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Review

A Global Analysis of Research Outputs on Neurotoxicants from 2011–2020: Adverse Effects on Humans and the Environment

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Abstract: Neurotoxicants are detrimental to the mammalian nervous system at higher concentrations after exposure, and could result in several neurological abnormalities, especially on the nervous and reproductive systems, and sometimes death. The present study, therefore, aimed to evaluate the research growth on neurotoxicants and their effects on humans and the environment over the last decade from 2011 to 2020. Data on this subject were obtained from the SCI-Expanded of Web of Science, and analyses were performed on the retrieved data in RStudio. The number of published documents fluctuated over the studied years, with an annual growth rate of 4.46%, and the highest number of publications were recorded in 2020 (n = 40). Single authored documents, documents per author, authors per documents, and collaboration index were 24, 0.219, 4.57, and 4.87, respectively. Networks of collaboration in this study were noticeable among authors, institutions, and countries; thus, making efforts to strengthen networking globally would be a good idea. Results from this study also show that the growing trend of research in the field is quite encouraging, thus providing future directions to upcoming researchers, and contributes immensely to reducing the exposure and several disorders linked to these neurotoxicants globally.

Keywords: developmental neurotoxicity; oxidative stress; neurotoxicants; Parkinson's disease; neurological disorders; children; pesticides; bibliometric analysis

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1. Introduction

Neurotoxicity is the disruption of the mammalian nervous system that follows (directly or indirectly) exposure to certain hazardous chemical(s) when present in the tissue at a level higher than the threshold [1]. The chemicals are thus referred to as neurotoxins, neurotoxicants, neurotoxic pollutants, or neurotoxic chemicals in some cases. They have the capacity to negatively affect the neurological development of a craniate or spineless population and/or ecosystems [2,3]. The natural (or biological) chemicals are called neurotoxins, while those arising from synthesis or industrial production are regarded as neurotoxicants. Neurotoxins are more toxic, target specific, and have perfectly understood mechanisms with circumspect biological activities. Some chemicals in this category with high potential for neurotoxicity can be obtained from bacteria, fungi, fish, plants, coelenterates, algae, insects, molluscs, amphibians, arachnids, reptiles, and selected mammals. Others in this class with less potency only exhibit neurotoxic effects when found in large amounts for ample time, e.g., metals, such as lead, arsenic, mercury, and other compounds comprising any of these poisonous elements, for example, methylmercury [1,4,5]. Manganese, selenium, and vitamin B6 also belong to this group when available in very high doses but can support normal body function (including the nervous system) at very low concentrations. Thiaminase and some other natural materials, which always impede certain substances required in the body system, are implicated as causes of certain neurological illnesses in humans and animals [1].

However, neurotoxicants, which are of synthetic origin, include materials used for inducing euphoria (e.g., methamphetamine), over-the-counter pharmaceutical drugs (e.g., bismuth preparations), unprocessed materials used for fragrance production (e.g., 2,6-dinitro-3-methoxy-4-tert-butyltolue), beverages (such as ethanol), production chemicals (e.g., n-hexane), pesticide (e.g., Aldrin), environmental contaminants (mercury, lead, arsenic, etc.), household products (such as antidandruff shampoos, e.g., pyridinethione), prescription medications (such as vincristine, ethambutol, isoniazid), and pyrolysis outputs, such as food that is baked, fried, or broiled (for example acrylamide). There are some other materials in this category, including substances used for special applications in private and military settings (e.g., sarin, an organophosphorus compound) [1,6,7]. It is noteworthy that some metals are sometimes characterized as neurotoxins with respect to their natural sources, while in some other cases, they are treated as neurotoxicants, given their synthetic origins and environmental pollution effects. Neurobehavioral perniciousness is a substantial consequence of human exposure to these toxic environmental/industrial chemicals [1,8].

Grandjean and Landrigan [9] reported over 1000 substances found to be neurotoxic to laboratory animals, of which 201 (termed human neurotoxicants) were injurious to the nervous system of grown-ups (adults), especially people who are constantly exposed to the selected chemicals in their workplace, or those involved in suicide trials or poisoning instances. Five of these human neurotoxicants were categorized as developmental neurotoxicants (methylmercury, lead, PCBs, arsenic, and toluene); however, a grouping of others on the list was difficult owing to the non-availability of sufficient laboratory data [3,9–11]. Six other chemicals were later added to the list of chemicals affecting the development of human brains, including polybrominated diphenyl ethers, chlorpyrifos, DDT/DDE, manganese, tetrachloroethylene, and fluoride. Polyvinyl chloride was identified as one of the dominant toxicants with neurotoxic effects in the atmosphere in another study. It is therefore believed that more chemicals in this category are yet to be discovered [8,9].

Regardless of the specific sites of the target of these chemicals or the metabolic products within the nervous system exposed to high doses of the substances for a period sufficient to bring about biological changes, the occurrence of neurotoxic effects is inevitable. Such exposure may result in several changes within the system, including pharmacological, morphological, biochemical, behavioral, biophysical, physiological, and/or functional changes. Such variations are usually seen as pointers for neurotoxicity [8,12]. These chemicals could have lifetime effects, particularly on the nervous and reproductive systems, and may well end in fatality if the amount exposed to, over a length of time, is significant. Some may even affect an unborn child if the mother is exposed to an extreme concentration during the gestation period [2]. A huge percentage of these compounds have the capacity to release free radicals, which could penetrate and cause injury to a nervous system containing a substantial amount of polyunsaturated fatty acids [13]. When assessing the impacts of these neurotoxic chemicals on lipid peroxidation, it was observed that reactive oxygen species (ROS) instantly react with lipids, thus generating free radicals and semistable peroxides. The reaction of these hazardous chemicals with subcellular organelles and membranes is known to be very harmful [8].

Some neurotoxic reagents show direct action on neural cells, whereas others obstruct metabolic processes, which the nervous system depends upon. Several neurotoxic agents target neural function for disruption, while others bring about a defection in the adult nervous system or cause damage to it [14]. The dysfunction may be sudden and last only for a moment before its eventual disappearance; it may gradually appear after a period (days or weeks), but disappearance or reversion may take a couple of months or ages if it does not result in permanent defects [1]. Observation of strange development in neurologic function or moderate alterations to some biologic functions could indicate exposure to neurotoxic substances, or an onset of neurologic diseases. However, when such observed changes are beyond normal, then it could indicate a serious level of disorder [8,14]. A sizeable number of these neurotoxicants are known to infiltrate the environment through exposure at workplaces, and intentional/unintentional release. Some are used daily in the production of several personal care/household products. Human exposure to these hazardous chemicals could be by air inhalation, food ingestion, skin contact, and/or drinking of polluted water [2,8]. Neurologic toxicity due to these pollutants is in most cases self-regulating if the exposure does not continue, even though the duration between exposure and exhibition of neurotoxic effects might be very long [1].

Exposure to these neurotoxicants is ranked among the top 10 causes of diseases and illnesses relating to workplaces as reported by the National Institute for Occupational Safety and Health (NIOSH). Moreover, over one-quarter of the chemicals that were assigned threshold bounds by the ACGIH (American Conference of Governmental Industrial Hygienists) have exhibited neurotoxicity. They also contribute significantly to the development of many health difficulties in humans [15]. When an individual is exposed to these hazardous compounds, it may activate epigenetic pathways, and thus cause chronic and multi- or cross-generational impacts [3,8,16–18]. Around 10–15% of childbirths are reportedly affected by the development of neurobehavioral disorder every year, while other neurological disorders, including attention-deficit/hyperactivity disorder (ADHD), dyslexia, autism spectrum disorder (ASD), and several additional cognitive disabilities, are skyrocketing globally [9,19,20]. These dysfunctions have grave impacts on behaviors (such as predator escape response, mating and feeding mannerisms/reactions), academic accomplishment, population growth, wellbeing, ecosystems, and all aspects of life in society [3,9,21,22]. Despite the numerous reported studies on the impact of neurotoxicants on humans in the literature, to the best of our knowledge, a report documenting the quantity of research in the field is lacking and thus, the present study becomes imperative. Bibliometrics, being an uncommon device for the characterization and systematic mapping of research undertakings in a particular field of study, combines both mathematical and statistical models to engender knowledge structure that has the capacity for projection of the research direction in a chosen field [23,24]. It thus enables academics, researchers, and policymakers to strategize and design a way forward regarding the upcoming research activities in that area of interest [25].

As a result, in the present study, a bibliometric approach was used to investigate research development on the term "neurotoxicants" with respect to "environmental pollution" and "neurological disorder". We studied the trends of documentations and published articles regarding the subject, using the Web of Science database (from 2011 to 2020). Although numerous publications address neurotoxicity, bibliometric analysis data on neurotoxicants and their effects on both the environment and human health are rare. Hence, this study aimed to study the progression of research on neurotoxicants and their hazardous effects on humans, as well as the pollution arising in the environment with respect to these neurotoxic chemicals within the stated period.

