

Research themes, trends and future priorities in the field of climate change and health

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About the Series

This Working Paper Series is a new publication of Integrated Research on Disaster Risk (IRDR), following the decision of the IRDR Scientific Committee in April 2019 to act to ‘Expand IRDR Network and Scientific Output’ (No. 5 of the IRDR Action Plan 2018-2020).

IRDR is an international scientific programme under co-sponsorship of the International Science Council (ISC) and United Nations Office for Disaster Risk Reduction (UNISDR) and with support from China Association for Science and Technology (CAST) and Chinese Academy of Sciences (CAS). Started in 2010, the Programme has been pioneering in the promoting international and interdisciplinary studies on DRR and has made its contributions through scientific publication and policy papers as well as dialogue toward shaping international agenda in the understanding disaster risks, bridging science and policy gaps and promoting knowledge for actions, all required in the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) and its top priorities. Over time, the scientific agenda of IRDR has attracted many international renowned expertise and institutions. IRDR community is now, institutionally speaking, characterized by its strong Scientific Committee and six thematic working groups, thirteen IRDR national committees (IRDR NCs) and one regional committee (IRDR RC), eighteen international centres of excellence (IRDR ICoEs), a group of some one hundred fifty Young Scientists (IRDR YS) and a broad partnership with national, regional and international institutions working for SFDRR.

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Team of IRDR-IPO

Research themes, trends and future priorities in the field of climate change and health

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Abstract

Climate change is one of the biggest threats to human living and health in the 21st century. Whilst a large number of papers have been published addressing the health impact of climate change, there is a lack of comprehensive bibliometric analysis in the crosscutting field. By analyzing 22,293 articles indexed in the Web of Science Database, this paper provides a summary of the major research themes, research trends and hot topics in the field of climate change and health. Suggestions, recommendations and future priorities identified by experts in the field of atmospheric sciences, epidemiology, public health, climate change, environmental sciences, and policy development are also provided to guide future research.

Keywords: climate change, health, bibliometric analysis, research trends, future priorities

Main Text

1 Introduction

Climate change is considered as the top risk in the next decades (WEF, 2022). On Dec 13, 2020, the United Nations (UN) secretary-general Antonio Guterres called all world leaders to declare a State of Climate Emergency until carbon neutrality is reached (UN, 2020). The impact of climate change has been noted for decades. The establishment of Intergovernmental Panel on Climate Change (IPCC) in 1988, with the objective to provide governments at all levels with scientific information for developing climate policies, marked the international consensus on the overwhelming negative impact of climate change. The adoption of Paris Agreement, Sendai Framework for Disaster Risk Reduction 2015 - 2030, and the Sustainable Development Goals of Agenda 2030 in 2015, marked the international commitment to combat climate change and adapt to its effects (UNFCCC, 2015; UNDRR, 2015; UN, 2015). Climate change affects all aspects of our lives, including marine, freshwater and terrestrial ecosystems and ecosystem services, water and food security, settlements and infrastructure, health and wellbeing, and economies and culture (IPCC, 2022). Reducing the complex, cascading and systemic risks induced by climate change are believed to be a key priority in the following decades, which requires strengthened disaster risk research and advanced risk-informed governance.

IPCC published assessment reports (AR) every 5 - 6 years, providing regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaption and mitigation, which have become the key documents to guide actions to combating climate change. The Lancet Countdown international project initiated in 2015, which focuses on tracking progress on health and climate change and supports by over 120 leading experts from academic institutions and UN agencies across the global, also published annual reports with summary of the public health impact of climate change, the consequences of delayed action and the health benefits of a robust response. While these reports provide terrific summary of the observed risks and potential threats, they provide little information regarding the whole picture of research in the field of climate change and health. In this paper, we try to summary the major research themes and identify research trends and hot topics in the field of climate change and health, through the bibliometric analysis of published scientific papers. We also provide suggestions and recommendation for future research.

The Integrated Research on Disaster Risk (IRDR) has taken the lead to develop a global research agenda of ‘A Framework for Global Science in Support of Risk-informed Sustainable Development and Planetary Health’ (IRDR, 2021), to guide impactful international disaster risk research and its funding. As a support to the new global research agenda Research Priority 1 ‘Understand risk creation and perpetuation in the

contemporary risk landscape’, this paper provides a summary of current research on the health risks of climate change, their evolving trends, and future priorities.

2 Research themes and trends

2.1 Methods

Research themes and trends were obtained based on the bibliometric analysis of scientific papers included in the Web of Science Core Collection (WOSCC) database (<https://www.webofscience.com/wos/woscc/basic-search>) with default time frame setting (1990-present), accessed through Fudan University, China on 2nd Nov, 2021.

Step 1: Paper screening

Papers related to climate change and health were screened by constraining ‘Topic’ and ‘Year Published’ in the WOSCC database with the following criteria, modified from the criteria used by the 2021 Report of the Lancet Countdown on Health and Climate Change (Romanello et al. 2021):

(Topic) "climat chang*" or "global warming*" or "green?house effect*" or "green?house gas*" or "GHG*" or "climat* cris?s" or "climat* variability" or "climat* induced" or "climat* warming*" or "green?house emission*" or "climat* scenario*" and (Topic) health* or illness* or infecti*or well?being* or death* or mortality or disease* and (Year Published) 1900-2020*

The screening rules returned a total of 35,552 records. The result was further narrowed to 27,776 records by selecting ‘Article’ as the ‘Document Type’ as original articles were believed to provide the first-hand analysis of the impact of climate change.

Step 2: Keywords collection

Amongst the 27,776 papers, only 22,293 papers contained keyword information in the WOSCC record (‘Author Keyword’ as marked in the WOSCC record). A total of 48,230 keywords were collected. The majority of the keywords (85.3%) appeared less than 3 times, indicating that there is no consensus on the selection of keywords in the field of climate change and health. This also suggests that the research focus in the field of climate change and health varied significantly.

The 48,230 keywords were pre-treated before analysis by combining those with the same meaning but different word forms, such as singular and plural (e.g., model and models), British English and American English (e.g. urbanization and urbanisation), hyphens (e.g. heat-wave and heatwave), abbreviations (e.g. particulate matter and PM), using OpenRefine Software (<https://openrefine.org>). After pre-treatment, the number of keywords was reduced to 44,893. Those 14 keywords (climate change, climate change

scenarios, climate scenarios, climate variability, climate warming, death, disease, global warming, greenhouse effect, greenhouse gas emissions, greenhouse gases, health, mortality, well-being), which were used for paper screening and did not provide any information regarding research theme, were excluded in the analysis.

Step 3: Keyword clustering and research theme extraction

Research themes in the field of climate change and health were derived from social network analysis of keyword co-occurrence using VOSviewer Software (version 1.6.17, <https://www.vosviewer.com>). 1,673 keywords with a frequency of at least 10 (≥ 10), covering 19,886 papers (89.2% of the papers including keywords information) were selected in the analysis. The co-occurrence analysis divided keywords into 9 clusters, indicating the presence of 9 main research themes. Detailed information of 9 research themes were presented in the following section.

Step 4: Research trend analysis

The research trend in the field of climate change and health was derived based on the change in the keyword frequency and the number of papers within 9 research themes in the past 30 years (1991 - 2020). The significance of the research trend was analyzed based on non-metric multidimensional scaling (NMDS) analysis using PAST V3 software (Hammer et al. 2001).

