

# Climate change, pollution, deforestation and mental health: research trends, gaps and ethical considerations

Submission as a *Research Article*

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Word count main text: 5637

Word count abstract: 210

Conflict of Interest: none

Funding source: MEW was funded by the Clinician Scientist Programme of the Medical Faculty of Ulm University.

Acknowledgements: We thank the reviewers and editor for their constructive feedback.

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This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the [Version of Record](#). Please cite this article as [doi: 10.1029/2022GH000632](#).

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Accepted Article

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## Key Points

- Climate change, pollution and deforestation threaten global mental health and need to be addressed as a mental health issue
- Data mining can help to uncover trends and gaps in research
- Mental health research on climate change and pollution is growing, while research linking these to environmental injustice is less prominent

## Abstract

Climate change, pollution and deforestation have a negative impact on global mental health. There is an environmental justice dimension to this challenge as wealthy people and high-income countries are major contributors to climate change and pollution, while poor people and low-income countries are heavily affected by the consequences. Using state-of-the-art data mining, we analysed and visualised the global research landscape on mental health, climate change, pollution and deforestation over a 15-year period. Metadata of papers were exported from PubMed®, and both relevance and relatedness of terms in different time frames were computed using VOSviewer. Co-occurrence graphs were used to visualise results. The development of exemplary terms over time was plotted separately. The number of research papers on mental health and environmental challenges is growing in a linear fashion. Major topics are climate change, chemical pollution, including psychiatric medication in wastewater, and neurobiological effects. Research on specific psychiatric syndromes and diseases, particularly on their ethical and social aspects is less prominent. There is a growing body of research literature on links between mental health, climate change, pollution and deforestation. This research provides a graphic overview to mental healthcare professionals and political stakeholders. Social and ethical aspects of the climate change-mental health link have been neglected, and more research is needed.

## Key words

climate change; mental health; data mining; medical ethics; contamination; environmental justice

## 1. Introduction

The aim of this paper is to assess the development of the biomedical research landscape on links between mental health, climate change and pollution over the last 15 years, using state-of-the-art data mining methods to elucidate research trends and gaps and to discuss ethical implications. As a bibliometric study with an ethical analysis it offers a pictorial synopsis of the occurrences of the main terms along with their most frequently associated terms, thus helping researchers in identifying the main areas of cooperation and the ones needing more interdisciplinary work.

Both mental illness and environmental degradation are global challenges, and there is a growing body of research literature on links between the two. Research gaps have been identified by mental health experts (Royal College of Psychiatrists, 2021a). There is an ethical dimension concerning environmental justice as high-income countries and wealthy populations are responsible for high proportions of pollutants and greenhouse gases, while low-income countries and poor people disproportionately suffer from their environmental impact because of higher exposure to unfavourable conditions and lower adaptive capacity (Dwyer, 2019; European Environment Agency, 2019; Paavola, 2017). Furthermore, there are interpersonal differences in how people react to environmental change. The mental health impacts of climate change is more pronounced among persons with lower socioeconomic status (SES) (Levy & Patz, 2015). Acute weather events have direct mental health impacts, and their effects disproportionately affect persons with low SES. Lack of resources and living in rural areas make it more difficult for people to protect themselves from the consequences of climate change and to seek professional mental health assistance. Sparsity of natural resources such as food and drinking water are linked with migration, violence, anxiety and suicidal ideation (Levy & Patz, 2015; Thoma et al., 2021). Acute events, such as major environmental degradation and loss of livelihood due to changing climatic conditions may also lead to depression, post-traumatic stress disorder and long-lasting grief (Palinkas & Wong, 2020).

### 1.1 A call for action: psychiatric associations

This growing awareness of the connection between environmental factors and mental health is mirrored in the activities of psychiatric associations worldwide. The World Psychiatric Association features a section *Ecology, Psychiatry & Mental Health* (WPA, 2021), the American Psychiatric Association and the American Psychological Association have issued a resource document on mental health and climate change (Clayton et al., 2021; Ursano et al., 2017) and the same holds true for the German psychiatric association (Deutsche Gesellschaft für Psychiatrie und Psychotherapie, Psychosomatik und Nervenheilkunde, 2019). The Royal College of Psychiatrists (RCPsych) “declares a climate and ecological emergency to avert a health and mental health catastrophe” (Royal College of Psychiatrists, 2021b). In a position statement, the RCPsych (2021a) points out the mental health impact of climate change, loss of biodiversity and forced migration with a focus on populations experiencing major health inequities such as migrants, ethnic minorities, homeless and disabled persons, women, children and the elderly. The RCPsych discusses the psychological dimension of this crisis and proposes solutions including sustainable mental healthcare, e.g. through prevention, more mental health activities in green spaces and reducing social inequality. In the same vein, the “*Lancet* Commission on global mental health and sustainable development” links the United Nations’ Sustainable Development Goals (SDG) with an agenda for global mental health (Patel et al., 2018).

There is also increasing awareness that the healthcare system itself has an impact on the environment through its carbon footprint, chemical pollution and deforestation for new buildings. In industrialised countries, such as England and Germany, its carbon emissions

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account for about 5 % of the total (Mezger et al., 2021; Royal College of Psychiatrists, 2021a). Accordingly, the German professional code demands from physicians to help protect the natural livelihood to promote population health (Bundesärztekammer, 2021). The RCPsych pledges CO<sub>2</sub>-neutrality until 2040 (Royal College of Psychiatrists, 2021a).

Furthermore, healthcare professionals are highly trusted and reach many people, which means that they can spread knowledge on the influence of climate change on population health (Mezger et al., 2021). The climate emergency obliges health professionals to make use of their reputation and knowledge to insist on swift climate action.

### *1.2 The environment and mental health*

Exposure to the natural environment or green spaces has a positive effect on mental health (Bratman et al., 2019; Karjalainen et al., 2010). Subjective general health has been associated with proximity to green spaces, mediated by factors such as mental health, social support and physical activity (Dadvand et al., 2016). There is an extensive body of research on the positive effects of forests on human health, both mental and physical, including vital signs and the immune system (Karjalainen et al., 2010), and preliminary evidence for therapeutic effects of forests on psychiatric patients (Bielinis et al., 2019). Aerts and colleagues (2018) in a review on biodiversity state evidence for positive effects of exposure to nature, green spaces and biodiversity on psychological and physical well-being but see research gaps and conflicting evidence with regards to biodiversity. When assessing the effect of green spaces on people, we need to be aware that poorer people and minorities are more exposed to polluted and degraded environments, as the environmental justice scholarship has shown, and that persons with higher SES living in areas of high pollution (e.g. city centres) seem to be more resilient against negative health consequences (Science for Environment Policy, 2016; Shrader-Frechette, 2005). Moreover, people value biodiversity differently, either for intrinsic reasons, or for the ecosystem system services it provides (Timmermann, 2015). Especially for people living in close contact with their environment such as indigenous people and farmers, the environment is a strong part of their identity and human-induced changes to this environment can lead to grief and a feeling of losing one's identity (Cunsolo & Ellis, 2018; Middleton et al., 2019). Local flora and fauna are key elements of people's biocultural heritage (S. Khan et al., 2021) and many cultural practices are inconceivable without contact to the living environment from which they originate (Rozzi, 2013).