2. Materials and Methods

2.1. Data Search, Extraction, and Analysis

There are several databases that could be used to extract bibliometric information. Of these, Web of Science (WoS) stands out as a unique, all-inclusive, and reliable database for this purpose, given its accommodation of several studies (millions in more than 12,000 journals) with high impact factors and extremely good quality across the globe [26–30]. In the present study, we adopted title search with the following keywords: "environmental pollution" and "neurological disorder" or "neurotoxicants" separately on the WoS database (http://www.webofknowledge.com, accessed on 28 September 2021). The use of title search instead of topical search enhanced notable and substantial recovery and reduced loss of specificity and sensitivity to the barest minimum. It also helped to remove several documents that could give false positives [27,31]. Retrospective data (1 January 2011 to 31 December 2020) for the search keywords were retrieved at 11:16 am on 12 April 2021. We explored SCI-EXPANDED to retrieve the data used in this study as recommended by Ho [32] and other researchers. The SCI-EXPANDED analysis of Web of Science is the most efficient database for backtracking citations [33] and the most important database for an overview of scientific production [34]. All the available documents, including articles, corrections, editorial materials, letters, meeting abstracts, news items, and reviews, were exported as shown in Table 1 below [24,35–37]. The search for those keywords from the WoS database hosted by Clarivate Analytics produced a total of 321 records (256 research articles, 1 correction, 2 editorial materials, 1 letter, 2 meeting abstracts, 1 news item, and 58 reviews), after which the data were cleaned up and validated independently by two authors, in order to exclude those publications that were not relevant to the subject matter in the analysis (Table 1). The yielded records were downloaded in Bibtex file format and uploaded for bibliometric data processing into the RStudio [35,37–39].

Table 1. Main information of neurotoxicant studies from 2011 to 2020.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2011:2020
Sources (Journals, Books, etc.)	138
Documents	321
Average years from publication	5.25
Average citations per documents	26.31
Average citations per year per doc	3.761
References	19,413
DOCUMENT TYPES	
Article	256
Correction	1
Editorial Material	2
Letter	1
Meeting Abstract	2
News Item	1
Review	58
DOCUMENT CONTENTS	
Keywords Plus (ID)	1682
Author's Keywords (DE)	1107
AUTHORS	
Authors	1467
Author Appearances	1727
Authors of single-authored documents	21
Authors of multi-authored documents	1446
AUTHORS COLLABORATION	
Single-authored documents	24
Documents per Author	0.219
Authors per Document	4.57
Co-Authors per Document	5.38
Collaboration Index	4.87

2.2. Data Processing

Retrieved data were imported into "bibliometrix (biblioshiny)" and analyzed for descriptive bibliometric statistics, global publication outputs per year, annual production and citation by countries, sources of publications and impacts, collaboration networks across the world, and trend topics, amongst many others using Rstudio (v. 1.4.1103) software with the bibliometrix R-package (v. 3.6.3) (http://www.bibliometrix.org,accessedon28September2021, accessed on 28 September 2021) [38,40]. RStudio with the bibliometrix r-package was employed to visualize, tabulate, and contextually map a number of bibliometric parameters, such as the author's keywords; keywords plus; authors; author appearances; institution, country, and authors' collaboration networks; citations; cocitation networks; coword network analysis; occurrences of keywords; and many others retrieved from https://www.bibliometrix.org (accessed on 28 September 2021). Journal Citation Report was manually employed to determine the impact factor (IF) of journals (https://jcr.incites.thomsonreuters.com, accessed on 28 September 2021) [31,35].

3. Results and Discussion

3.1. Main Information

Research output trends on "neurotoxicants" with respect to "environmental pollution" and "neurological disorder" from 2011 to 2020 were mapped in this study. The 321 research documents retrieved from the WoS (SCI-Expanded) as highlighted in Table 1 were written in English and published in 138 sources by 1467 authors. Single-authored documents were produced by only 21 authors, and multi-authored documents were produced by 1446 authors. The documents generally contained 19,413 references while the average years from publication were 5.25. Furthermore, average citations/document were 26.31 and average citations/year/document were 3761. Keyword plus (ID) and the author's keywords (DE) from these documents were 1682 and 1107, respectively. Under authors' collaboration, research documents that were single authored were 24 with documents/author being 0.219. The authors/documents was 4.57, co-authors/documents was 5.38, and the collaboration index (CI) was 4.87. The CI obtained in the present study was higher than those documented by several other researchers [25,37,38,41] but lower compared to the CI of 23.4 reported by Okaiyeto and Oguntibeju [31]. In total, 297 of the 321 documents retrieved in this study were produced by more than one author (researcher), and this constituted 92.52% of the total. Hence, this accounts for the high value of the collaboration index obtained, compared to only 24 documents (7.48%) that were published by single authors.

3.2. Annual Trend of Production and Citation

Bibliometric analysis helps to determine the level of growth in the number of articles published in a certain area of scientific studies. A yearly decline in the number of publications in an area could imply decreasing interest among researchers in the scientific field [31,35]. Concerning the trends in the production of research documents on neurotoxicants, neurotoxic disorder, and their environmental pollution effects, a significant increase was noticed from 2011 to 2020. Precisely, 154 (48%) of the 321 research documents retrieved were published between 2011 and 2015, while the remaining 167 (52%) were produced between 2016 and 2020 (Figure 1). The year 2020 recorded the highest number of outputs, with 40 documents (12.5%), whereas the least outputs were obtained in 2012 (n = 26; 8.1%). However, some fluctuations in the annual production figure were noticed within the period of assessment. Notwithstanding, research in this field recorded an annual growth rate of 4.46% over 10 years. This is comparable to what was reported in previous studies [35,37,41], thus showing that research in this area is receiving huge attention worldwide. It is noteworthy that this assessment was only based on data gathered from WoS, with the exclusion of information in other databases.

Assumedly, the higher the citations of an article, the higher its quality or the impact of the research work in the field [42]. The annual total average of citations in this research field reveals a noticeable fluctuation over the years. The highest number of citations was recorded in 2013 and 2014 while the least was in 2020 (Figure 1). Factors that affect the citations of research documents include the following: publication year and accessibility (open/close) of the publication to the public, especially fellow researchers in that scientific area [42]. Citations usually grow with the age of published papers; thus, recently published articles are linked with fewer citations compared to old ones. Moreover, papers published in open-access journals are more accessible to researchers and so are cited more than those produced in closed-access journals [31].

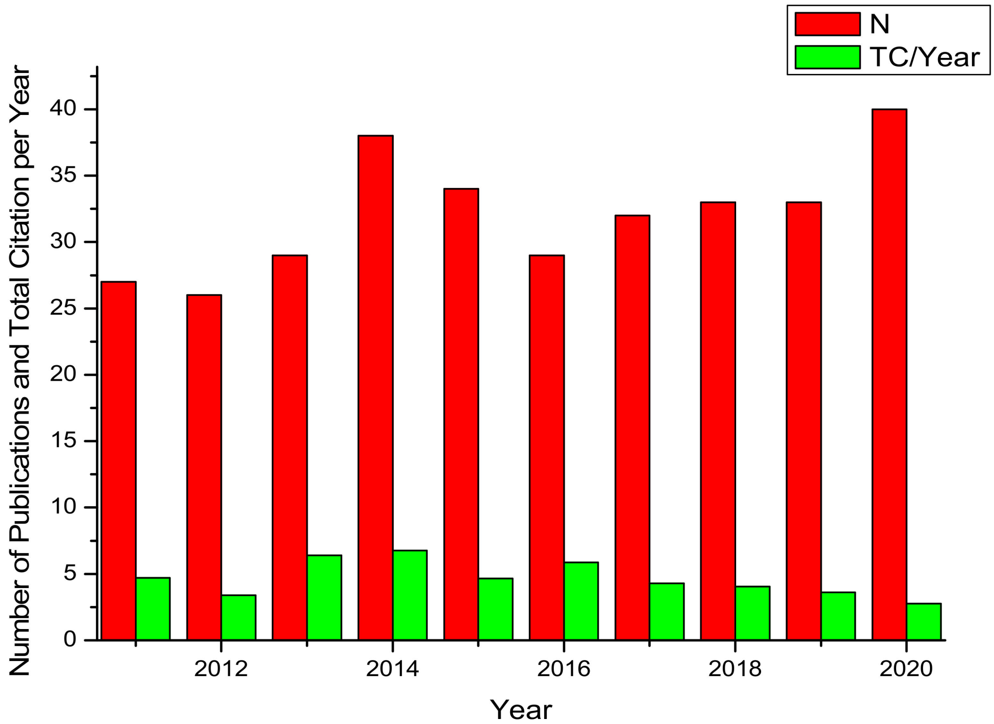

Figure 1. Number of publications (N) and total citation per year from 2011 to 2020.