2.2 Research themes

The social network visualization based on keyword co-occurrence analysis divided the 1673 keywords into 9 clusters, marked with difference colors (Fig 1). Each cluster corresponded to one research theme.

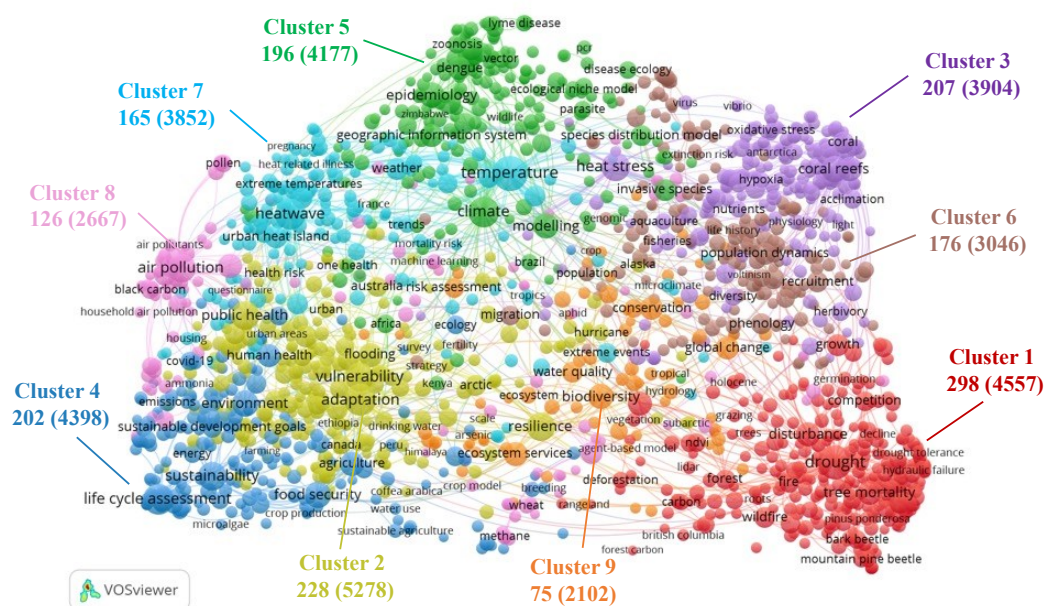


Fig 1 Social network map derived from VOSviewer Software based on the co-occurrence analysis of 1673 keywords (frequency ≥ 10) in the field of climate change and health. 9 clusters are differentiated by color. The numbers next to each cluster represent of number of keywords within the cluster (outside the brackets) and the number of research articles associated with these keywords (inside the brackets). The size of the nodes represents the frequency of the keyword and the line connected two nodes represents the frequency of the co-occurrence of two keywords in the same paper.

2.2.1 Research theme 1 (cluster 1)

There is a total of 298 keywords (associated with 4,557 research articles) belongs to research theme 1, marked in red color in Fig 1. The top 20 keywords with high frequency of occurrence in this cluster are drought (715), tree mortality (213), remote sensing (206), disturbance (204), growth (142), tree rings (127), wildfire (115), fire (104), competition (103), forest management (103), dendrochronology (101), forest (99), NVDI (90), bark beetle (88), dendroecology (83), photosynthesis (78), biomass (76), carbon sequestration (74), MODIS (73), water stress (73). This research theme mainly focuses on the impacts of drought and its derived disasters (such as fire and wildfire) on the forest and vegetation (e.g. tree mortality, growth, biomass, carbon sequestration). The representative keyword for this theme is ‘drought’.

The change of top10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 2 to show the change of hot research topics. ‘Drought’ was the top keyword at each time interval, suggesting it was the central focus of this research theme. The rank of ‘remote sensing’ increased from the 5th during 2006 - 2010 to the 2nd during 2016 - 2020, indicating it’s a frequently used method in this research theme and it’s highly likely to be an important or hot method for further researches. ‘Wildfire’ is the only new keyword that ranked top 10 during 2016 - 2020, corresponding with the significantly increased wildfire events in the recent years. This suggests that the linkage between climate change, wildfire and health has received great attention. Considering wildfire events are highly likely to increase in the future (UNEP, 2022), this topic might become an emerging research focus of this theme in the near future.

2.2.2 Research theme 2 (cluster 2)

There is a total of 228 keywords (associated with 5,278 research articles) belongs to research theme 2, marked in yellow color in Fig 1. The top 20 keywords with high frequency of occurrence in this cluster are adaptation (573), vulnerability (374), resilience (351), public health (350), flooding (193), climate change adaptation (151), arctic (130), environmental health (130), mitigation (125), risk (118), Australia (111), risk perception (110), policy (103), disaster (91), mental health (91), Canada (88), Bangladesh (87), perception (87), impacts (80), climate change impacts (78). This research theme is about climate change risk assessment and adaptation, with major focus on aspects including adaptation, vulnerability and resilience. The representative keyword for this theme is ‘risk assessment and adaptation’.