### *1.3 Aims of the study*

Our aim is to analyse and visualise the dynamic biomedical research landscape on climate change, pollution, deforestation and mental health of the last 15 years. This approach allows us to visualise the key terms associated with a changing natural environment and mental health, including links to direct effects on the brain and physical integrity, and indirect effects, through the perception of environmental degradation and extreme weather events. We have three research questions: (i) Which major research trends can be identified? (ii) Which research gaps can be identified? And, (iii) on basis of any identified research gaps, what are the ethical implications for researchers, mental healthcare personnel and political stakeholders? Here we are particularly interested in who assumes responsibilities and what effects of climate change and environmental degradation are recognized as injustices that need to be redressed.

## **2. Material and Methods**

### *2.1 Data retrieval*

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PubMed® searches were conducted between June 17 and 25, 2021 with the search string:

("climate change" OR pollution OR deforestation OR "global warming") AND ("mental health" OR "mental illness" OR psych\*). We relied on the abovementioned reports from the American, British and German psychiatric associations to identify the key search terms. Consensus was reached after a discussion between the authors.

PubMed® is an extensive database on biomedicine and health fields that is freely available and permits to export metadata for data mining tools. It also indexes a large number of journals with health-related content in the social sciences and humanities. Through its connection to MEDLINE it can access citations from over 5200 journals worldwide in 40 languages (NCBI, 2021). Its search algorithm has been optimised to lead to accurate results despite different forms of spelling and spelling mistakes (Fiorini et al., 2018).

Metadata of articles were exported using three ranges of publication time to provide an overview of major research trends: 01/01/2006-12/31/2010; 01/01/2011-12/31/2015; 01/01/2016-12/31/2020. We decided to concentrate only on this fifteen-year time period to focus our attention to the later developments. Although cut-off lines have something arbitrary, the start date in 2006 has two advantages: (i) most of the larger journals had made their articles accessible in machine-readable formats, and (ii) international comparative studies triggered by the Millennium Development Goals started to become available. Taking an earlier study year would have led to an inaccurate overview, due to the large number of texts that have not been fully digitalized using optical character recognition tools. To see if the search term “environmental degradation” adds relevant content, the analysis for the time frame 01/01/2016-12/31/2020 was done again with the search string mentioned above but additionally including “environmental degradation”, the result is shown in Appendix 1. For a more fine-grained analysis, data were also extracted per year. Hereby we can show how research focussing on environmental factors and mental health shifts its emphasis as expressed by the frequency of a subgroup of exemplary terms.

## *2.2 Analysis of publication numbers*

The number of publications per year was exported to Microsoft Excel (version 2013), visualised in a line graph and the slope was calculated.

## *2.3 Data mining and visualisation*

We used titles and abstracts for analysis as this bibliographic metadata has been shown to be sufficient for profiling tasks and is freely available (Mai et al., 2018; Nishioka et al., 2015). Data analysis was performed using VOSviewer 1.6.15, developed at Leiden University, as in previous bibliometric research (Wigand et al., 2021; Wigand & Ursin, 2021). VOSviewer can compute the relevance, number of occurrences and relatedness of terms (van Eck & Waltman, 2014), using the state-of-the-art natural language processing (NLP) library Apache OpenNLP (<https://opennlp.apache.org/>) to identify noun phrases, which are word sequences consisting only of nouns and adjectives and ending on a noun, e.g. “climate change”, “poor mental health” or “morbidity” (Van Eck & Waltman, 2011). VOSviewer calculates the relevance of noun phrases via their distribution and groups noun phrases with a high relevance into clusters (van Eck & Waltman, 2011). We opted for the default setting of the VOSviewer to determine relevance score. This setting gives standard terms in academic articles such as “new method”, “results” and “conclusion” low relevance scores to blend out irrelevant information. In contrast, terms that the software considers of high relevance are pointed higher (van Eck & Waltman, 2017). Using this filter only terms who scored in the top 60% are blended in. Relatedness is determined by the software based on co-occurrences in the input data (van Eck & Waltman, 2011). Results are visualised as bibliometric networks, where closeness of noun phrases indicates the number of co-occurrences, similar colours

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show semantic relatedness and the size of circles indicates the number of occurrences. While these bibliometric networks can intuitively show the prominence and relatedness of themes in large amounts of text data, we also used VOSviewer to compare, among the terms scored in top 60% of relevance, the 30 noun phrases with most occurrences over the three time periods to have an objective measure of change in themes over time.

#### 2.4 Plotting the development of exemplary terms

Following the data mining analysis, the multi-disciplinary team of authors, from psychiatry, ethics, computer science and history of medicine, developed categories and chose exemplary terms for each category. As our aim is to visualise the research landscape, we followed qualitative content analysis processes to derive inductively the main categories on the basis of their occurrence and their main relations. We opted for this approach as we are analysing large datasets where only major trends and their relations can be assessed and where there is no consensus on predefined categories (Elo & Kyngäs, 2008; Vaismoradi et al., 2013). Two factors were decisive to identify a term as exemplary: number of occurrences and low contextual ambiguity (i.e. in which relation the term stood). The categories were developed independently by three of the authors (MEW, CT, AS) on the basis of the main terms (Table 1), after which they were compared and discussed until consensus was reached. The two other authors (TB, FS) reviewed the categories and the chosen exemplary terms. The normalised frequency of occurrences of these terms was plotted by dividing the number of occurrences by the total number of publications per year.

### 3. Results

#### 3.1 Bibliographic data

The search string mentioned above yielded a total of 11,547 results. Figure 1 shows the growing number of search results per year with an approximately linear slope of 68.6.

##### 3.1.1 Period 2006-2010

This time frame yielded 1,554 results, VOSviewer detected 33,165 terms, 809 with more than 10 occurrences and selected 485 terms (60 %) based on the relevance score (default setting). Figure 2 shows the co-occurrence network.