3.3. Most Productive Authors

The information obtained from WoS on neurotoxicants between 2011 and 2020 indicated that 1467 researchers authored the 321 documents retrieved for this analysis. Similarly, the authors per document in this study was 4.57, thus, showing the strength of collaboration exhibited by researchers in this field. Table 2 shows the 20 most productive authors in this research area, with an h-index ranging from 2 to 10 and citations ranging from 44 to 835. The h-index has always been used to assess the worth of scientific outputs [43]. It is also used to estimate how impactful (by citations) and productive an author or group of authors is/are within an institution or a country [44]. Scientists, journals, institutions, and countries are usually compared using the h-index value, which is based on a list of published articles arranged in order by the times cited count, calculated using the principle that h articles are cited h times at minimum [45]. However, the comparison among researchers using the h-index must be within a particular field because it is considered unfit for such purpose across lines of discipline. Notwithstanding, it is a very important tool in bibliometric analysis, as it always accurately reflects the attainment and contribution to scientific knowledge of individual authors [46,47].

In the present study, the relevance of authors, institutions, and countries with respect to their contributions to knowledge concerning neurotoxicants, their environmental effects, and accompanying neurological disorders were assessed. The impact of research documents is determined most by the number of times research documents are cited by other researchers. Although a citation may not be the perfect measure of impact, it provides some key information that would help to reach a reasonable conclusion on the matter [48,49]. As indicated in Table 2, which contains the top 20 authors, Slotkin TA and Seiderler FJ contributed 14 (4.36%) and 13 (4.05%) articles for each of the 321 documents retrieved from WoS, respectively, and had the highest h-index of 10 and 9, correspondingly. However, Grandjean P (h-index = 4), who was ranked 14th on the list, had the highest number of citations, with 835 citations, compared to the top two authors, with 331 and 460 citations, respectively, despite his fewer number of published articles in the field. This showed that citations are not only influenced by the number of articles produced by a researcher and/or h-index but also by the publication year [31].

Table 2. Most relevant authors between 2011 and 2020.

Author	h_index	TC	NP
Slotkin TA	10	331	14
Seidler FJ	9	460	13
Leist M	6	137	8
Shafer TJ	6	208	7
Dorea JG	4	122	6
Skavicus S	5	72	6
Aschner M	4	69	5
Card J	5	60	5
Costa LG	5	302	5
Mundy WR	5	160	5
Bellinger DC	4	44	4
Chen H	3	90	4
Delp J	3	47	4
Grandjean P	4	835	4
Gutbier S	2	47	4
Harrill JA	4	107	4
Hoelting L	3	108	4
O'callaghan JP	4	202	4
Padilla S	4	211	4
Wright RO	4	116	4

NP: Number of Publications; TC: Total Citations.

3.4. Most Relevant Organizations

Twenty organizations with the highest number of research articles in this field are listed in Table 3. From the table, Univ Konstanz published the highest number of research documents (12.8%) while Univ Cincinnati produced the least (9 documents: 2.8%). Likewise, 15 of the top 20 organizations are in the United States of America, contributing 225 (70.1%) of the 321 obtained from WoS.

Table 3. Top 20 relevant organizations from 2011 to 2020.

Affiliations	Articles	Country	Organization Type
Univ Konstanz	41	Germany	University
Duke Univ	37	USA	University
Univ Washington	24	USA	University
Harvard Univ	23	USA	University
Univ Calif Davis	18	USA	University
Boston Univ	14	USA	University
Harvard Med Sch	13	USA	Medical School
Natl Hlth and Environm Effects Res Lab	13	USA	Research Laboratory
Univ Brasilia	13	Brazil	University
Univ Fed Santa Catarina	13	Brazil	University
Columbia Univ	12	USA	University
Penn State Univ	11	USA	University
Res Triangle Pk	11	USA	Research Park
Univ Calif San Diego	11	USA	University
Albert Einstein Coll Med	10	USA	College of Medicine
Ctr Dis Control And Prevent	10	USA	National Public Health Agency
Fujian Med Univ	9	China	Medical University
Icahn Sch Med Mt Sinai	9	USA	Private Medical School
Inst Hlth and Consumer Protect	9	Italy	Joint Research Centre
Univ Cincinnati	9	USA	University

3.5. Most Relevant Sources

In bibliometric analysis, subject categories and journals are regarded as fundamental units needed to explain research scope distributions in a particular topic of discourse [50].

In this study, the sources (journals) where researchers in this scientific field published their works (especially as it concerns neurotoxicants, their environmental impacts, and attendant neurologic disorders) were evaluated. This included the journal impact factors, the number of articles published in each journal, and the number of citations received by individual publications. The 20 most impactful journals in this field are listed in Table 4. The h-index and impact factors (IFs) of the 20 journals varied from 2 for "environmental pollution" to 15 for "neurotoxicology" and from 1.902 for "toxicologic pathology" to 9.621 for "environment international", respectively. The first seven journals on the list are Neurotoxicology, Toxicological Sciences, Neurotoxicology and Teratology, Toxicology, Archives of Toxicology, Environmental Health Perspectives, and Toxicology and Applied Pharmacology. They all recorded 29 (9.03%), 18 (5.61%), 17 (5.30%), 12 (3.74%), 11 (3.43%), 8 (2.49%), and 8 (2.49%) articles published within the specified period (2011–2020), respectively, with corresponding citations of 722, 265, 428, 283, 430, 636, and 377 citations, respectively. This ranking was consistent with Bradford law, which also grouped the top 20 journal sources into two zones, with the first eight falling into zone 1 and the other 12 belonging to zone 2, according to their levels of relevance in the field [51,52]. Even though it may not be considered the best index for evaluating an author's impact in a certain field, citations are an important parameter in bibliometric analysis, as it builds up over several years. Hence, recently published articles may have fewer citations compared to those published many years earlier [37,53,54]. With this analysis, "neurotoxicology" had both the highest number of articles and total citations; hence, it is the most impactful among the top 20 journals in this field of study. Other information provided in Table 4 includes the g_index, m_index, and PY_start year. Nine of the journals started publishing articles in this field as early as 2011. With respect to data retrieved for this investigation, some of them sustained this production annually except for skipping one, two, or three years within the 10 years of study (2011–2020). This is quite peculiar with the first three sources in the list, thus demonstrating their commitment and consistency in this kind of research. The impact factor is usually estimated by the division of a journal's total production (number of articles published) in the past two years with the total number of citations received within the period. It is used as a measure each journal's impact in the scientific world and is always displayed on each journal's website [55]. In the present study, it is noteworthy that journals with the highest impact factors are not necessarily those with the highest number of articles nor citations, suggesting that those with the highest IFs might be publishing more research articles in other fields of study than "neurotoxicology". In this table, the highest number of publications was recorded in 2015, 2019, 2013, 2014, and 2020, with 19, 18, 17, 17, and 17 published documents, respectively (Table 4).

3.6. Most Globally Cited Documents and Locally Cited References

The global citation of a document depicts it's the number of citation occurrences on the Web of Science database for the period the data were downloaded. It does rely on the weight of the citing articles (how impactful) rather than their popularity. A paper cited by an impactful paper attracts audience that is more impactful, whereas the number of citations an article receives reflects its popularity, not minding the quality or worth of the citing paper(s). However, the local cited reference (LCR) refers to the number of citations contained in the list of references of a published paper for other articles within the collection. It does explain the number of times the papers included in that collection were cited by other papers in the same collection. This is driven more by popularity than impact [56,57].

Table 4. Most relevant and impactful sources of journal articles from 2011 to 2020.