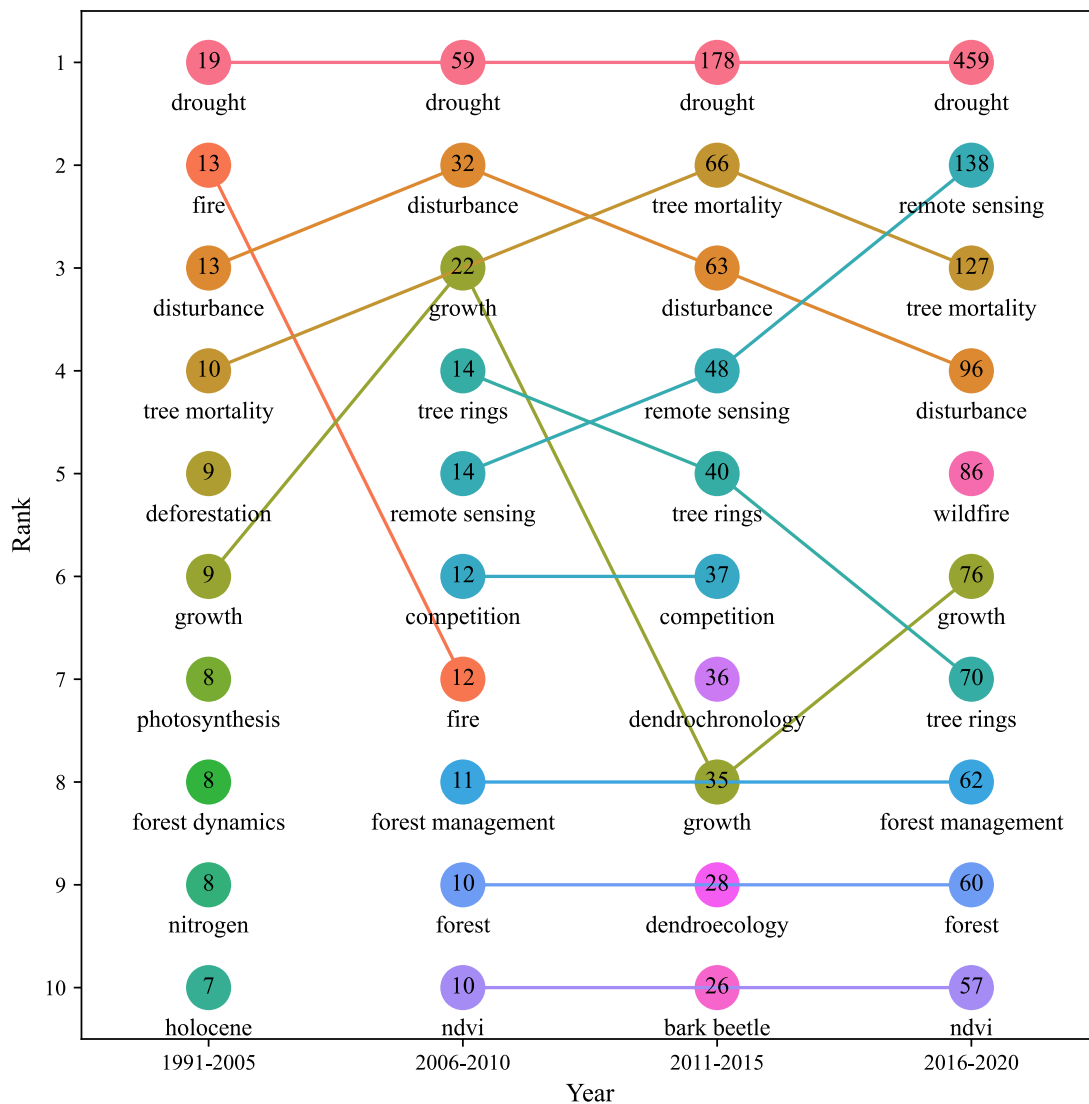


Fig 2 The change of top 10 keywords of with high frequency of occurrence in research theme 1 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

The change of top10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 3 to show the change of hot research topics. ‘Adaptation’ was the top keyword at each time interval. ‘Vulnerability’ and ‘resilience’ remained in the top 4 at all time intervals. The rank of ‘resilience’ increased from the 4th during 2006 - 2010 to the 2nd during 2016 - 2020. These suggested that adaptation, vulnerability and resilience were the central focus of this research theme. ‘Public health’ was the other top 4 keywords during the whole time period, indicating that public health was the major concern and goal for climate change risk governance. The rank of ‘flooding’ increased from the 9th during 1991 - 2005 to the 5th during 2011 - 2020, implying that flooding is one of the key risks threatening public health and has attracted more and more attention in the past 30 years.

‘Environment health’ was a new keyword that ranked top 10 during 2016 - 2020, revealing that risk interconnectivity between climate change, environment and health has become a new focus in the past few years. ‘Risk perception’ and ‘perception’ were also new keywords that ranked top 10 during 2016 - 2020, reflecting that the public’s risk perception has been noted as the key factors determining the effectiveness of risk governance. Researches related to these topics are anticipated to be future hotspots.

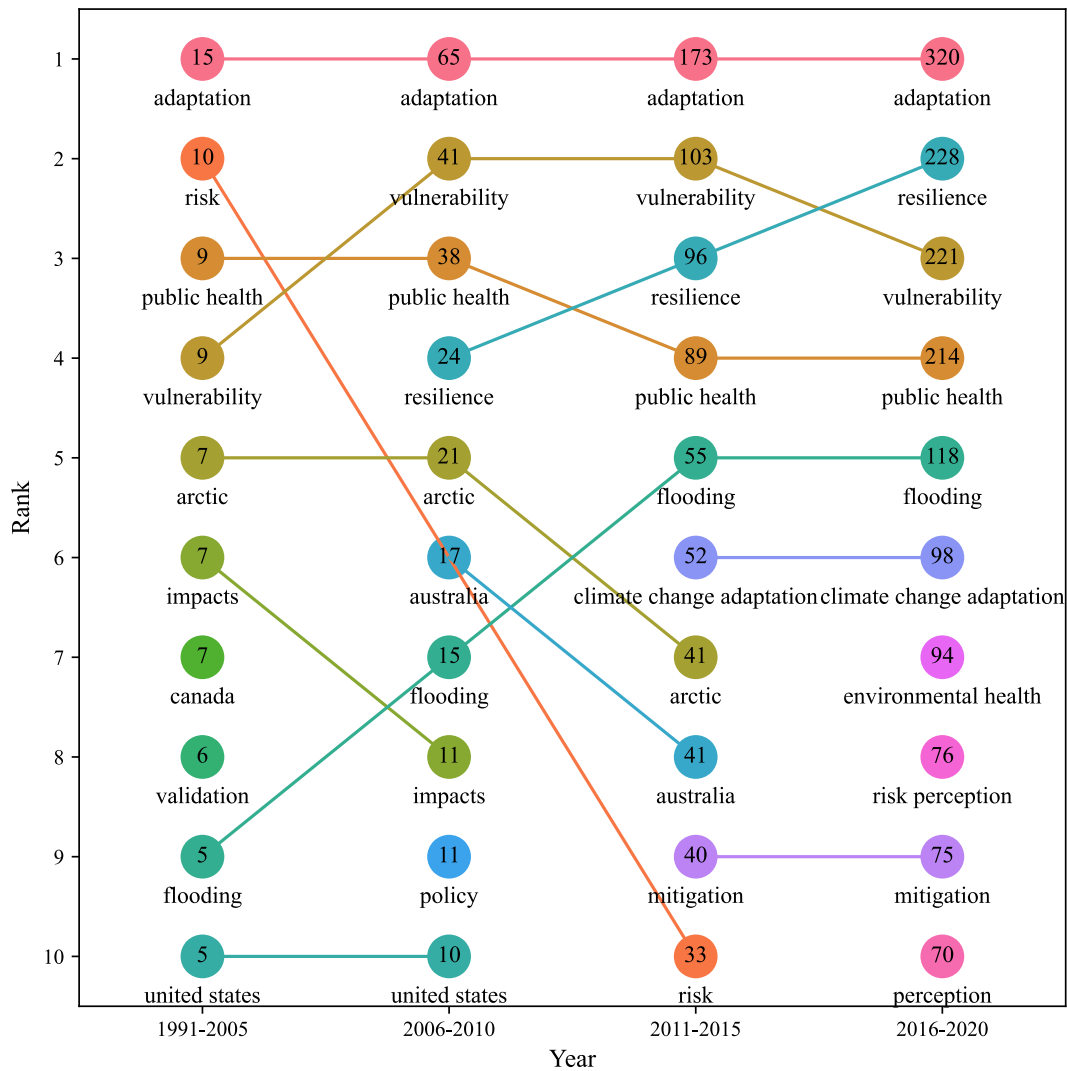


Fig 3 The change of top 10 keywords of with high frequency of occurrence in research theme 2 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

2.2.3 Research theme 3 (cluster 3)

There is a total of 207 keywords (associated with 3904 research articles) belongs to research theme 3, marked in purple color in Fig 1. The top 20 keywords with high frequency of occurrence in this cluster are heat stress (369), coral reefs (292), coral bleaching (203), ocean acidification (146), coral (140), global climate change (110), ENSO (106), bleaching (103), salinity (80), El Nino (80), eutrophication (79), acclimation (78), herbivory (78), fisheries (74), recovery (73), sea level rise (72), sea surface temperature

(71), multiple stressors (70), cyanobacteria (66), stress (65). This research theme mainly focuses on the impact of global warming on marine biota (especially coral reefs) and ocean circulation. The representative keyword for this theme is ‘ocean’.

