https://doi.org/10.1080/10408444.2024.2303481.
74. Barrett, J.R. More concerns for farmers. Neurologic effects of chronic pesticide exposure. *Environ. Health Perspect*. **2005**, *113*, A472. https://doi.org/10.1289/ehp.113-a472a.
75. Perry, J.; Cotton, J.; Rahman, M.A.; et al. Organophosphate exposure and the chronic effects on farmers: A narrative review. *Rural Remote Health* **2020**, *20*, 4508. https://doi.org/10.22605/RRH4508.
76. Doi, M.; Usui, N.; Shimada, S. Prenatal environment and neurodevelopmental Disorders. *Front. Endocrinol*. **2022**, *13*, 860110. https://doi.org/10.3389/fendo.2022.860110.
77. Roberts, J.R.; Dawley, E.H.; Reigart, J.R. Children's low-level pesticide exposure and associations with autism and ADHD: A review. *Pediatr. Res*. **2018**, *852*, 234–241. https://doi.org/10.1038/s41390-018-0200-z.
78. Bogaert, E.; d'Ydewalle, C.; Van Den Bosch, L. Amyotrophic lateral sclerosis and excitotoxicity: From pathological mechanism to therapeutic target. *CNS. Neurol. Disord. Drug Targets* **2010**, *9*, 297–304. https://doi.org/10.2174/187152710791292576.
79. Van Cutsem, P.; Dewil, M.; Robberecht, W.; et al. Excitotoxicity and amyotrophic lateral sclerosis. *Neurodegener. Dis*. **2005**, *2*, 147–159. https://doi.org/10.1159/000089620.
80. Kamel, F.; Umbach, D.M.; Bedlack, R.S.; et al. Pesticide exposure and amyotrophic lateral sclerosis. *Neurotoxicol.* **2012**, *33*, 457–462. https://doi.org/10.1016/j.neuro.2012.04.001.
81. Cheng, J.L.; Cook, A.L.; Talbot, J.; et al. How is excitotoxicity being modelled in iPSC-derived neurons? *Neurotox. Res.* **2024**, *425*, 1–20. https://doi.org/10.1007/S12640-024-00721-3.
82. Tang, K.H. Climate Change and Plastic Pollution: A Review of Their Connections. *Trop. Environ. Biol. Technol*. **2023**, *1*, 110–120. https://doi.org/10.53623/tebt.v1i2.341.
83. Prüst, M.; Meijer, J.; Westerink, R.H. The plastic brain: Neurotoxicity of micro- and nanoplastics. *Part. Fibre Toxicol.* **2020**, *17*, 24. https://doi.org/10.1186/s12989-020-00358-y.
84. Auta, H.S.; Emenike, C.U.; Fauziah, S.H. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. *Environ. Int*. **2017**, *102*, 165–176. https://doi.org/10.1016/j.envint.2017.02.013.
85. Shen, M.; Huang, W.; Chen, M.; et al. (Micro)plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change. *J. Clean Prod*. **2020**, *254*, 120138 https://doi.org/10.1016/j.jclepro.2020.120138.
86. Ford, H.V.; Jones, N.H.; Davies, A.J.; et al. The fundamental links between climate change and marine plastic pollution. *Sci. Total Environ.* **2022**, *86*, 150392. https://doi.org/10.1016/j.scitotenv.2021.150392.

87. Cheung, C.K.H.; Not, C. Impacts of extreme weather events on microplastic distribution in coastal environments. *Sci. Total Environ*. **2023**, *904*, 166723. https://doi.org/10.1016/j.scitotenv.2023.166723.
88. Daniel, D.B.; Ashraf, P.M.; Thomas, S.N. Impact of 2018 Kerala flood on the abundance and distribution of microplastics in marine environment off Cochin, Southeastern Arabian Sea, India. *Reg. Stud. Mar. Sci*. **2022**, *53*, 102367. https://doi.org/10.1016/j.rsma.2022.102367.
89. Hitchcock, J.N. Storm events as key moments of microplastic contamination in aquatic ecosystems. *Sci. Total Environ*. **2020**, *734*, 139436. https://doi.org/10.1016/j.scitotenv.2020.139436.
90. Nakajima, R.; Miyama, T.; Kitahashi, T.; et al. Plastic After an Extreme Storm: The Typhoon-Induced Response of Micro- and Mesoplastics in Coastal Waters. *Front. Mar. Sci*. **2022**, *8*, 1–11. https://doi.org/10.3389/fmars.2021.806952.
91. Paing, Y.M.M.; Eom, Y.; Song, G.B.; et al. Neurotoxic effects of polystyrene nanoplastics on memory and microglial activation: Insights from in vivo and in vitro studies. *Sci. Tot. Environ*. **2024**, *924*, 171681. https://doi.org/10.1016/j.scitotenv.2024.171681.
92. Ma, M.; Coulon, F.; Tang, Z.; et al. Unveiling the Truth of Interactions between Microplastics and Per- and Polyfluoroalkyl Substances (PFASs) in Wastewater Treatment Plants: Microplastics as a Carrier of PFASs and Beyond. *Environ. Sci. Technol.* **2025**, *59*, 2211–2221. https://doi.org/10.1021/acs.est.4c08898.
93. Lin, P.; Liu, L.; Ma, Y.; et al. Neurobehavioral toxicity induced by combined exposure of micro/nanoplastics and triphenyltin in marine medaka (*Oryzias melastigma*). *Environ. Pollut*. **2024**, *356*, 124334. https://doi.org/10.1016/j.envpol.2024.124334.
94. Cheng, H. Future Earth and Sustainable Developments. *Innovation* **2020**, *1*, 100055. https://doi.org/10.1016/j.xinn.2020.100055.