Source	IF	h_Index	g_Index	m_Index	TC	NP	PY_Start	NP per Year									
								2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Neurotoxicology	4.294	15	26	1.36	722	29	2011	3	8	4	4	2	3	1	3	0	1
Toxicological Sciences	4.849	9	16	0.82	265	18	2011	1	1	0	1	2	0	2	2	7	2
Neurotoxicology and Teratology	3.763	11	17	1	428	17	2011	3	3	2	1	5	1	1	1	0	0
Toxicology	7.563	9	12	1	283	12	2013	0	0	2	0	4	2	3	0	1	0
Archives of Toxicology	5.153	8	11	0.8	430	11	2012	0	1	2	1	1	0	2	1	1	2
Environmental Health Perspectives	9.031	5	8	0.46	636	8	2011	1	0	3	1	1	1	0	0	0	1
Toxicology and Applied Pharmacology	4.219	7	8	0.64	377	8	2011	2	0	1	1	0	0	0	3	0	1
Ecotoxicology and Environmental Safety	6.291	5	5	1	42	5	2017	0	0	0	0	0	0	1	0	4	0
Environmental Health	5.984	4	5	0.67	69	5	2016	0	0	0	0	0	1	1	1	2	0
Environmental Research	6.498	4	5	0.44	140	5	2013	0	0	1	0	1	1	0	0	1	1
Toxicologic Pathology	1.902	3	5	0.27	42	5	2011	2	0	0	0	0	0	0	0	0	3
Toxicology In Vitro	3.500	4	5	0.44	87	5	2013	0	0	1	0	1	1	1	0	0	1
Brain Research Bulletin	4.077	4	4	0.36	49	4	2011	1	0	0	1	1	0	1	0	0	0
Chemical Research in Toxicology	3.739	3	4	0.38	37	4	2014	0	0	0	1	1	0	0	1	1	0
Environment International	9.621	4	4	0.36	134	4	2011	1	1	0	1	0	0	1	0	0	0
Environmental Pollution	8.071	2	4	0.5	22	4	2018	0	0	0	0	0	0	0	2	0	2
Neurotoxicity Research	3.911	3	4	0.27	71	4	2011	1	1	0	0	0	0	0	1	0	1
Plos One	3.240	4	4	0.5	129	4	2014	0	0	0	4	0	0	0	0	0	0
Science of the Total Environment	7.963	3	4	0.3	43	4	2012	0	1	0	0	0	0	1	0	0	2
Toxicology Letters	4.372	3	4	0.33	183	4	2013	0	0	1	1	0	1	0	0	1	0
Total								15	16	17	17	19	11	15	15	18	17

NP: number of publications; PY_start: Publication year (start year); TC: Total citations; IF: Impact factors.

The top 20 globally cited documents and top 20 locally references assessed based on their total citations (TCs) and total citations per year (TC/Year) in neurotoxicant studies from 2011–2020 are displayed in Tables 5 and 6. The top five among the globally cited articles were authored by Grandjean and Landrigan [9], Eskenaz et al. [58], Dishaw et al. [59], Li et al. [60], and Roberts et al. [61]. These were published in Lancet Neurol. (TC: 749; TC/Year: 93.6), Environmental Health Perspectives (TC: 256; TC/Year: 28.4), Toxicol Appl Pharmacol (TC: 227; TC/Year: 20.6), Int. J. Mol. Sci. (TC: 196; TC/Year: 21.8), and Environmental Health Perspectives (TC: 161; TC/Year: 17.9), respectively. The coverage of these articles is spread across different titles, including "Neurobehavioural effects of developmental toxicity", such as autism, attention-deficit hyperactivity disorder, dyslexia, and other cognitive impairments, with pronounced consequences on children across the globe [9]. In another study, the relationship between in utero and child PBDE exposure to neurobehavioral development among participants in CHAMACOS in California was studied. The objective of the study was achieved by measuring the levels of PBDEs (a prominent group of neurotoxicants) in mothers' (before birth) and children's serum samples. The concentrations determined were thereafter related to the attention, motor functioning, and psychological perception of children at ages of 5 and 7 years [58]. Others include investigations about PentaBDE and Tris (1,3-dichloro-2-propyl) phosphate (TDCPP) as possible developmental neurotoxicants, using PC12 cells [59], a review article on "Oxidative Stress and Neurodegenerative Disorders" [60], and "Perinatal Air Pollutant Exposures and Autism Spectrum Disorder" in children by Roberts et al. [61]. Of the five, Grandjean and Landrigan [9] recorded outstanding TC and TC/Year, which included multiple citations recorded by others in the same category as shown in Table 5. TC and TC/Year in this table generally ranged from 80 to 749 and from 7.3 to 93.6. Three of the top 20 globally cited articles were produced in "Environmental Health Perspective" and another 2 in "Neurotoxicology".

Table 5. Most globally cited documents between 2011 and 2020.

Paper	Title	Total Citations	TC per Year
Grandjean P, 2014, Lancet Neurol	Neurobehavioral effects of developmental toxicity	749	93.62
Eskenazi B, 2013, Environ Health Perspect	In utero and childhood polybrominated diphenyl ether (PBDE) exposures and neurodevelopment in the CHAMACOS study	256	28.44
Dishaw LV, 2011, Toxicol Appl Pharmacol	Is the PentaBDE replacement, tris (1,3-dichloro-2-propyl) phosphate (TDCPP), a developmental neurotoxicant? Studies in PC12 cells	227	20.64
Li J, 2013, Int J Mol Sci	Oxidative Stress and Neurodegenerative Disorders	196	21.78
Roberts AL, 2013, Environ Health Perspect	Perinatal air pollutant exposures and autism spectrum disorder in the children of Nurses' Health Study II participants	161	17.89
White RF, 2016, Cortex	Recent research on Gulf War illness and other health problems in veterans of the 1991 Gulf War: Effects of toxicant exposures during deployment	156	26
Linares V, 2015, Arch Toxicol	Human exposure to PBDE and critical evaluation of health hazards	155	22.14
Chen A, 2011, Environ Health Perspect	Developmental Neurotoxicants in E-Waste: An Emerging Health Concern	152	13.82
Costa LG, 2014, Toxicol Lett	A mechanistic view of polybrominated diphenyl ether (PBDE) developmental neurotoxicity	136	17
Fairbrother A, 2014, Environ Toxicol Chem	Risks of neonicotinoid insecticides to honeybees	133	16.63
Heusinkveld HJ, 2016, Neurotoxicology	Neurodegenerative and neurological disorders by small inhaled particles	115	19.17

Table 5. *Cont.*

Paper	Title	Total Citations	TC per Year
Mariussen E, 2012, Arch Toxicol	Neurotoxic effects of perfluoroalkylated compounds: mechanisms of action and environmental relevance	107	10.7
Powers CM, 2011, Neurotoxicol Teratol	Silver Nanoparticles Alter Zebrafish Development and Larval Behavior: Distinct Roles for Particle Size, Coating, and Composition	107	9.73
Winneke G, 2011, J Neurol Sci	Developmental aspects of environmental neurotoxicology: lessons from lead and polychlorinated biphenyls	107	9.73
Nehlig A, 2013, Br J Clin Pharmacol	The neuroprotective effects of cocoa flavanol and its influence on cognitive performance	103	11.44
Hogberg HT, 2011, Neurotoxicology	Application of micro-electrode arrays (MEAs) as an emerging technology for developmental neurotoxicity: evaluation of domoic acid-induced effects in primary cultures of rat cortical neurons	91	8.27
Slotkin TA, 2011, Reprod Toxicol	Does early-life exposure to organophosphate insecticides lead to prediabetes and obesity?	85	7.73
Llop S, 2013, Toxicology	Gender differences in the neurotoxicity of metals in children	82	9.11
Mitchell MM, 2012, Environ Mol Mutagen	Levels of select PCB and PBDE congeners in human post-mortem brain reveal possible environmental involvement in 15q11-q13 duplication autism spectrum disorder	80	8
Tilton FA, 2011, Comp Biochem Physiol C-Toxicol Pharmacol	Swimming impairment and acetylcholinesterase inhibition in zebrafish exposed to copper or chlorpyrifos separately, or as mixtures	80	7.27

Table 6. Most locally cited references from 2011 to 2020.