There is a red cluster (n=162 terms) with “child” (n=231) and “smoking” (n=221) as prominent terms. There is a yellow cluster (n=90 items) featuring terms such as “age” (n=216), “mother” (n=83), “pregnancy” (n=66) and “offspring” (n=33) and terms of toxic substances such as “methylmercury” (n=18), “pcb”/“pcbs” (n=36/27) (polychlorinated biphenyl) and “bpa” (n=17) (bisphenol A). Other terms in this cluster are “neurodevelopment” (n=20), “impairment” (n=42), “function” (n=107) and “epidemiological study” (n=23). There is a green cluster (n=142 terms) around the term “concentration” (n=263), featuring other terms such as “compound” (n=129), “treatment” (n=129), “water” (n=127), “wastewater” (n=62), “aquatic organism” (n=19) and also psychiatric or neurological medication such as “fluoxetine” (n=39) and “carbamazepine” (n=82). There is a blue cluster (n=91 terms) around the term “climate change” (n=75) with other terms such as “challenge” (n=54), “conservation” (n=45), “sustainability” (n=17) and “habitat” (n=26).

Concerning the main co-occurrences, we can highlight four nodes. There are a large number of links between “smoking”, “household” and “child” hinting to an emphasis on the health consequences of indoor smoking. The proximity of the terms “concentration”, “treatment”, “water”, “presence” and “wastewater” reveal a special concern for water quality. Between the main clusters, we see frequent connections between “policy” and “climate change” indicating

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an emphasis on political solutions and several terms related to the health of the foetus between the term “child” and the different terms associated to “pollution”.

### 3.1.2 Period 2011-2015

This time frame yielded 2,753 results, VOSviewer detected 56,618 terms, 1,487 with more than 10 occurrences and selected 892 terms (60 %) based on the relevance score (default setting). Figure 3 shows the co-occurrence network.

There is a red cluster (n=222 items) with “smoking” (n=330) and “child” (n=382) as prominent terms. Terms pertaining to smoking such as “tobacco use” (n=63), “smoking ban” (n=57) and “secondhand smoke exposure” (n=69) are in this cluster. Small unconnected dots feature the terms “race ethnicity” (n=15) and “african american” (n=13). There is a yellow cluster (n=223 items) featuring terms such as “brain” (n=99), “blood” (n=66), “toxicity” (n=108), “neurotoxicity” (n=36) and “tissue” (n=69), toxic substances such as “lead” (n=64), “bpa”/“bisphenol”/“bisphenol a” (n=79/86/19) and “hydrogen sulfide” (n=52), and psychiatric terms such as “anxiety”/“anxiety disorder” (n=107/16) and as a small unconnected dot “autism spectrum disorder” (n=13). There is a green cluster (n=214 terms) with terms such as “concentration” (n=498), “compound” (n=248), “treatment” (n=245), “carbamazepine” (n=227) and “wastewater” (n=133) as prominent terms. Other terms in this cluster include “drinking water” (n=44), “cocaine” (n=32) and several terms in semantic proximity to “wastewater treatment plant” (n=71). There is a blue cluster (n=233 terms) around the word “climate change” (n=250), featuring terms such as “attitude” (n=154), “policy” (n=213), “mental health” (n=118), “responsibility” (n=22), “ecosystem service” (n=13), “conservation” (n=69) and “migration” (n=25).

In this second period, when it comes to co-occurrences of terms, we see some relevant changes. While the links between “climate change” and “policy” remain as strong as in the earlier period, we can observe three developments. First, links between “child” and “smoking” became more diversified, with mentions to “father” and “school”. Second, there are much stronger links between “brain” and “memory” and the terms associated to pollution. Third, there are several strong links between “child” and “brain” and “memory”, indicating greater awareness of the effect of pollutants for cognitive development, particularly during foetal and early childhood stages.

### 3.1.3 Period 2016-2020

This time frame yielded 4,536 results, VOSviewer detected 92,468 terms, 2,556 with more than 10 occurrences and selected 1,534 terms (60 %) based on the relevance score (default setting). Figure 4 shows the co-occurrence network.

There is a red cluster (n=365 terms) around the term “association” (n=828) with terms such as “child” (n=585), “air pollution” (n=508), “pregnancy” (n=211) and “prenatal exposure” (n=100). Some psychiatric terms can be found in this cluster such as “depressive symptom” (n=62), “autism spectrum disorder” (n=60) and “dementia” (n=47). Several potentially toxic substances can be found in this cluster, e.g. “phthalate” (n=56). There is a yellow cluster (n=305 terms) featuring biological terms such as “brain” (n=166), “tissue” (n=126), “inflammation” (n=88) and “metabolism” (n=114). There are also terms such as “bisphenol”/“bisphenol a” (n=105/25) and “hydrogen sulfide” (n=54) in this cluster. There is a green cluster (n=346 terms) around the term “concentration” (n=798). Other terms in this cluster are “water” (n=381), “degradation” (n=186), “pharmaceutical” (n=309), “toxicity” (n=203) and “carbamazepine” (n=318). There is a blue cluster (n=518 terms) featuring “climate change” (n=593) as a central term. Other important terms are “mental health”

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(n=287) and “smoking” (n=292) with related terms. Around the term “climate change”, there are terms such as “attitude” (n=208), “science” (n=180), “conservation” (n=137), “forest” (n=66) and “biodiversity” (n=51).

In this third period, we again see some changes in co-occurrences. Interestingly “climate change” is not primarily linked to “policy” anymore, we see new major links to “school” and “mental health”. Research linking terms associated to pollution and water are also diversified, with references to “soil” and “crop”. The links between terms related to pollutants and brain functionality have become stronger than in the previous period. An interesting development is to see “women” strongly linked to “mental health” and “smoking”, while in the earlier period we could observe “father” and “male” in relation to smoking and terms related to pollution and brain function (i.e. environmental determinants).

Table 1 presents the top 30 terms, their absolute incidence and relative frequencies during all three time frames.

### 3.2 Major categories

Recurring terms identified in the search process were grouped into five categories that were formed inductively by the inter-disciplinary author team. These categories comprised: (1) general environmental terms, such as “climate change”, “pollution” and “resilience”; (2) chemical pollution, e.g. “fluoxetine”, “carbamazepine”, “bisphenol a” and “prenatal exposure”; (3) extreme weather events, e.g. “drought” and “hurricane”; (4) social impact and ethical issues, including “attitudes”, “awareness”, “environmental justice”, “norms”, “inequality”, “poverty”, “low income country”, “migrant”, and “social determinant”; (5) syndromes and diagnoses, e.g. words from the semantic fields of “depression”, “attention deficit hyperactivity disorder”, “autism”, and “Alzheimer”.

Figure 5 gives an overview of the development of a subgroup of our exemplary terms over time. This subgroup consists of a smaller selection of terms from each category to allow visualization. The normalised frequency of “climate change” increased most conspicuously, and also the truncated term “depress\*” shows an increase. “Resilience” shows a slight increase, terms such as “extreme weather event” and “inequality” remain on a low level, while limited data suggest a moderate upward trend for the latter.