The change of top10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 4 to show the change of research topics. ‘Heat stress’ due to global warming has become the major focus in the recent years, of which the rank increased from the 4th during 1991 - 2005 to the 1st during 2011 - 2020. The impact of climate change on coral reefs has received much attention, with keywords including ‘coral reefs’, ‘coral bleaching’, ‘coral’, ‘bleaching’ being top10 keywords. This suggested that coral reef is a very good indicator for monitoring the impact of climate change on marine biota. ‘Acclimation’ and ‘recovery’ were new keywords that ranked top10 during 2016 - 2020, implying that research on acclimation and recovery of marine biota may be an emerging focus of this research theme in the future. ‘Salinity’ was also a new keyword that ranked top10 during 2016 - 2020, indicating that in addition to ocean acidification, changing salinity has become a key channel through which climate change affect marine biota. ‘Fishery’ was also a new keyword that ranked top10 during 2016 - 2020, suggesting that the impact of climate change on fishery has become a new focus in the recent years.

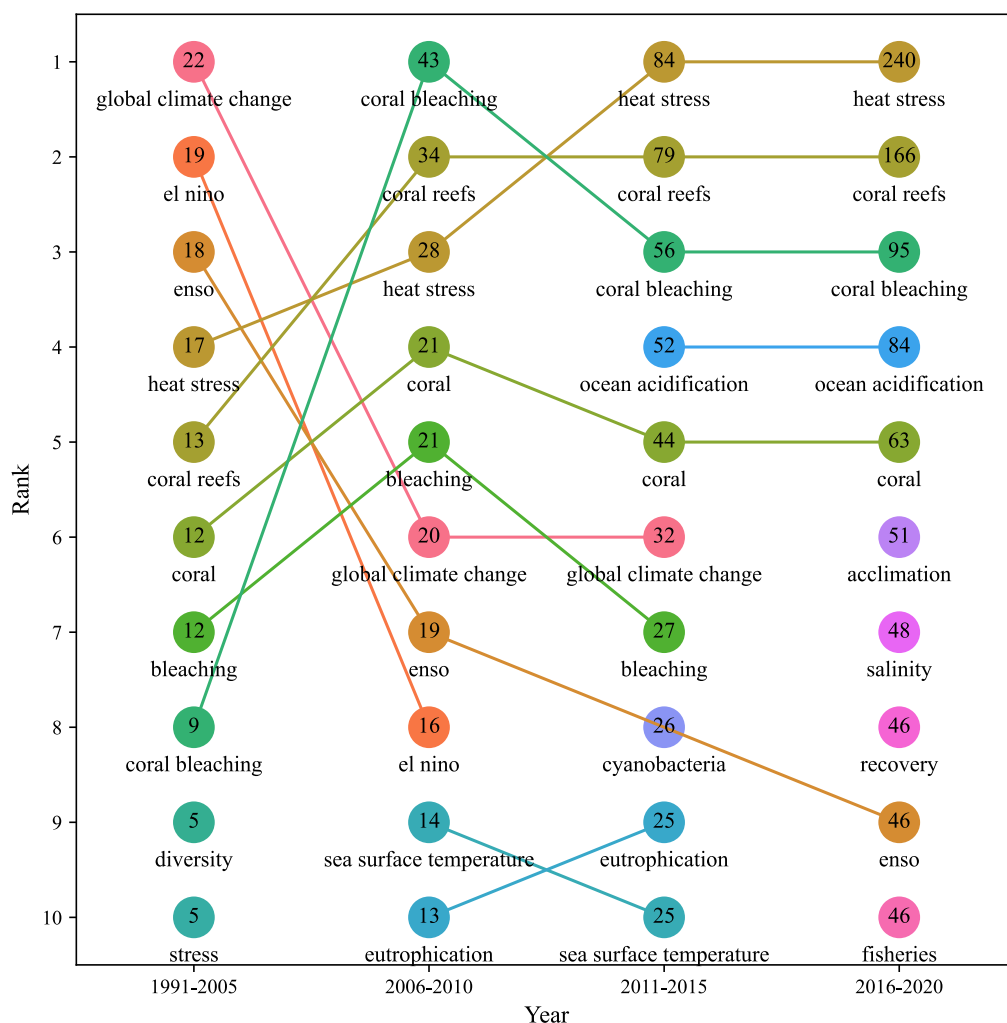


Fig 4 The change of top 10 keywords of with high frequency of occurrence in research theme 3 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

2.2.4 Research theme 4 (cluster 4)

There is a total of 202 keywords (associated with 4398 research articles) belongs to research theme 4, marked in blue color in Fig 1. The top 20 keywords with high frequency of occurrence in this cluster are life cycle assessment (465), sustainability (358), environment (277), food security (266), agriculture (192), human health (186), environmental impact (170), sustainable development (169), pollution (105), sustainable development goals (99), land use (94), ecology (93), covid-19 (89), India (89), nutrition (89), water (80), energy (75), renewable energy (74), carbon footprint (70), livestock (68). This research theme mainly explores the threats and paths of sustainable development in the context of climate change, with special focus on food, water, energy and environment. The representative keyword for this theme is ‘sustainable development’.

The change of top 10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 5 to show the change of hot research topics. Studies on sustainability and sustainable development increased dramatically in the past 30 years. The sustainable development goals (SDGs) adopted by the United Nations in 2015 has become the new guide for researches in this research theme, marked as ‘sustainable development goal’ being one of new keywords that ranked top 10 during 2016 - 2020. ‘Life cycle assessment’ is a key method for assessing sustainability and its rank increased from the 2nd during 1991 - 2010 to the 1st during 2011 - 2020. It is believed to continue to be a key method in this research theme. Although started in 2020, ‘covid-19’ ranked the 10th during 2016 - 2020, revealing its high impact on the sustainable development.

2.2.5 Research theme 5 (cluster 5)

There is a total of 196 keywords (associated with 4,177 research articles) belongs to research theme 5, marked in green color in Fig 1. The top 20 keywords with high frequency of occurrence in this cluster are climate (468), epidemiology (231), modelling (226), malaria (185), dengue (165), geographic information system (164), vector-borne disease (156), invasive species (154), species distribution model (128), infectious disease (123), mosquito (109), seasonality (92), Africa (89), zoonosis (86), Europe (80), vector (76), ticks (73), parasite (69), disease ecology (67), arbovirus (67). This research theme focuses on the impact of climate change on the distribution and transmission of infectious diseases. The representative keyword for this theme is ‘infectious disease’.