Cited References	Title	Citations
Grandjean P, 2006, Lancet, V368, P2167, https://doi.org/10.1016/S0140-6736(06)69665-7	Developmental neurotoxicity of industrial chemicals	49
Grandjean P, 2014, Lancet Neurol, V13, P330, https://doi.org/10.1016/S1474-4422(13)70278-3	Neurobehavioural effects of developmental toxicity	29
Rice D, 2000, Environ Health Persp, V108, P511, https://doi.org/10.2307/3454543	Critical periods of vulnerability for the developing nervous system: evidence from humans and animal models.	23
Crofton KM, 2011, Altex-Altern Anim Ex, V28, P9	Developmental neurotoxicity testing: recommendations for developing alternative methods for the screening and prioritization of chemicals	17
Herbstman JB, 2010, Environ Health Persp, V118, P712, https://doi.org/10.1289/Ehp.0901340	Prenatal PBDEs and Neurodevelopment: Herbstman et al. Respond to Goodman et al. and to Banasik and Strosznajder	17
Howard AS, 2005, Toxicol Appl Pharm, V207, P112, https://doi.org/10.1016/J.Taap.2004.12.008	Chlorpyrifos exerts opposing effects on axonal and dendritic growth in primary neuronal cultures	15
Canfield RL, 2003, New Engl J Med, V348, P1517, https://doi.org/10.1056/Nejmoa022848	Intellectual Impairment in Children with Blood Lead Concentrations below 10 µg per Deciliter	14
Costa LG, 2007, Neurotoxicology, V28, P1047,https://doi.org/10.1016/J.Neuro.2007.08.007	Developmental neurotoxicity of polybrominated diphenyl ether (PBDE) flame retardants	14

Table 6. *Cont.*

Cited References	Title	Citations
Krug AK, 2013, Arch Toxicol, V87, P123, https://doi.org/10.1007/S00204-012-0967-3	Human embryonic stem cell-derived test systems for developmental neurotoxicity: a transcriptomics approach	14
Livak KJ, 2001, Methods, V25, P402, https://doi.org/10.1006/Meth.2001.1262	Analysis of relative gene expression data using real-time quantitative PCR and the 2(-Delta Delta C(T)) Method	14
Rauh VA, 2006, Pediatrics, V118, Pe1845, https://doi.org/10.1542/Peds.2006-0338	Impact of prenatal chlorpyrifos exposure on neurodevelopment in the first 3 years of life among inner-city children	14
Eskenazi B, 2013, Environ Health Persp, V121, P257, https://doi.org/10.1289/EHP.1205597	In utero and childhood polybrominated diphenyl ether (PBDE) exposures and neurodevelopment in the CHAMACOS study	13
Bal-Price AK, 2012, Altex-Altern Anim Ex, V29, P202, https://doi.org/10.14573/ALTEX.2012.2.202	Advancing the science of developmental neurotoxicity (DNT): Testing for better safety evaluation	12
Coecke S, 2007, Environ Health Persp, V115, P924, https://doi.org/10.1289/EHP.9427	Workgroup Report: Incorporating In Vitro Alternative Methods for Developmental Neurotoxicity into International Hazard and Risk Assessment Strategies	12
Radio NM, 2008, Toxicol Sci, V105, P106, https://doi.org/10.1093/TOXSCI/KFN114	Assessment of chemical effects on neurite outgrowth in PC12 cells using high content screening	12
Scholz D, 2011, J Neurochem, V119, P957, https://doi.org/10.1111/J.1471-4159.2011.07255.X	Rapid, complete, and large-scale generation of post-mitotic neurons from the human LUHMES cell line	12
Bal-Price A, 2015, Arch Toxicol, V89, P269, https://doi.org/10.1007/S00204-015-1464-2	International STakeholder NETwork (ISTNET): creating a developmental neurotoxicity (DNT) testing road map for regulatory purposes	11
Grandjean P, 1997, Neurotoxicol Teratol, V19, P417, https://doi.org/10.1016/S0892-0362(97)00097-4	Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury	11
Landrigan PJ, 2005, Environ Health Persp, V113, P1230, https://doi.org/10.1289/EHP.7571	Early environmental origins of neurodegenerative disease in later life	11
Rauh V, 2011, Environ Health Persp, V119, P1196, https://doi.org/10.1289/EHP.1003160	Seven-Year Neurodevelopmental Scores and Prenatal Exposure to Chlorpyrifos, a Common Agricultural Pesticide	11

The impact or influence of an article in the scientific research community is mostly measured by citations [62]. The influence grows as the citation number increases [63]. In the same vein, citations increase with negative criticism of the article's content [64]. Hence, the growth becomes conspicuous over several years, and this is evident in the results presented in Tables 5 and 6. Hence, the top 20 globally cited articles were published between the year 2011 and 2016. Recently published articles require more years to accumulate citations [65]. The top 20 locally cited papers in Table 6 follow the same trend, as they were produced between 1997 and 2015, with citations ranging from 11 to 49. The most locally cited reference was authored by Grandjean and Landrigan [18]. It is a review paper titled "Developmental neurotoxicity of industrial chemicals". It is noteworthy that an article written by the same authors in 2014 [9] is second among the first five (Table 6), addressing the "Neurobehavioral Effects of Developmental Toxicity". The third, fourth, and fifth articles were authored by Rice and Barone Jr. [66], Crofton et al. [67], and Herbstman et al. [68]. The focuses of these research papers include "Critical Periods of Vulnerability for the Developing Nervous System: Evidence from Humans and Animal Models", "Developmental Neurotoxicity Testing: Recommendations for Developing Alternative Methods for the Screening and Prioritization of Chemicals", and "Prenatal Exposure to PBDEs and Neurodevelopment". All these publications address "neurotoxicity" with respect to the period in which an individual could be vulnerable, developing other methods for the screening of neurotoxicants, exposure to, and effects of some of these neurotoxic chemicals to human, especially pregnant women and children.

3.7. Most Relevant Countries

The 20 most contributing countries by corresponding authors in this research field are listed in Table 7. Of the top 20 countries listed in Table 7, three were from the North American continent, another three were from South America, five were from Asia, eight were from Europe, and the last continent was Australia. This shows that European countries were more relevant in the field, although with lesser publications as compared to the USA, which demonstrated a high capacity for both single country publications (SCPs) and multiple country publications (MCPs), which were 122 and 38, respectively. Whereas, all the European countries had 65 articles, 40 SCP, and 25 MCP, which is somewhat below the contributions from the USA only as a country, which indicate their giant role in the field is understudied. Contributions from other countries, such as China (Articles: 20; SCP: 11; MCP: 9), Germany (Articles: 19; SCP: 12; MCP: 7), Italy (Articles: 16; SCP: 10; MCP: 6), and Brazil (Articles: 15; SCP: 10; MCP: 5), are also substantial. The ratio of MCP to the number of articles termed the "MCP ratio" was high for Australia (0.667), Colombia (0.5), Kuwait (0.5), and Mexico (0.5) compared to others. However, Canada, Denmark, and Poland had no MCP and it is noteworthy that the results of the contributing countries represented in this section were based on the corresponding authors' countries analysis, and in a situation where authors have multiple affiliations with two or more countries, only the primary affiliation is represented and this is the reason why countries, such as Canada, Denmark, and Poland, with no MCP were seen in the countries collaboration network showing connections with some other countries in Section 3.8 below.

Table 7. The 20 most contributing countries by corresponding authors between 2011 and 2020.

Country	Articles	Freq	SCP	MCP	MCP_Ratio
USA	160	0.50314	122	38	0.237
China	20	0.06289	11	9	0.45
Germany	19	0.05975	12	7	0.368
Italy	16	0.05031	10	6	0.375
Brazil	15	0.04717	10	5	0.333
Spain	11	0.03459	7	4	0.364
India	10	0.03145	9	1	0.1
Japan	8	0.02516	6	2	0.25
United Kingdom	7	0.02201	4	3	0.429
France	5	0.01572	3	2	0.4
Korea	5	0.01572	4	1	0.2
Canada	4	0.01258	4	0	0
Australia	3	0.00943	1	2	0.667
Czech Republic	3	0.00943	0	3	1
Argentina	2	0.00629	0	2	1
Colombia	2	0.00629	1	1	0.5
Denmark	2	0.00629	2	0	0
Kuwait	2	0.00629	1	1	0.5
Mexico	2	0.00629	1	1	0.5
Poland	2	0.00629	2	0	0

3.8. Authors, Institutions, and Countries Collaboration Networks

Collaboration is one of the crucial factors that drives research forward and increases productivity, as it enhances networks among researchers that are conducting similar studies locally and internationally. It gives room for inter and intra-disciplinary sharing/exchange of ideas and helps to boost cooperation at different levels among scientists who are involved in related investigations [69]. In fact, such collaboration is now attracting support and approval from funding agencies, governments, and policymakers across the globe. Scientific collaborations also boost the output quality of such research and contribute impressively to the speed at which the process is accomplished [70]. Other benefits of scientific collaborations among authors, institutions, and countries with respect to research include accessibility of funds, equipment, and human resources and ease of solving difficult problems by bringing together different skills among experts [71,72].

Figure 2 shows details about the inter-country collaborations among authors in general (including the first, corresponding, and as co-authors of articles) using various colors to indicate their clusters of cooperation. Altogether, six clusters were observed in the map. The node representing each country and the lines (links) that connect them with other countries have different sizes and thicknesses, respectively, indicating their relevance and the strength of collaborations that exist among them. The names of the countries involved are by default written in small letters [73]. The USA was observed to be the lead country with the biggest node, having the highest number of links with different countries of the world, including China, Canada, France, India, Denmark, Mexico, Japan, Spain, Korea, Luxembourg, and Australia. Hence, it is obvious that the top-rated countries in this field of research exhibit strong cooperation with each other. It could be seen that developed countries dominate the research field, and this indicates the significance of the subject being understudied. Besides, scientific research leaders are mainly from the developed countries of the world.