## 4. Discussion

Climate change and other environmental challenges have a deep impact on global mental health and can be regarded as a “climate and ecological emergency” (Royal College of Psychiatrists, 2021b). Accordingly, our analysis yielded a growing body of research literature on this topic. Our discussion follows the five categories mentioned above.

### 4.1 General environmental terms

Based on the high frequency of references to general environmental terms, we can observe a steady increase in the number of publications on environmental factors influencing mental health. The term “climate change” is gaining importance within the last 15 years of our analysis. The impact of climate change on mental health is widely recognised, and the peak seen in 2011 (Figure 5) might have to do with the release of the American Psychological Association’s climate change report in 2010 (Kurtzman & Singer, 2010), leading to follow-up articles and special issues in the following year. Interestingly, throughout all three periods the strongest co-occurrence link to the term “climate change” is with “policy”, revealing a strong preference for governmental interventions. “Resilience”, although an important concept in mental health (Davydov et al., 2010), is represented to a lesser extent. Furthering resilience,

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a sense of agency and self-esteem vis-à-vis the effects of climate change and ecological emergency, especially in young people, should be a priority for psychologists and psychiatrists (Royal College of Psychiatrists, 2021a). Such efforts can link with recent developments in ethics that have started to recognize the importance of resilience in times of high uncertainty, particularly as an ideal to be pursued to shield the most disadvantaged population groups during disruptions (Kolers, 2016). As we already know that climate change will cause severe disruptions, it becomes necessary to prepare people and communities to respond to an increased demand for mental health systems by training professionals, building support networks and creating awareness.

#### 4.2 Chemical pollution

Waste produced by humans was, for most of history, organic and biodegradable (Dwyer, 2019). Beginning with the Industrial Revolution and accelerated in the last decades, many chemical pollutants have been released into the environment, e.g. through mining and development of new synthetic chemicals (Naidu et al., 2021). Anthropogenic chemical pollution can affect the central nervous system and lead to neurodevelopmental, psychiatric and neurological sequelae (Naidu et al., 2021). Neurotoxic chemicals can increase the risk of diseases such as attention deficit disorders and autism spectrum disorders (E. M. R. Smith & Miller, 2019). There is a strong emphasis on studying the cognitive effects of pollutants on fetuses and small children.

There is growing evidence that ambient air pollution can be a risk factor for neuropsychiatric disorders including stroke, Parkinson, depression and neurodevelopmental disorders, maybe mediated by inflammatory responses and oxidative stress (Hahad et al., 2020). Cognitive development of children can be negatively affected by prenatal exposure to air pollution and second hand smoke (S. Shah et al., 2020). In our analyses, we found smoking to be a major topic in the earlier time frames, which mirrors political discussions about smoking bans in Europe and many US States in the early 2000s.

Also, toxic substances which are not airborne can increase the risk of neuropsychiatric disorders and negatively affect neurodevelopment if exposure is early in life or prenatal. Heavy metals can affect neurodevelopment (S. Shah et al., 2020), and terms related to heavy metals such as “lead” and “methylmercury” are present in our analysis. “Phthalate”, another term we found in our analysis, and its metabolites can affect neurodevelopment and child behaviour (Daniel et al., 2020; J. Inhyang Kim et al., 2021; S. Shah et al., 2020). Other exposures emerge from human-made catastrophes such as the “Deepwater Horizon oil spill” with a negative impact on mental health in affected areas, i.e. an increase in depressions, anxiety and post-traumatic stress disorders (H. J. Osofsky et al., 2011).

Many pharmaceuticals in wastewater are recognised as micropollutants with potentially toxic effects on aquatic life, which poses the question of cost-effective removal or degradation (H. Khaleeq Khan et al., 2020). Pharmaceuticals may also affect wild vertebrates, leading to research e.g. on fluoxetine and birds (Whitlock et al., 2019). In our analysis, we recognised carbamazepine, which is prescribed in neurological and psychiatric contexts, and the antidepressant fluoxetine as prominent terms, and also the antidepressant sertraline and the tranquiliser oxazepam. Fluoxetine is an interesting example because it was heavily advertised especially in the US, widely taken (Harrington, 2019) and novels such as “Prozac nation” (Wurtzel, 2017 [1994]) were written about it. This leads to the idea that Fluoxetine was also taken in contexts where there was no clear medical indication and that this over prescription is shown in the contamination of water and wildlife with this substance.

To reduce chemical pollution within the health sector, the approach of “Choosing Wisely” as suggested by the RCPsych (2021a) might help to reduce prescriptions to cases with a clear

indication and thus minimise environmental impact through over prescribing. Choosing wisely in this context means an international programme aiming at the reduction of unnecessary procedures, tests and interventions in medicine (Levinson et al., 2015). From an ethical perspective, we can see a strong appeal to professional medical responsibility. This can be regarded as a broad understanding of the ethical principle of non-maleficence (Beauchamp & Childress, 2019), because a more cautious and precise approach to prescription practice might reduce harm to patients and to the environment and thus all living beings. This idea can be traced back to the beginnings of bioethics and to Fritz Jahr's bioethical imperative to treat every living being as an end in itself as far as possible (Steger, 2015). It is noticeable that many efforts to reduce the exposure to chemicals are framed as an issue of professional responsibility, either at an individual or institutional level, while giving a lesser role to legislative work at a national and regional level.

#### *4.3 Extreme weather events*

The impact of events can be classified by their acuity: acute events (e.g. hurricanes, wildfires), longer-lasting weather-events (e.g. droughts, heat waves) and long-term changes (e.g. water scarcity, disruption to food supply) which can potentially render the planet uninhabitable for humans (Palinkas & Wong, 2020). We found terms relating to acute and longer-lasting weather events ("hurricane", "drought"). Major single events, such as Hurricanes Katrina, Sandy, Ike and Maria, led to more thematic publications, but not to a shift in overall research trends. Nonetheless, there are already some indications that studies on mental health effects of environmental disruptions are systematically distinguishing between the duration of the event and its possible distinct mental health implications (Cianconi et al., 2020; Palinkas & Wong, 2020).

There is a growing awareness that the medical sector is a significant contributor to climate change and as any other sector needs to reduce greenhouse gases emissions (Royal College of Psychiatrists, 2021b). Climate action requires cooperation between different members of the sector. Not only psychiatrists, but many health professionals are aware that public health requires planetary health urging cooperation for the common good (Horton et al., 2014; Kurth, 2017). The mental health effects of extreme weather effects are not only pressing researchers to perform studies on these events. Such events serve as a continuous reminder of the dangers of climate change for public health and the importance of taking collective action by starting with one's own profession.