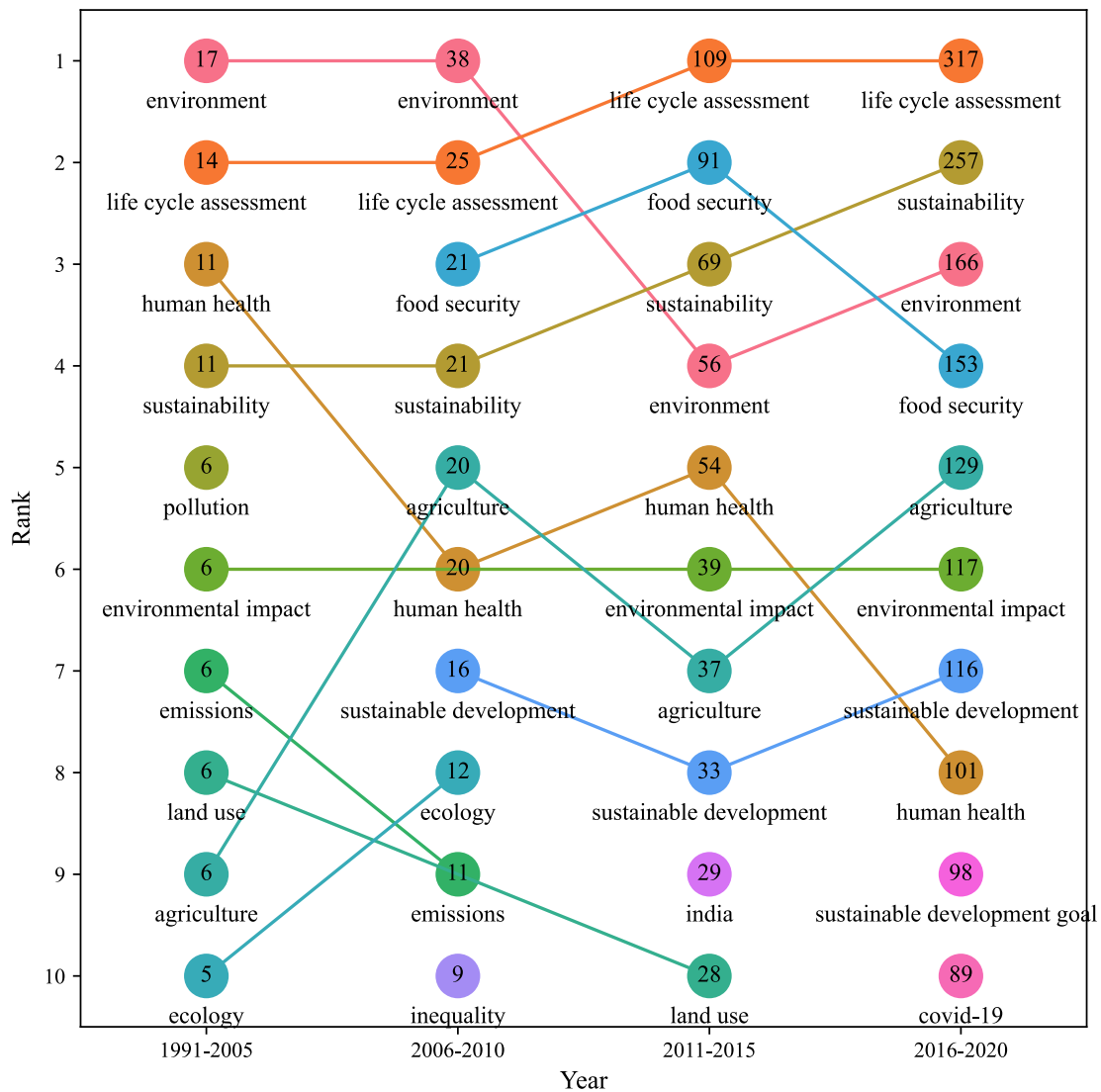


Fig 5 The change of top 10 keywords of with high frequency of occurrence in research theme 4 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

The change of top 10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 6 to show the change of hot research topics. Epidemiological investigation and modeling are the main methods to investigate the occurrence, development and transmission of infectious disease. The rank of ‘epidemiology’ and ‘modelling’ remained in top 4 at all time periods. Disease ‘malaria’ and ‘dengue’ received most concerns, indicating they were most sensitive to climate and their spread and special attention should be paid to these two diseases in the context of climate change. ‘Infectious disease’ is the only new keyword that ranked top10 during 2016 - 2020, implying that the connection between infectious disease and climate change has been widely noted and received much attention in the recent years.

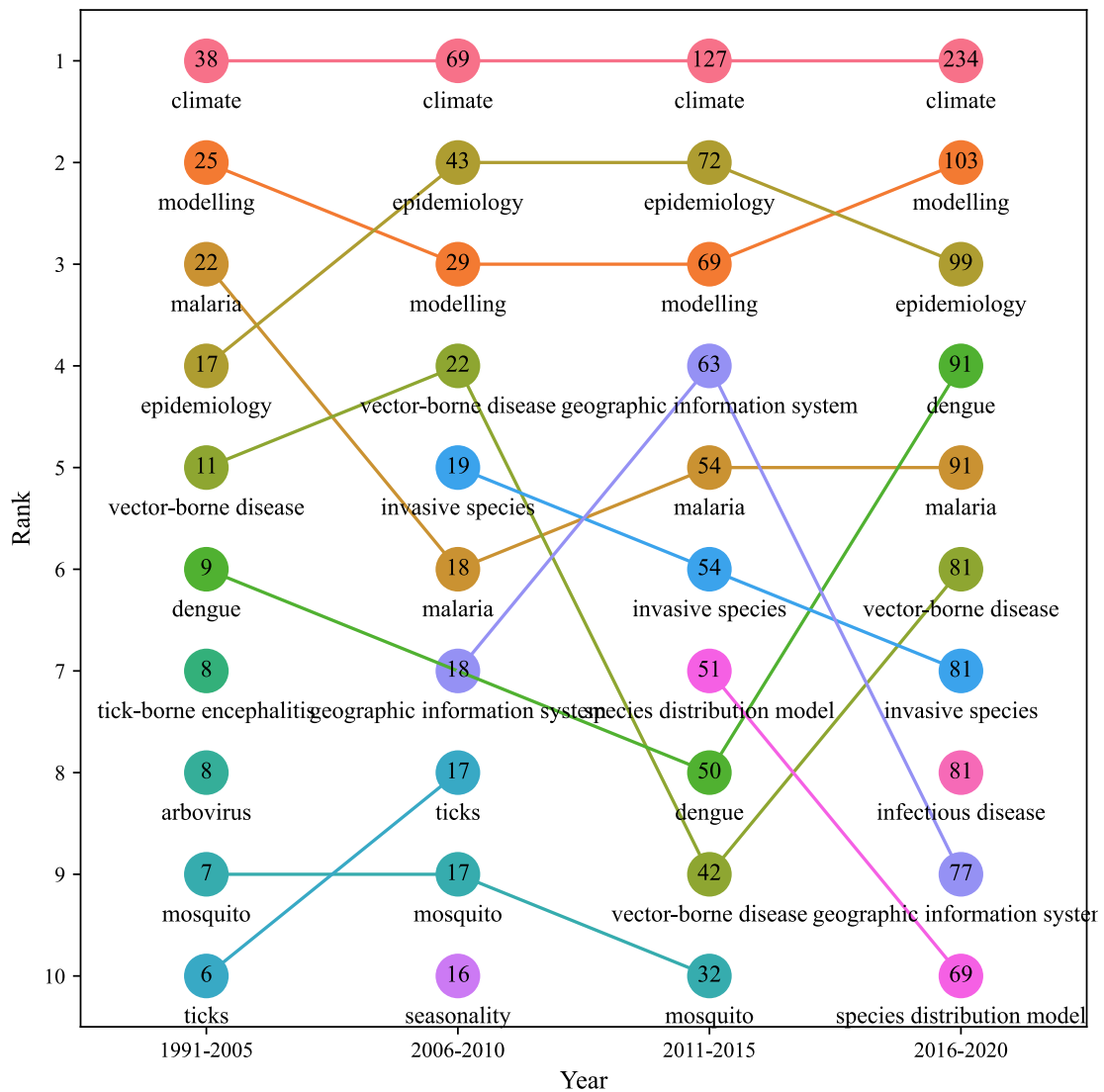


Fig 6 The change of top 10 keywords of with high frequency of occurrence in research theme 5 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

2.2.6 Research theme 6 (cluster 6)

There is a total of 176 keywords (associated with 3046 research articles) belongs to research theme 6, marked in brown color in Fig 1. The top 20 keywords with high frequency of occurrence in this cluster are population dynamics (152), phenology (135), recruitment (133), survival (126), migration (102), demography (92), pathogen (87), extinction (68), predation (64), reproduction (63), amphibians (61), amphibian declines (59), dispersal (59), biogeography (59), batrachochytrium dendrobatidis (57), local adaptation (56), phenotypic plasticity (56), density dependence (54), range expansion (54), population (52). This research theme mainly explores the impact of climate change on plants and animals at species-level (e.g. phenology, growth, reproduction) and population-level (e.g. migration, structure). The representative keyword for this theme is ‘phenology’.