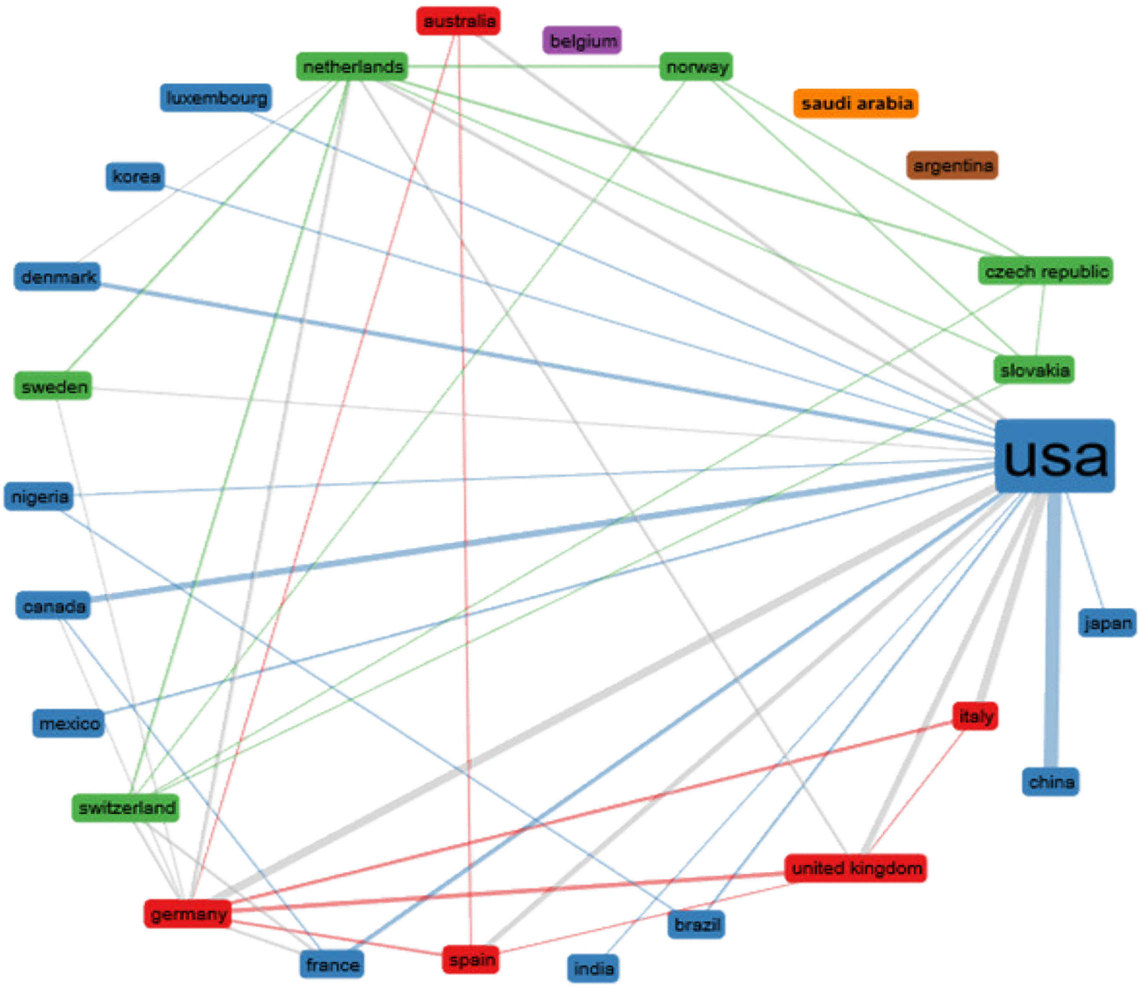

Figure 2. Collaboration among countries from 2011 to 2020.

Similarly, the cooperation among the top authors and institutions in this research field is depicted in Figures 3 and 4. The following researchers exhibited strong collaboration as depicted in Figure 3: Seidler FJ, Slotkin TA, Leist M, Delp J, Gutbier S, Hoelting I, and Klima S. This is revealed in the thickness of the lines that connect them. They are all among the top 20 authors as shown in Table 2, except Klima S. The five of them (5 nodes) belong to the same cluster. There are about 14 clusters altogether on the map, as shown by the different colors representing each cluster of collaboration. Authors with the same color are in the same cluster (i.e., working closely together or having intimate collaboration) [74]. Other most relevant authors (with big nodes), such as Schymanski EL and Shafer TJ, however, do not show any strong collaboration with other researchers, as captured in Figure 3.

Figure 3. Authors' collaboration among various institutions between 2011 and 2020.

Figure 4 reveals about 17 clusters of collaboration among various institutions of learning, with a total of number of 26 nodes. Some of the top institutions in Table 3, such as Univ Konstanz, Harvard Univ, Ctr Dis Control and Prevent, Res Triangle Pk, Vrije, and Univ Amsterdam, amongst others had no collaboration with other research organizations. However, Duke Univ collaborates strongly with Natl Ctr Computat Toxicol and Natl Hlth and Environm Effects Res Lab. Similarly, Boston Univ and Univ Michigan, and Univ Cincinnati and Cincinnati Children's Hosp Med Ctr had strong research collaboration.

3.9. Co-Citation Network Analyses

The co-citation analyses conducted in this study were carried out to evaluate the close relationship or similarities that exist between different published articles, based on how often they were frequently cited together [75]. These analyses always help to obtain a full understanding of the notable information concerning a topic or research theme in a certain field of study from the greater part of the available sources, references, and cited authors, and to identify the most important research articles in that field. Co-citation grows over the years; hence, recently published papers gather lesser co-citations than older ones [53]. In the present study, the results of the co-citation analyses of authors with respect to research investigations conducted between 2011 and 2020 are summarized in Figure 5. Although the biblioshiny output (excel spreadsheet) for the co-citation network shows about 50 nodes grouped into 3 clusters, the visualized map (Figure 5) only reveals about 23 nodes, with an all-in-one cluster (red) for convenience's sake. Some authors in the cluster exhibit very strong co-citation with others; this is revealed in the thickness of their links and the sizes of their respective nodes. Weaker co-citations are also demonstrated with weaker links [73]. Grandjean P., Costa L.G., Slotkin T.A., Landrigan P.J., Crofton K.M., Eskenazi B., Oecd, and Rice D. were among the authors shown to have stronger co-citation in the figure compared to others. Most of them are captured in Tables 2, 5 and 6 as the most impactful and cited (locally and globally).