#### *4.4 Social impact and ethical issues*

Terms such as "ethics" or "environmental justice" do not rank high in number of occurrences in our analysis and we did not find a strong representation of ethical aspects and mental health in the research landscape of the past 15 years. This omission is particularly troublesome, as particularly the poor have limited access to mental health services and we therefore have an overrepresentation of case studies affecting wealthier population groups. As pollution and environmental degradation affects disproportionately the poor, it is not only unjust that they have less access to mental health services, but it is also likely that they have higher needs for these services and there are fewer health professionals with expertise in their clinical profiles. "Attitude" is among the top 30 terms in all time frames. Environmental attitudes are important indicators of pro-environmental behaviour and can include moral aspects (Feinberg & Willer, 2013). Terms such as "attitude", "responsibility", "policy" and "conservation" appear in proximity to "climate change". Here it needs to be however noted, that some of the occurrences of "attitude" may not be linked to climate change or pollution, but to the attitude towards mental health services, particularly on unwillingness in seeking professional help – a topic of much research attention.

Feelings of grief and anxiety vis-à-vis environmental destruction are increasingly discussed in mental health contexts and in the lay press. Terms used for these emotions include eco-distress, climate grief, ecological grief and solastalgia (Royal College of Psychiatrists, 2021a). There are arguments not to pathologise these feelings as they are justified and can lead to meaningful action to protect the environment (Cunsolo et al., 2020; Cunsolo & Ellis, 2018; Royal College of Psychiatrists, 2021a). However, research in this area is still sparse (Cunsolo & Ellis, 2018; Galway et al., 2019) and there are arguments to involve different stakeholders such as “clinicians, public health practitioners, families, researchers, educators, and policy makers” in an “urgent response” (Cunsolo et al., 2020, p. e261) because numbers are rising and clinical help might be needed if ecological grief reaches a threshold where social functioning is diminished or suicidality occurs. There is a strong awareness that climate change and environmental degradation disproportionately affects vulnerable individuals and groups, which can be persons with a low SES, homeless persons, but also persons working outdoors or persons living in areas with a high concentration of toxic waste products or a high risk of extreme weather events (Dwyer, 2019; Royal College of Psychiatrists, 2021a; Shrader-Frechette, 2005). After 2017 the analysed metadata shows a slight increase in the number of occurrences of the term “inequality” which hints to higher awareness of the disproportional impact of environmental hazards on the poor. Once widespread, attitudes towards climate change that lead to apathy or strong forms of grief are difficult to overcome and hinder organised responses to help those most affected. This challenge needs to be addressed on an international level to allow a more equitable sharing of burdens.

As a matter of gender equity, future work needs to analyse in more detail how the environmental effects on mental well-being are framed. It is noteworthy that during the period 2011-2015 the term “male” appeared with links to a large number of pollutants and the term “memory”, seeking an explanation associated with neurotoxicity, an environmental determinant, while during 2016-2020 we see closer co-occurrence links between “women” and “mental health” with “clinic”, “marital status” and “smoking” as intermediary terms, which can be rather interpreted as social determinants.

One of the key search terms, deforestation, did not show a large number of occurrences. This was a surprising outcome and we consider two possible explanations. Related terms, such as “habitat” showed up in the early 2006-2010 cluster, with the emergence of “ecosystem service” in the next cluster, and direct reference to “forest”, “biodiversity” and “conservation” in the last cluster 2016-2020, are indicative for a rising trend in research attention to the consequences of deforestation without a direct reference to our search term. There might be insufficient consensus on using a common keyword. Another explanation is that deforestation has primarily an effect on the mental well-being of people with close ties to nature, such as indigenous peoples (Rozzi, 2013), and therefore remains an under researched topic.

#### 4.5 Syndromes and diagnoses

There is evidence that environmental changes can trigger or worsen mental illness. Acute events are linked with post-traumatic stress disorder (PTSD), suicidality, anxiety and mood disorders (Palinkas & Wong, 2020). Exposure to longer-lasting weather events such as high temperature and heat waves is linked with increased morbidity and mortality due to mental illnesses such as substance abuse, organic mental illness, affective disorders and schizophrenia (J. Liu et al., 2021). Heat can directly impair biological brain function (J. Liu et al., 2021) and have a psychological impact, e.g. on Australian farmers confronted with dry land and dust (Cunsolo & Ellis, 2018). Long-term changes in climate can lead to displacement and conflict and pose an “existential threat” (Palinkas & Wong, 2020, p. 14). As there are global discrepancies in the provision of mental healthcare (Collins et al., 2011),

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many people affected by climate change induced mental illness will not receive adequate diagnosis and treatment. In the last period (2016-2020) there is a growth in the number of co-occurrences between the terms “climate change” and “student”, which partly can be interpreted as attention to school and university activism, but also includes research on the impact of climate change on mental health of younger people. The recognition of climate change as a global mental health issue within the context of huge disparities in accessing mental health services in the different regions of the world needs to come with greater knowledge sharing on diagnosis and therapies. The publication of case studies from all around the globe and comparative studies are already a first major step in knowledge sharing that should not be undermined by paywalls limiting access to scientific literature particularly for those working in the regions hardest hit by climate change.

#### *4.6 Limitations*

We only focused on the last 15 years and on one medical search engine, namely PubMed®. Comparing time frames of 5 years might contain a selection bias, which we tried to counteract by analysing certain terms by year. While PubMed® lists a variety of health-related social sciences and humanities journals, it does not include the major journals in environmental ethics. Future bibliometric research needs to look at further databases to close this gap. We cannot exclude a subjective bias in articulating major themes, categories and research gaps despite discussions in our multi-disciplinary team of authors and extensive review of literature. Similarly, the choice and classification of exemplary terms is likely to be influenced by our disciplinary backgrounds and prior research and clinical experience. Furthermore, while the search string is extensive, it by no means captures all the articles that are relevant. Some articles may be categorized with other keywords and listed erroneously under a category they do not belong to. Moreover, the metadata was analysed by software, which reduces some human mistakes, but leads to the inclusion of erroneous information that could have been spotted in a smaller dataset with a manual review. These factors affect the sensitivity and specificity of our search strategy.

#### *4.7 Conclusion*

Climate change, pollution and deforestation have a negative impact on global mental health. There is a growing body of research, but social and ethical considerations are underrepresented, particularly in the biomedical literature. Mental health professionals are invited to explore environmental injustices in their research and to reconsider almost forgotten measures “such as green walking projects, growing food and planting to increase biodiversity in hospitals” (Royal College of Psychiatrists, 2021a, p. 20).

#### **Open Research (availability statement):**

All data used for this publication is openly available via PubMed®. As PubMed® is an openly available resource (see <https://pubmed.ncbi.nlm.nih.gov/advanced/>), interested readers may replicate the search method specified in the article and adapt it for their own purposes to obtain relevant metadata.