The change of top 10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 7 to show the change of hot research topics. The rank of ‘phenology’ remained in top5 during all time periods and became the 1st during 2016 - 2020, revealing an increased focus on the impact of climate change on phenology. The impact of climate change on species’ survival and population’s migration were receiving increasing attention, with the rank of ‘survival’ reached the 2nd and the rank of ‘migration’ reached the 4th during 2016 - 2020. Another significant rise in the rank was noted for the keyword ‘pathogen’, from the 9th during 2006 - 2010 to the 5th during 2016 - 2020, suggesting that the effect on pathogen may be an important path through which the species and the population were affected by climate change. ‘Phenotypic plasticity’, ‘local adaption’ and ‘reproduction’ were new keywords that ranked top10 during 2016 - 2020, implying that species’ adaption ability has become a crucial factor determining their reproduction and survival in the context of climate change.

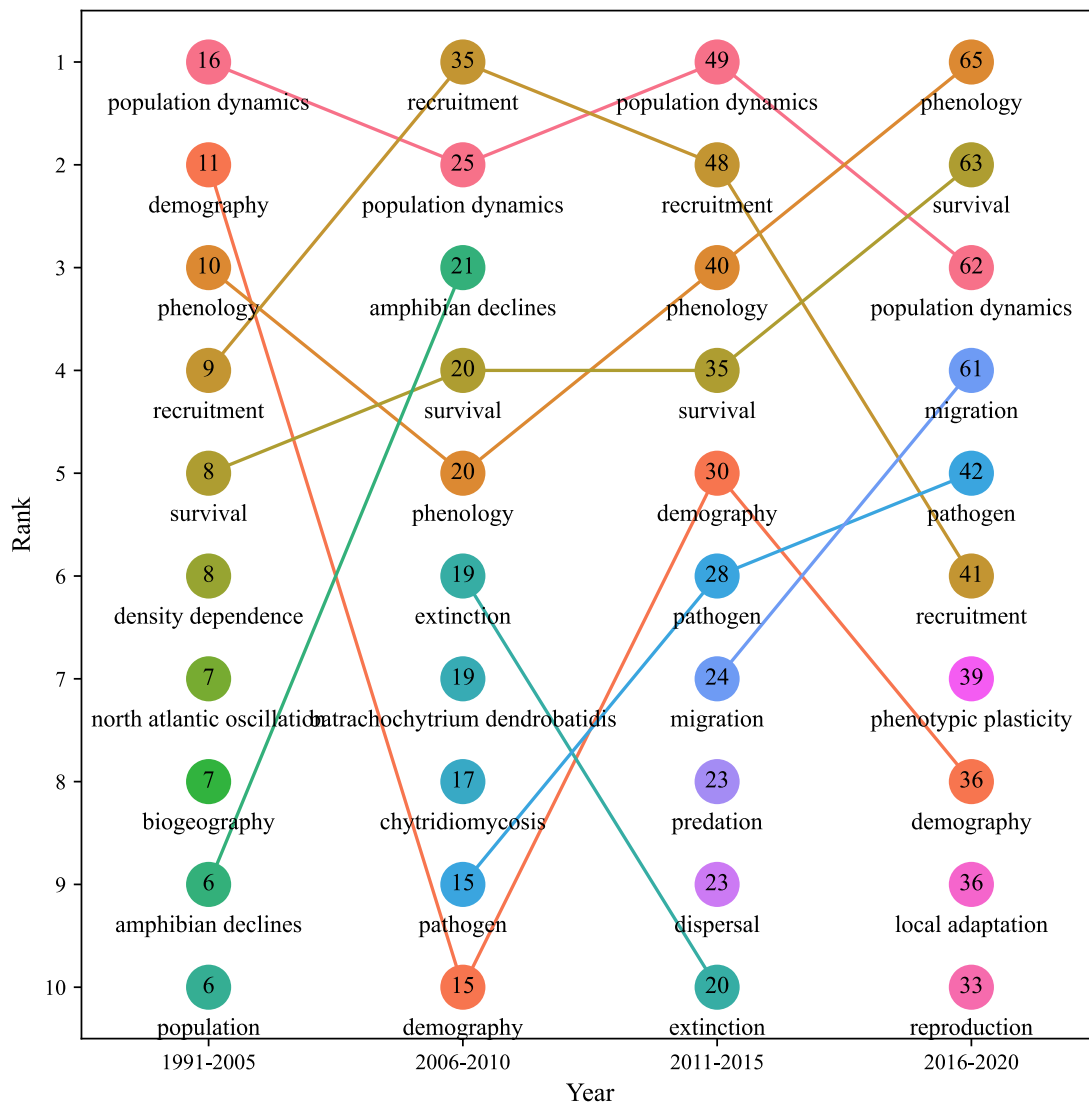


Fig 7 The change of top 10 keywords of with high frequency of occurrence in research theme 6 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

2.2.7 Research theme 7 (cluster 7)

There is a total of 165 keywords (associated with 3,852 research articles) belongs to research theme 7, marked in sky-blue color in Fig 1. The top 20 keywords with high frequency of occurrence in this cluster are temperature (789), heatwave (461), weather (146), urban heat island (141), heat (134), rainfall (128), precipitation (123), urbanisation (122), time series (100), extreme events (94), thermal comfort (86), extreme heat (84), South Africa (62), humidity (60), distributed lag non-linear model (59), productivity (56), children (56), urban planning (51), extreme temperatures (49), projection (48). This research theme mainly focuses on the risks associated with the extreme weather/climate events (especially heatwaves). The representative keyword for this theme is 'extreme heat'.

The change of top 10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 8 to show the change of hot research topics. 'Temperature' was the top keyword at each time interval, suggesting the change of temperature was the key cause for the health risks. Top10 keywords such as 'heatwave', 'heat', 'extreme heat' and 'thermal comfort' indicated that risks associated with heat (high temperature) was the one of the main focuses of this research theme and it is likely to continue to be the main focus in future studies. 'Urbanisation' was the only new keyword that ranked top10 during 2016 - 2020, implying the linkage of rapid urbanisation and the impact of extreme events at cities were receiving more attention in the recently years.

2.2.8 Research theme 8 (cluster 8)

There is a total of 126 keywords (associated with 2,667 research articles) belongs to research theme 8, marked in pink color in Fig 1. The top20 keywords with high frequency of occurrence in this cluster are air pollution (367), China (207), carbon dioxide (148), air quality (137), ozone (127), pm (107), black carbon (82), health impacts (81), co-benefits (72), pollen (66), climate change mitigation (62), pm2.5 (60), asthma (58), energy efficiency (47), wheat (46), health impact assessment (45), methane (42), health effects (42), allergy (42), climate impacts (41). This research theme explores the health impacts of air pollution (especially particulate matter, ozone) and the interaction between air pollution events and local climate. The representative keyword for this theme is 'air pollution'.