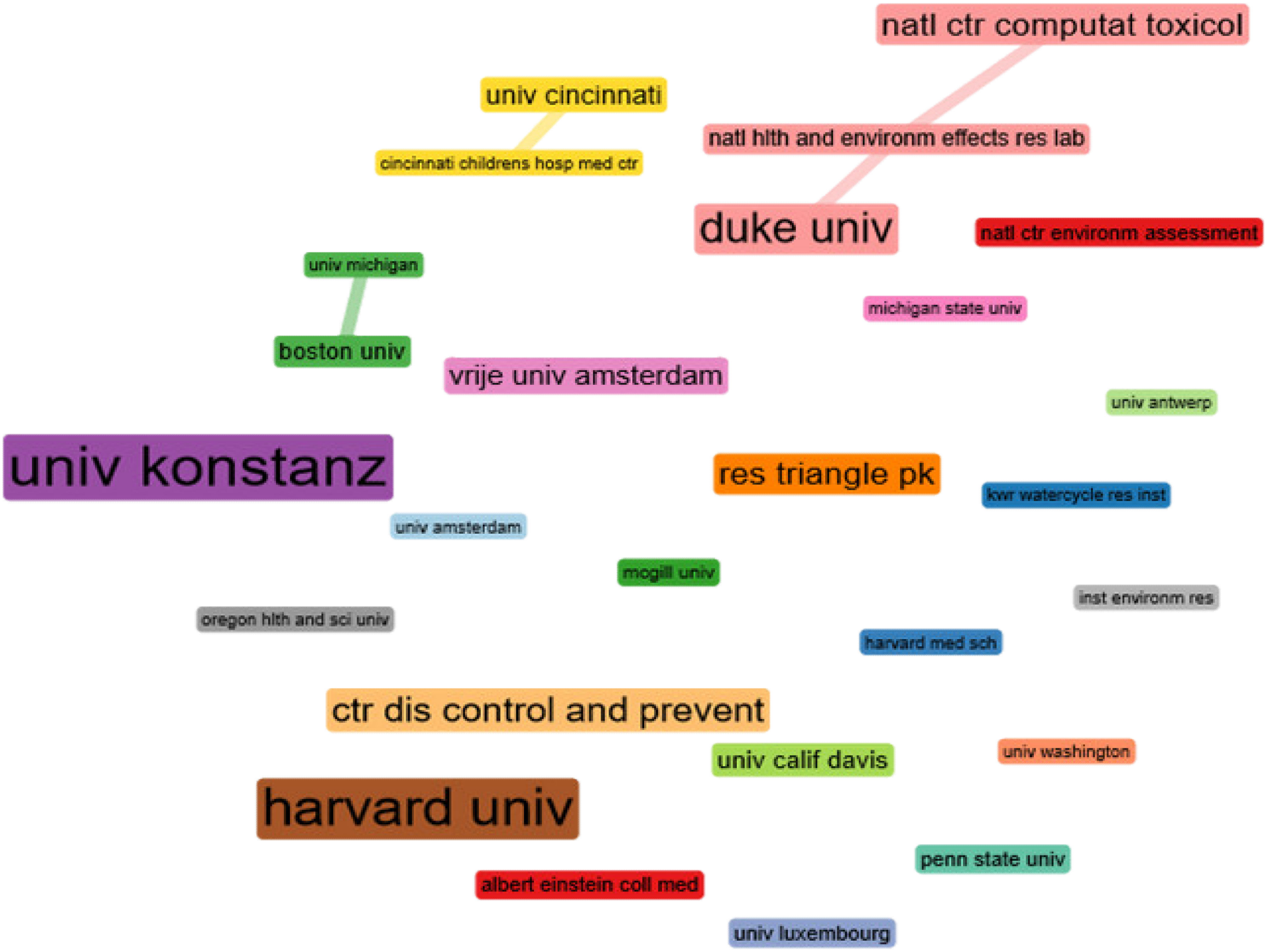

Figure 4. Network of collaboration among institutions from 2011 to 2020.

3.10. Co-Occurrence Keywords Network

Leading edges in scientific research over a specific period are easily predicted using the author's keywords (DE) and keywords plus (ID) [76]. Journal editors always require these at the submission stage of a manuscript for peer review and subsequent publication. Between six and eight of these words, which help us understand the major areas covered by the study, are often mandatorily provided before a successful manuscript submission [31]. Figures 6 and 7 reveal some top keywords and keywords plus used in this field of study between 2011 and 2020. The top keywords used by several authors as revealed by this study are neurotoxicity (n = 46), developmental neurotoxicity (n = 30), oxidative stress (n = 21), Parkinson's disease (n = 20), pesticides (n = 16), lead (n = 14), neurodevelopment (n = 14), chlorpyrifos (n = 11), neurotoxicants (n = 11), and zebrafish (n = 11). Similarly, the first 10 most relevant keywords plus as provided by this bibliometric study are the following: exposure (n = 59), in vitro (n = 41), oxidative stress (n = 36), Parkinson's disease (n = 31), brain (n = 30), toxicity (n = 29), developmental neurotoxicity (n = 28), neurotoxicity (n = 28), central nervous system (n = 20), and expression (n = 20). Noticeably, six of those DE and ID in this study were generally found to be uniquely common to both groups, including neurotoxicity, developmental neurotoxicity, oxidative stress, Parkinson's disease, children, and methylmercury.

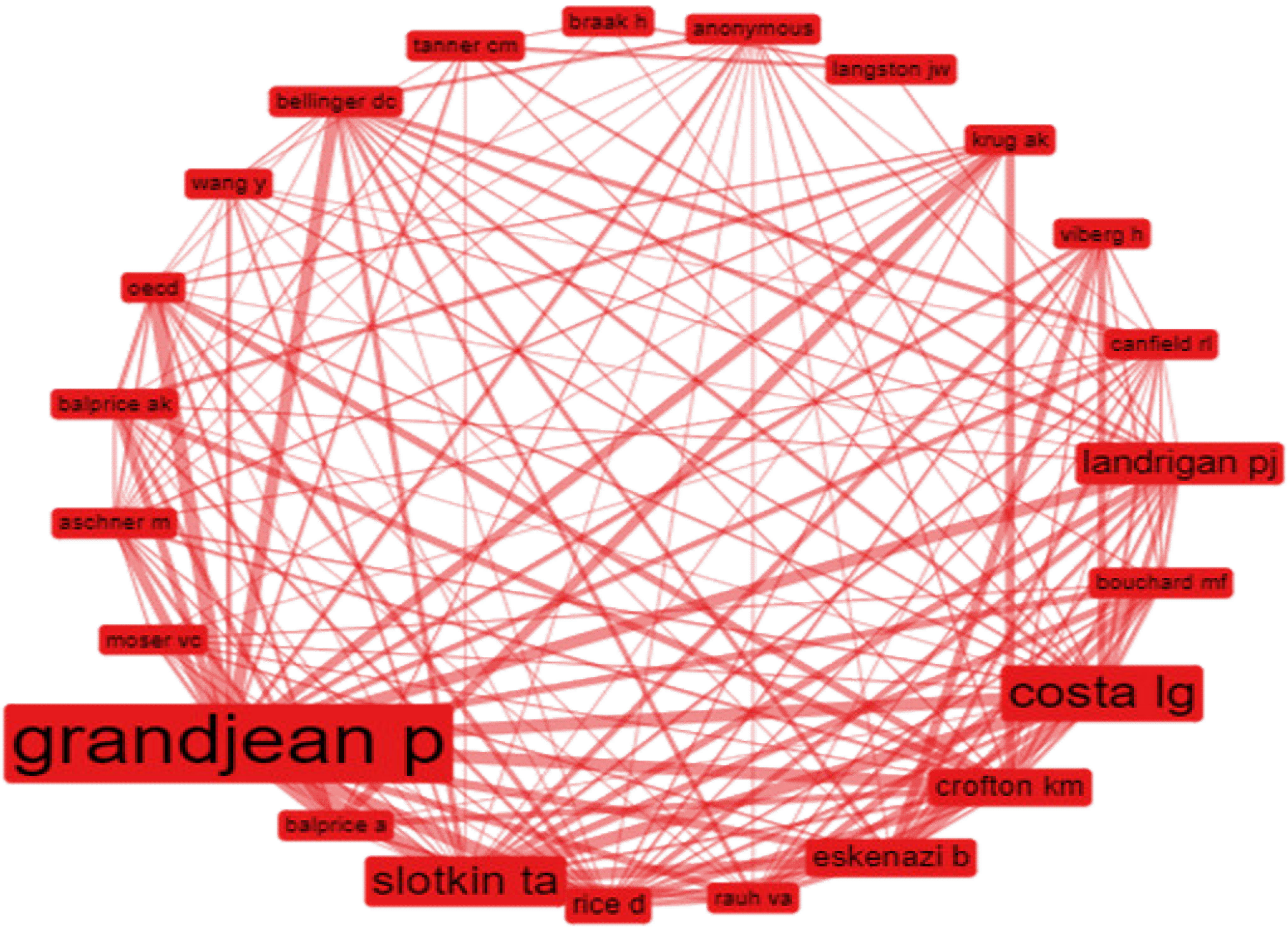

Figure 5. Authors' co-citation analysis between 2011 and 2020.

It is obvious that keywords with the highest number of occurrences (n > 15) were "neurotoxicity", "developmental neurotoxicity", "oxidative stress", "Parkinson's disease", and "pesticides". However, all the keywords plus showed occurrences that were ≥15 except "disease", "methylmercury", and "model" with n = 14 each. As the term "neurotoxicity" addresses harm caused to the brain or peripheral nervous system due to human exposure to some natural or synthetic toxic materials, the above-mentioned keywords and keywords plus showed pesticides (including chlorpyrifos), lead, and methylmercury as the top neurotoxicants. In addition, the huge effects of these toxic chemicals on "children", especially unborn babies, are noteworthy. Lead (Pb) has been reported to have possible impairment on the intelligence quotient (IQ) of these young fellows [8]. Besides, high concentrations of polychlorinated biphenyls (PCBs) in pregnant women's blood could reduce both the weights and IQs of unborn babies, as well as trigger many other neurological conditions [2]. Hence, "developmental neurotoxicity", defined as the damage done to the "developing brain and nervous system" of living organisms by some identified neurotoxicants or neurotoxins, has attracted the attention of scientists often [77], even though the available information regarding humans is very scarce. Zebrafish, medaka, and some other fish species have been used as model animals in the developmental neurotoxicological and ecotoxicological studies of many neurotoxicants, with an emphasis on their developmental stages (early life) [3,78,79].