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	<b>2006-2010 n=485 included terms</b>	<b>2011-2015 n=892 included terms</b>	<b>2016-2020 n=1,534 included terms</b>
1	concentration; n=263; 0.75	concentration; n=498; 0.55	association; n=828; 0.62
2	child; n=231; 0.48	child; n=382; 0.75	concentration; n=798; 0.25
3	smoking; n=221; 1.15	association; n=372; 0.52	climate change; n=593; 1.00
4	age; n=216; 0.41	smoking; n=330; 1.09	child; n=585; 0.60
5	survey; n=168; 0.77	age; n=307; 0.48	age; n=576; 0.49
6	smoker; n=144; 1.24	participant; n=295; 0.70	air pollution; n=508; 0.65
7	process; n=133; 0.32	survey; n=293; 0.75	water; n=381; 0.47
8	compound; n=129; 1.40	climate change; n=250; 0.94	treatment; n=375; 0.36
9	treatment; n=129; 0.57	compound; n=248; 1.04	species; n=335; 0.56
10	water; n=127; 1.09	treatment; n=245; 0.30	carbamazepine; n=316; 1.43
11	home; n=115; 1.04	smoker; n=239; 1.06	compound; n=312; 0.83
12	questionnaire; n=113; 0.67	carbamazepine; n=227; 1.63	presence; n=312; 0.35
13	intervention; n=111; 0.68	questionnaire; n=222; 0.68	pharmaceutical; n=309; 1.33
14	function; n=107; 0.54	presence; n=218; 0.38	policy; n=293; 0.91
15	policy; n=102; 0.87	intervention; n=215; 0.77	smoking; n=292; 0.90
16	range; n=100; 0.41	policy; n=213; 0.88	mental health; n=287; 0.75
17	presence; n=100; 0.33	water; n=208; 0.67	score; n=272; 0.63
18	prevalence; n=88; 0.63	home; n=199; 0.99	perception; n=260; 0.96
19	education; n=88; 0.54	pharmaceutical; n=188; 1.56	experiment; n=257; 0.54
20	score; n=86; 0.38	species; n=188; 0.53	practice; n=244; 0.82
21	interview; n=85; 0.77	drug; n=176; 0.92	present study; n=242; 0.30
22	mechanism; n=84; 0.65	perception; n=165; 0.83	education; n=236; 0.74
23	strategy; n=84; 0.44	experiment; n=160; 0.70	woman; n=232; 0.58
24	mother; n=83; 0.65	pollutant; n=160; 0.35	home; n=226; 0.81
25	carbamazepine; n=82; 2.55	issue; n=155; 0.60	product; n=212; 0.29
26	drug; n=82; 1.19	attitude; n=154; 1.09	pregnancy; n=211; 0.73
27	attitude; n=82; 1.06	prevalence; n=150; 0.67	attitude; n=208; 1.13
28	self; n=80; 0.54	education; n=144; 0.74	drug; n=208; 0.74
29	chemical; n=79; 0.43	woman; n=143; 0.59	application; n=206; 0.35
30	parent; n=78; 0.95	support; n=142; 0.84	experience; n=203; 0.83

Table 1. The 30 terms with most occurrences in all three time frames, calculated by VOSviewer. Number of occurrences and relevance values are given.

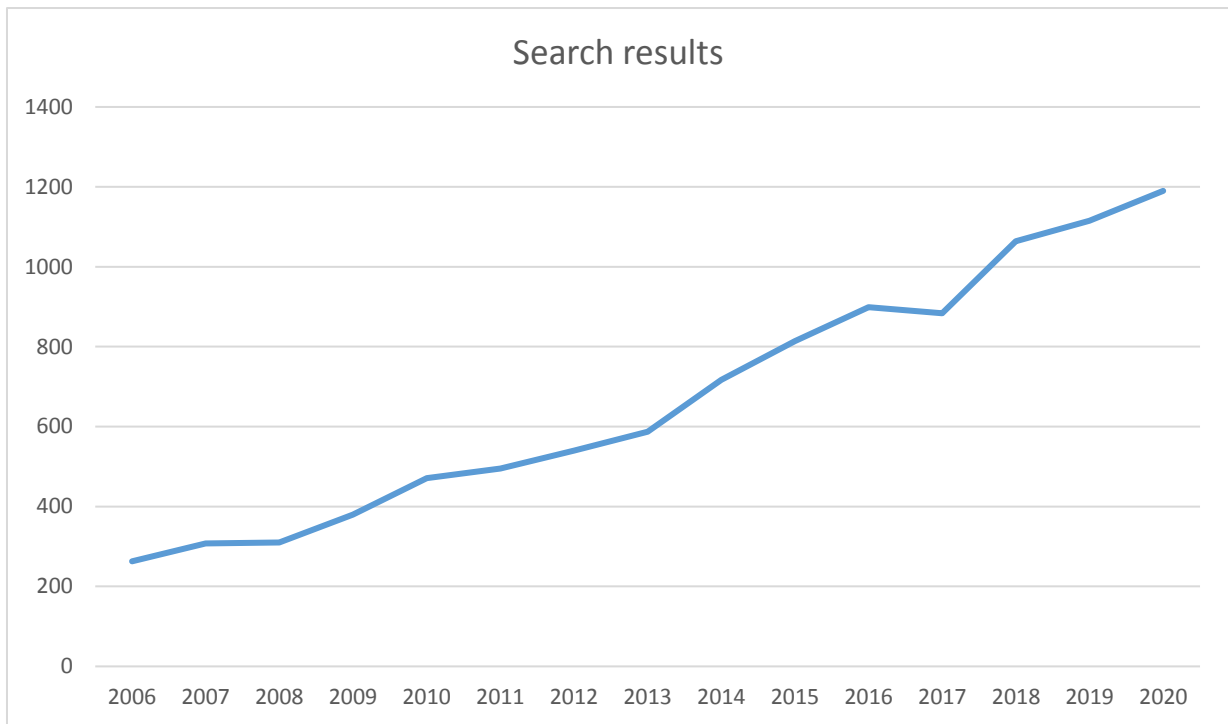


Figure 1. PubMed® search results by year for the search string: ("climate change" OR pollution OR deforestation OR "global warming ") AND ("mental health" OR "mental illness" OR psych\*). The growth is approximately linear with a slope of 68.6.