The change of top 10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 9 to show the change of hot research topics. 'Air pollution' was the top keyword at all time period. The rank of 'air quality' increased from the 7th during 2006 - 2010 to the 3rd during 2016 - 2020. These suggested that air pollution/quality was the central focus of this research theme. The rank of 'China' increased dramatically from the 7th during 1991 -

2005 to the 2nd during 2016 - 2020, revealing that the air pollution/quality problem in China are receiving increasing attention. Top 10 keywords including particulate matter ('pm' and 'pm2.5'), ozone and black carbon indicated these were the major pollutants inducing health concerns. 'Co-benefits' was a new keyword ranked top 10 during 2016 - 2020, showing that the coordinated action of climate mitigation and air quality control has attracted much attention in the recent years.

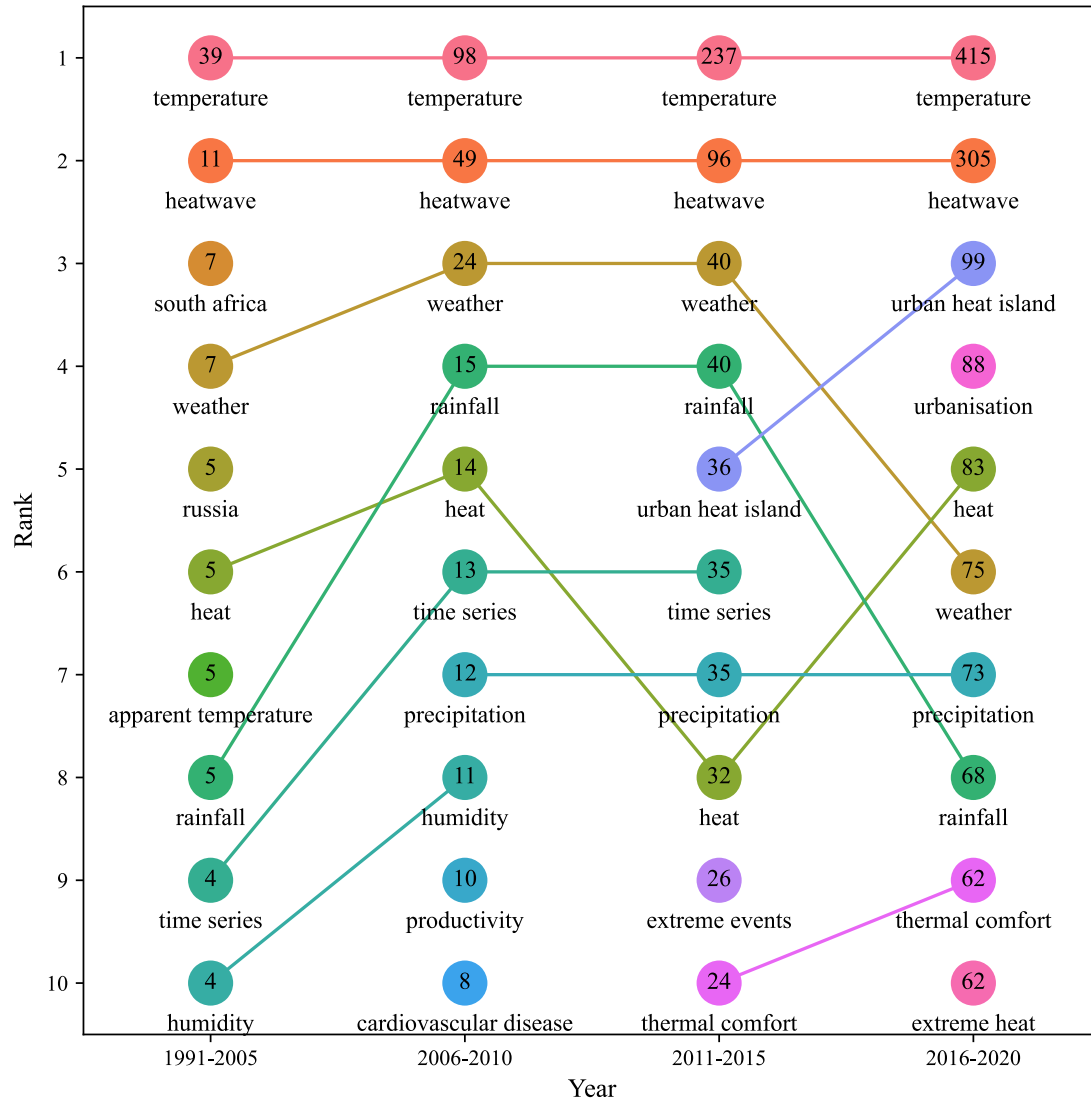


Fig 8 The change of top 10 keywords of with high frequency of occurrence in research theme 7 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