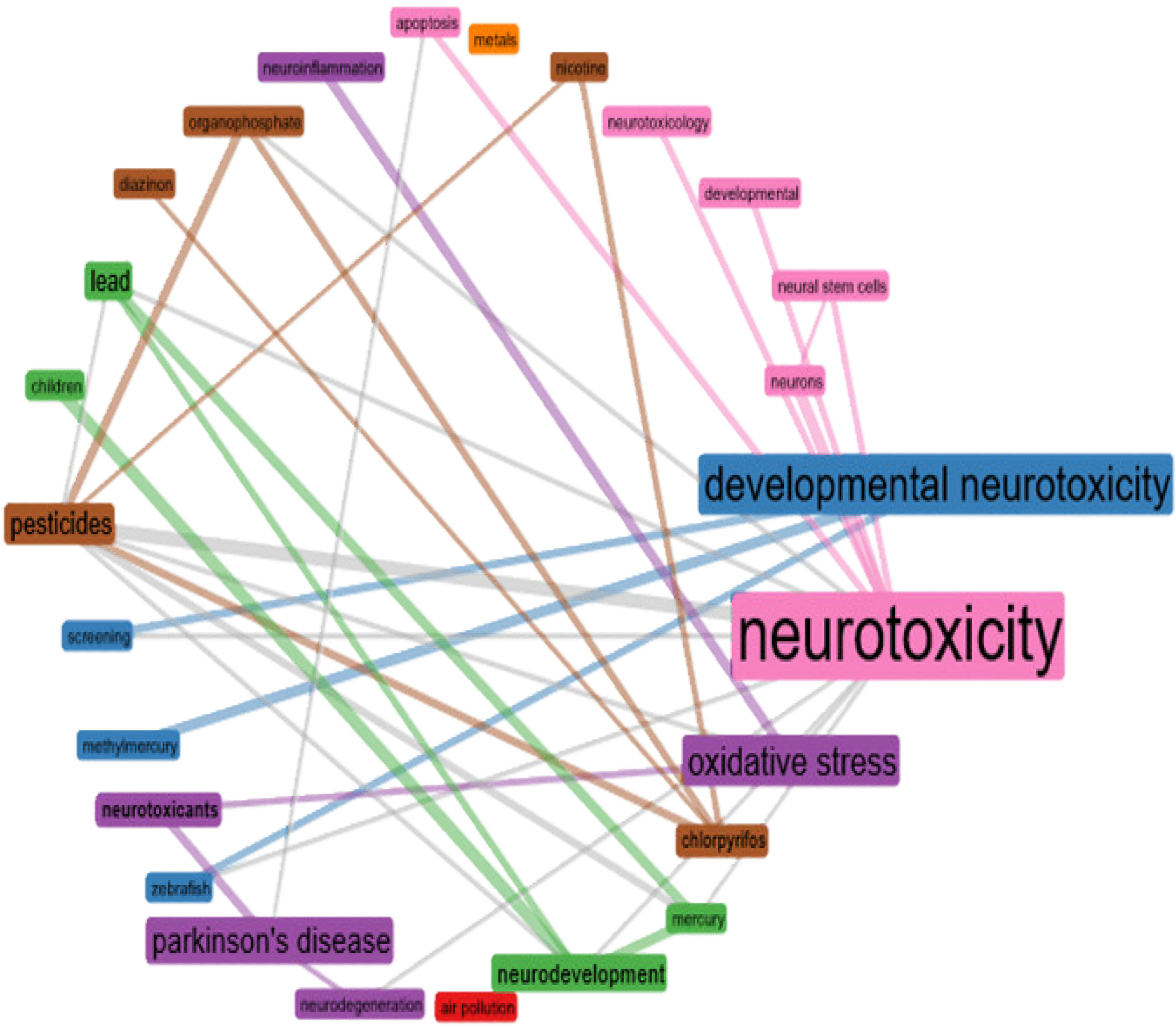

Figure 6. Top author's keywords from 2011 to 2020.

Key pesticides with neurotoxic tendencies are organophosphates, which have been found to be useful for boosting agricultural production of fibers and food [6]. The effects of these on humans include memory loss, unclear speech, sleep disorder, ataxy, shudders, confused mental state, paraesthesia, and schizophrenia [8]. The killing of pests using pesticides is most often achieved using neurotoxic mechanisms. Although they are commonly found in very low concentrations as complex mixtures in the aquatic environment, their neurotoxic effects on the population of many species in the system are enormous [80,81]. Related and unrelated modes of action (MoAs) in pesticides could result in concentration build-up (additive), collective neurotoxicity, and/or sudden death, subject to the kinds of dissimilar pesticides that come together [3,82–84]. In the same vein, methylmercury, a popular antifungal agent, has been shown to be neurotoxic, triggering several neurological diseases, including marred speech and hearing, shaky walk, muscle weakness, and retarded vision and movement, after human exposure, mostly by ingestion [2,8].

Figure 7. Co-occurrence network (keyword plus) between 2011 and 2020.

Just like Alzheimer's disease (AD), Parkinson's disease (PD) is a neurodegenerative disease that is linked to loss of neurons in some parts of the brain, including an area in the midbrain called the "substantia nigra", which generates a particular neurotransmitter known as dopamine (that regulates movement). Dopamine in the brain decreases as some cells in the "substantia nigra" also decrease. Loss of neurons in this part of brain and other parts always results in PD, with several symptoms, such as tremor, muscle stiffness, bradykinesia, walking difficulty, sleep disorders, depression, fatigue, and anxiety, among many others [85,86].

Meanwhile, oxidative stress occurs when the reactive oxygen species (ROS) generated in the body are not balanced with the available radical scavengers (otherwise called antioxidants) [87]. Insufficient production of antioxidants is dangerous, as the neurons are composed of polyunsaturated lipids, which are prone to oxidation, hence causing serious damaging effects on many biomolecules (sugars, lipids, polynucleotides, and proteins) [88]. This could even produce secondary products with similar damaging effects to the previous ROS. Oxidative stress is the key factor that controls the pathological processes of several chronic diseases, such as obesity, diabetes, and rheumatoid arthritis, and a larger portion of many neurological problems, especially those linked with aging, including Alzheimer's disease, Parkinson's disease, Huntington disease, and amyotrophic lateral sclerosis [89]. The central nervous system is highly susceptible to oxidative stress considering its large portion of O_2, very low level of antioxidants and similar enzymes, and high concentration of polyunsaturated lipids and other biomacromolecules, which are very oxidizable. It is worthy of note that several redox-active d-block metals possess capability to produce ROS catalytically, and hence, induce oxidative stress [90–93].

3.11. Study Limitations

Despite the numerous advantages of this type of review, it is important to state some limitations that are associated with this study. Publications related to neurotoxicity were only analyzed using the WoS database, which has wide coverage, suggesting that other articles published in journals not indexed in WoS (but available in other databases including Scopus) were excluded. Thus, the output of this study does not represent all the publications available on the subject. Moreover, the journals analyzed in this present study were limited to those written in English language, not minding the number of studies published in many other local/international languages. Therefore, it is recommended that future research in this field should consider all the listed limitations for inclusiveness.

4. Conclusions

This study discussed "neurotoxicants and their attendant environmental pollution and neurological disorders in living organisms" from 2011 to 2020. A total of 321 articles were retrieved from SCI-Expanded (Web of Science), focusing on articles, corrections, editorial materials, letters, meeting abstracts, news items, and reviews but excluding book chapters, proceeding papers, and note retractions. The documents retrieved had 1467 authors, while the number of authors/documents were 4.57, co-authors/documents were 5.38, and the collaboration index was 4.87. Countries were rated according to their productivity, total citations, and collaborations among researchers within the period. The results of the analyses revealed that the USA, China, and Germany were the countries with the highest collaborations in the field, correspondingly. This presents North America, Asia, and Europe as the top continents with huge contributions to research in this field. They also demonstrated an impressive collaboration network among their researchers. However, Africa was not represented among the first 20 countries with significant outputs in this research area. Therefore, we believe that this study will help new researchers to identify where and with whom to seek collaboration in their future research studies. Researchers in developing nations, especially Africa, should be encouraged to participate in this field of study and should seek assistance where necessary from top researchers and countries that have contributed immensely in the past. Poor participation among these nations might be attributed to a lack of funding and research facilities; hence, funding agencies should provide as much support as necessary for them as a means of encouragement. It is believed that adequate funding and other support would assist researchers (old and new) to carry out more research studies on the subject if available.

Author Contributions: Conceptualization, A.O.A. and K.O.; methodology, software, validation, and data curation, Z.T.-N., A.O.A. and K.O.; writing—original draft preparation, A.O.A.; writing—review and editing, Z.T.-N. and K.O.; funding acquisition, Z.T.-N. All authors have read and agreed to the published version of the manuscript.

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