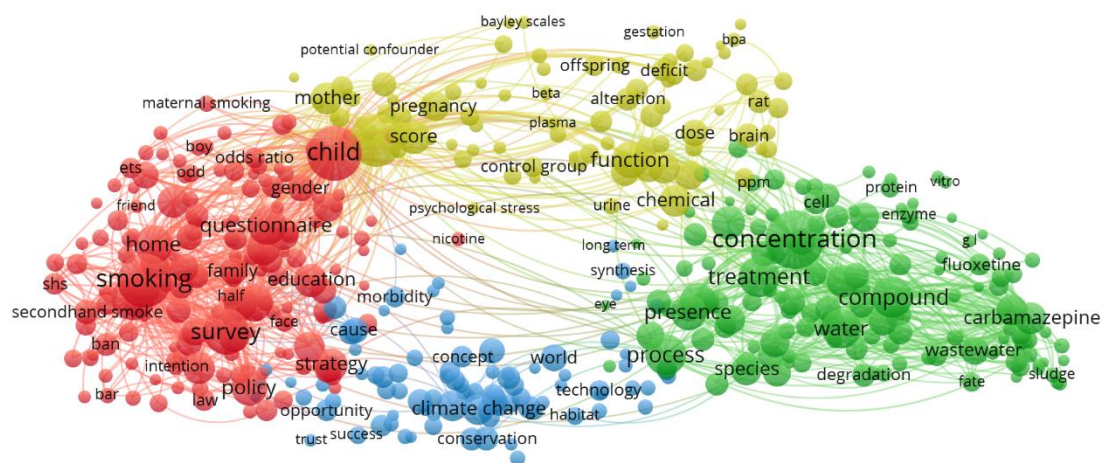


Figure 2. Co-occurrence network of relevant terms from PubMed®-listed publications on mental health and climate change, pollution and deforestation from 2006 to 2010.

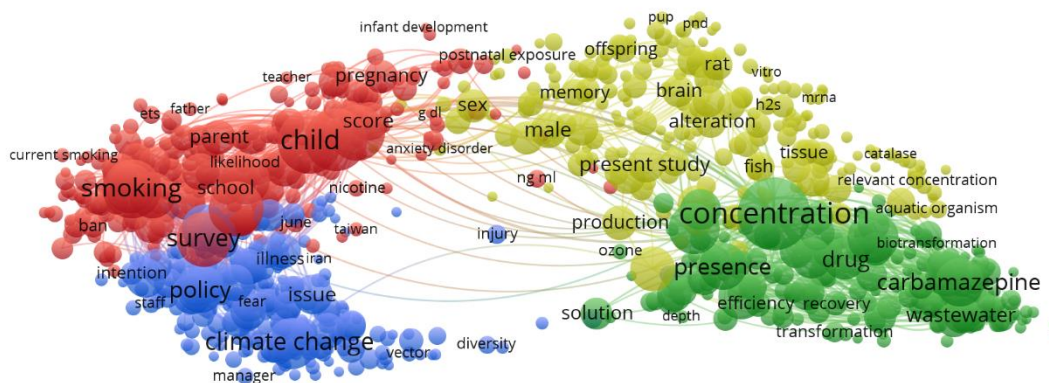


Figure 3. Co-occurrence network of relevant terms from PubMed®-listed publications on mental health and climate change, pollution and deforestation from 2011 to 2015.

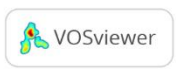
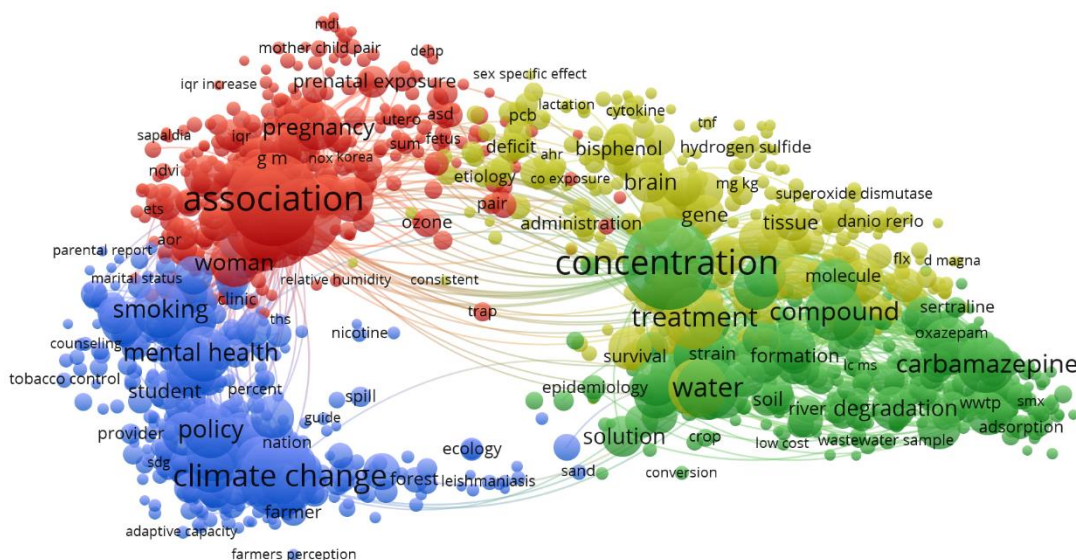
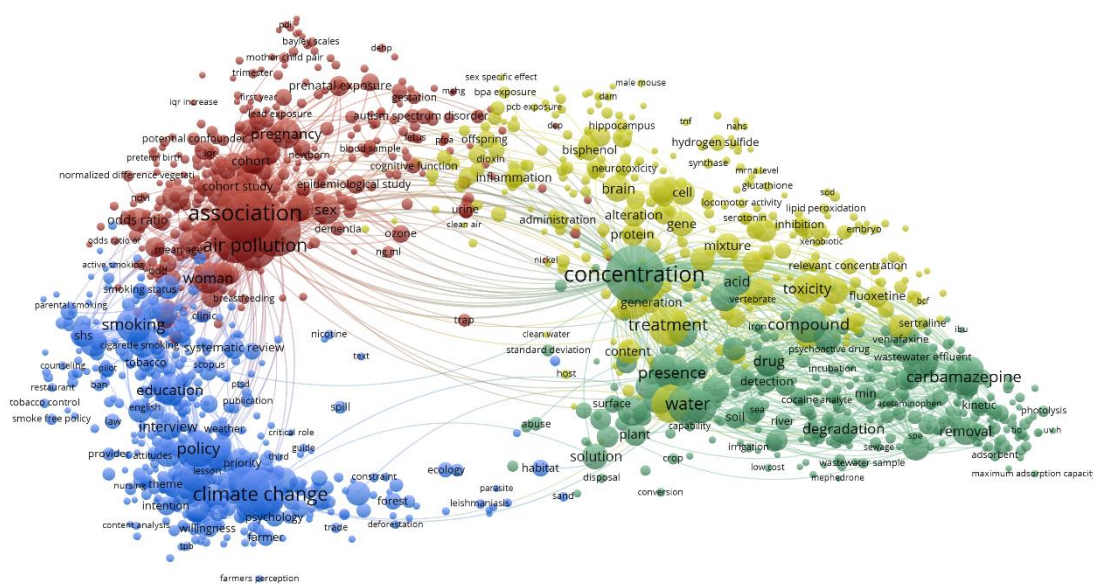


Figure 4. Co-occurrence network of relevant terms from PubMed®-listed publications on mental health and climate change, pollution and deforestation from 2016 to 2020.



Appendix 1. Co-occurrence network of relevant terms from PubMed®-listed publications on mental health and climate change, pollution, deforestation and environmental degradation from 2016 to 2020.

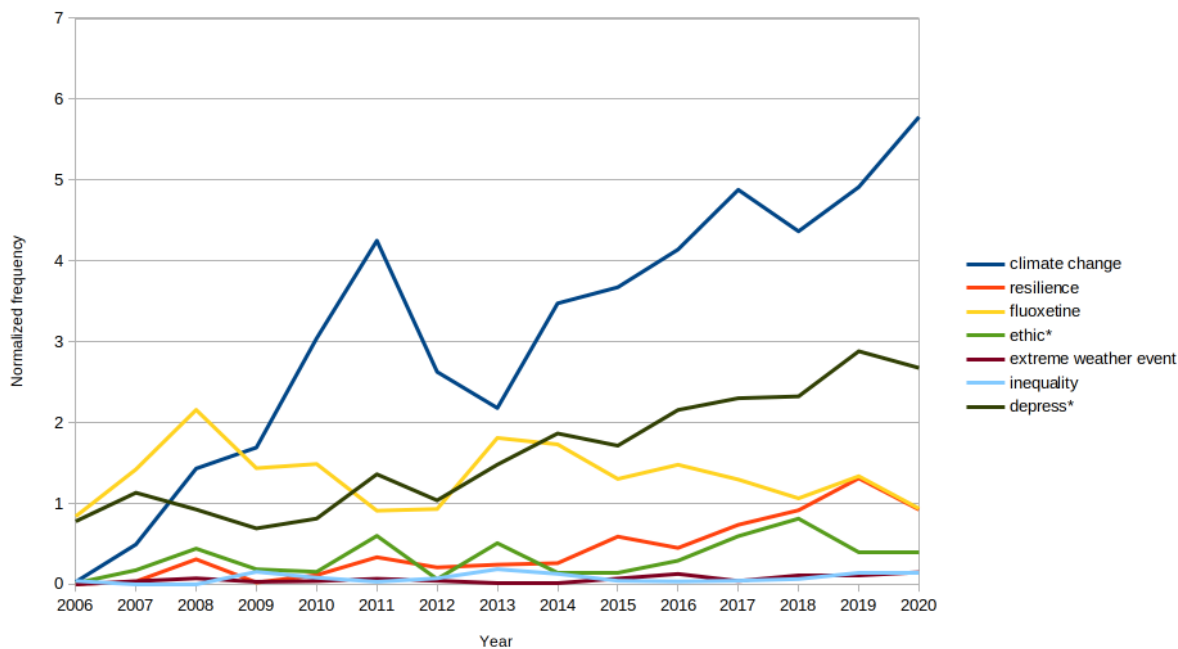


Figure 5. Normalized frequency of terms from PubMed®-listed publications on mental health and climate change, pollution and deforestation from 2006 to 2020.

(1) general environmental terms	climate change; pollution; resilience; species
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(2) chemical pollution	Fluoxetine; carbamazepine; bisphenol a; prenatal exposure; smoker; smoking; chemical; pollutant; hydrogen sulphide; CO exposure; wastewater sample; sludge
(3) extreme weather events	Drought; hurricane
(4) social impact and ethical issues	Attitudes; awareness; environmental justice; norms; inequality; poverty; low income country; migrant; social determinant; education; survival
(5) syndromes and diagnoses	Depression; attention deficit hyperactivity disorder; autism; Alzheimer; anxiety disorder

Appendix 2. List of exemplary terms in each major category.

	<b>2006-2010</b> <b>n=485 included terms</b>	<b>2011-2015</b> <b>n=892 included terms</b>	<b>2016-2020</b> <b>n=1,534 included terms</b>
1	concentration; n=263; 0.75	concentration; n=498; 0.55	association; n=828; 0.62
2	child; n=231; 0.48	child; n=382; 0.75	concentration; n=798; 0.25
3	smoking; n=221; 1.15	association; n=372; 0.52	climate change; n=593; 1.00
4	age; n=216; 0.41	smoking; n=330; 1.09	child; n=585; 0.60
5	survey; n=168; 0.77	age; n=307; 0.48	age; n=576; 0.49
6	smoker; n=144; 1.24	participant; n=295; 0.70	air pollution; n=508; 0.65
7	process; n=133; 0.32	survey; n=293; 0.75	water; n=381; 0.47
8	compound; n=129; 1.40	climate change; n=250; 0.94	treatment; n=375; 0.36
9	treatment; n=129; 0.57	compound; n=248; 1.04	species; n=335; 0.56
10	water; n=127; 1.09	treatment; n=245; 0.30	carbamazepine; n=316; 1.43
11	home; n=115; 1.04	smoker; n=239; 1.06	compound; n=312; 0.83
12	questionnaire; n=113; 0.67	carbamazepine; n=227; 1.63	presence; n=312; 0.35
13	intervention; n=111; 0.68	questionnaire; n=222; 0.68	pharmaceutical; n=309; 1.33
14	function; n=107; 0.54	presence; n=218; 0.38	policy; n=293; 0.91
15	policy; n=102; 0.87	intervention; n=215; 0.77	smoking; n=292; 0.90
16	range; n=100; 0.41	policy; n=213; 0.88	mental health; n=287; 0.75
17	presence; n=100; 0.33	water; n=208; 0.67	score; n=272; 0.63
18	prevalence; n=88; 0.63	home; n=199; 0.99	perception; n=260; 0.96
19	education; n=88; 0.54	pharmaceutical; n=188; 1.56	experiment; n=257; 0.54
20	score; n=86; 0.38	species; n=188; 0.53	practice; n=244; 0.82
21	interview; n=85; 0.77	drug; n=176; 0.92	present study; n=242; 0.30
22	mechanism; n=84; 0.65	perception; n=165; 0.83	education; n=236; 0.74



23	strategy; n=84; 0.44	experiment; n=160; 0.70	woman; n=232; 0.58
24	mother; n=83; 0.65	pollutant; n=160; 0.35	home; n=226; 0.81
25	carbamazepine; n=82; 2.55	issue; n=155; 0.60	product; n=212; 0.29
26	drug; n=82; 1.19	attitude; n=154; 1.09	pregnancy; n=211; 0.73
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30	parent; n=78; 0.95	support; n=142; 0.84	experience; n=203; 0.83