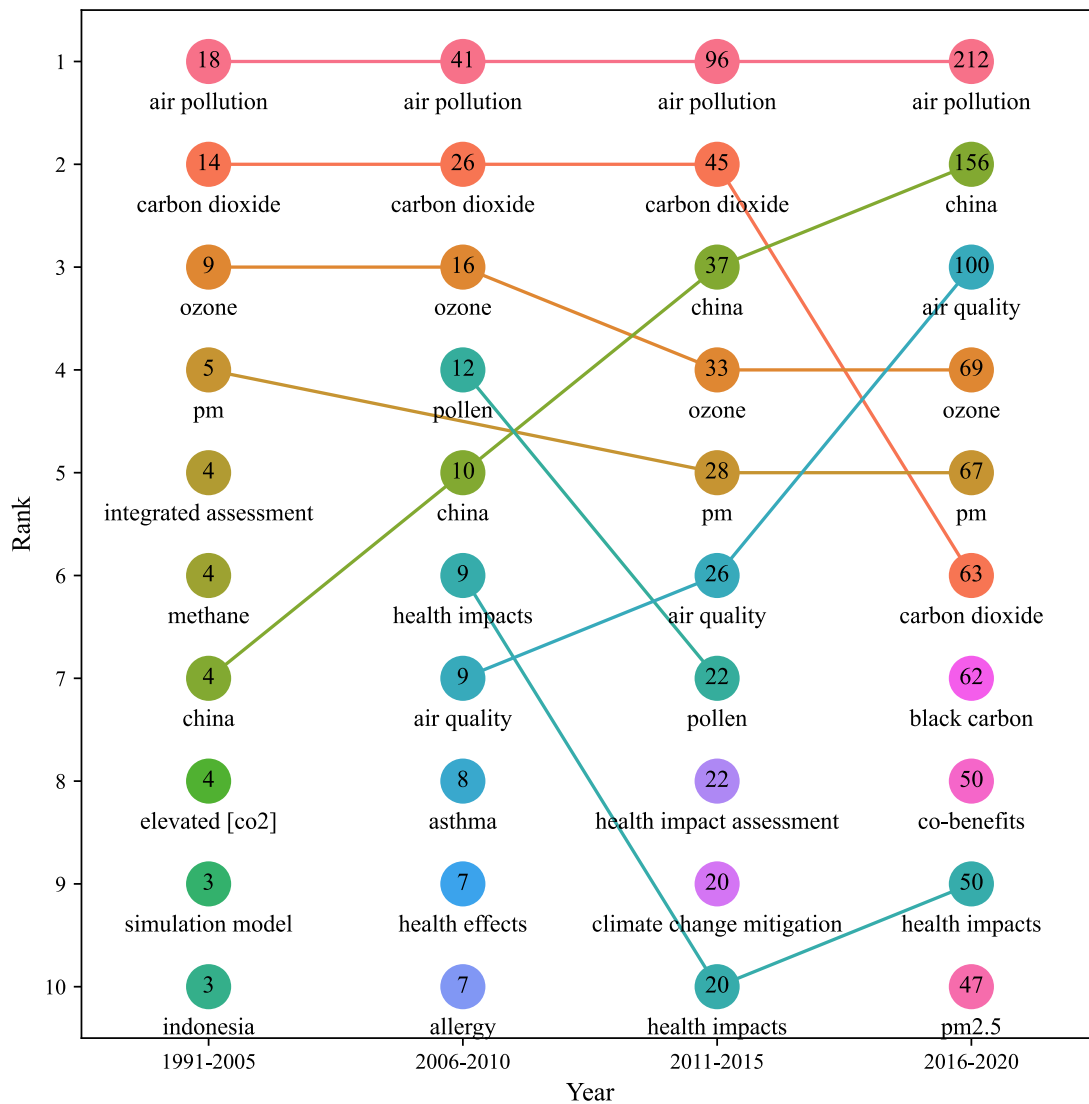


Fig 9 The change of top 10 keywords of with high frequency of occurrence in research theme 8 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

2.2.9 Research theme 9 (cluster 9)

There is a total of 75 keywords (associated with 2,102 research articles) belongs to research theme 9, marked in orange color in Fig 1. The top 20 keywords with high frequency of occurrence in this cluster are biodiversity (226), ecosystem services (195), global change (182), conservation (165), water quality (126), risk assessment (103), monitoring (92), management (86), land use change (63), wetlands (57), simulation (57), ecosystem (54), groundwater (46), water temperature (41), hydrology (39), ecosystem health (38), grassland (36), adaptive management (36), water management (34), water resources (32). This research theme is mainly about the impact of ecosystem function loss and biodiversity reduction caused by anthropogenetic activities (especially land use change) in the context of climate change. The representative keyword for this theme is ‘ecosystem change’.

The change of top 10 keywords with high frequency of occurrence at four different time intervals (1991 - 2005, 2006 - 2010, 2011 - 2015, 2016 - 2020) is illustrated in Fig 10 to show the change of hot research topics. 'Ecosystem services', 'biodiversity' and 'conservation' remained in the top 4 during 2011 - 2020, highlighting the importance of maintaining ecosystem services through biodiversity conservation. 'Water quality' was another main focus of this research theme. The impact of 'land use change' and the impact on 'groundwater' became important focuses in recent years, making them the new keywords ranked top 10 during 2016 - 2020.

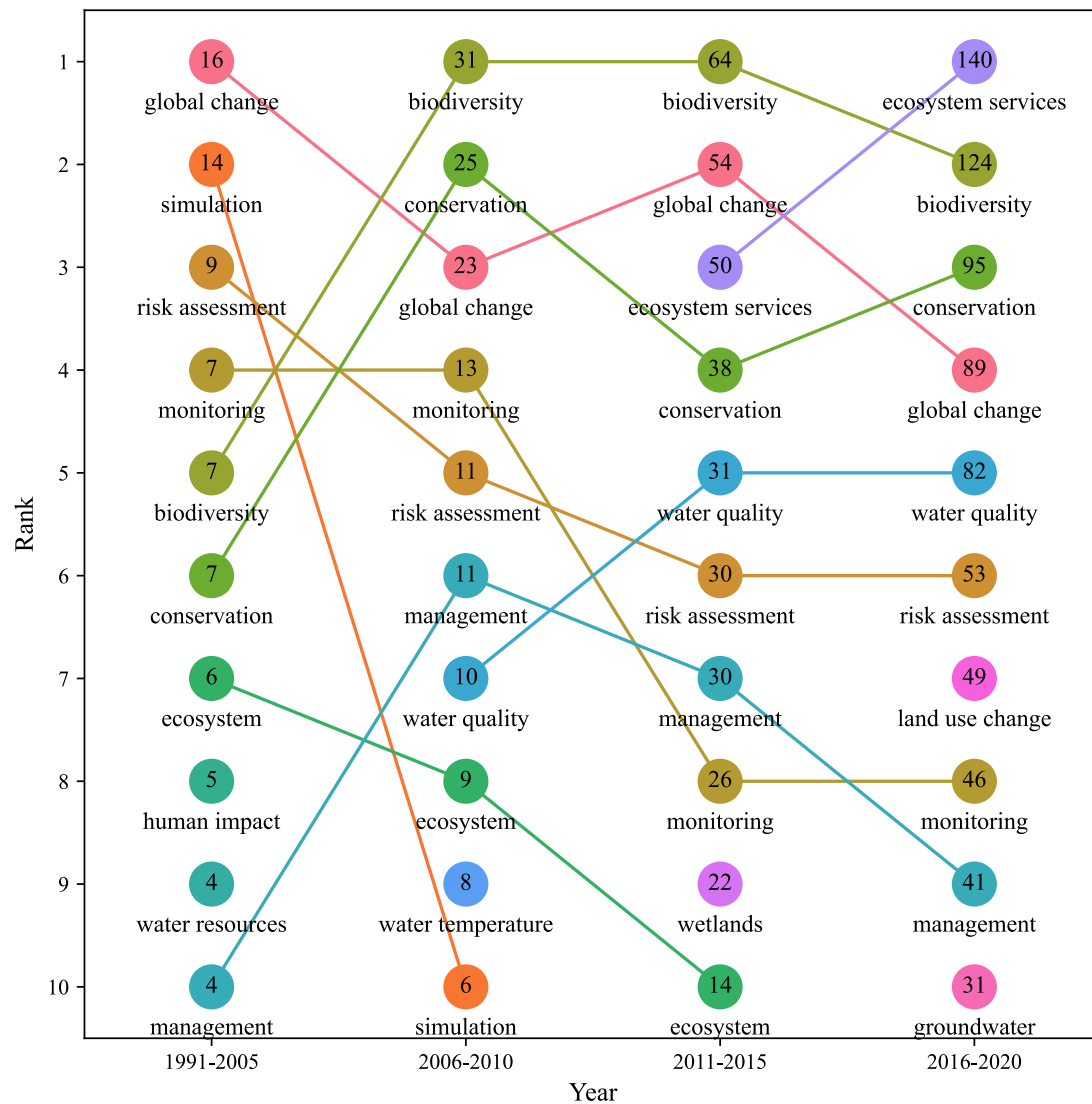


Fig 10 The change of top 10 keywords of with high frequency of occurrence in research theme 9 during 4 time periods. The number within the circle indicates the occurrence of the keyword underneath the circle.

2.3 Research trends

2.3.1 Overall trend of publication number

A total of 27,776 research articles published between 1900 - 2020 in the WOSCC belonged to the field of climate change and health. Only 3 papers were published before

1990 (Hirst and Stedman, 1960; Coakley, 1979; Post, 1984). Since 1990, the number of papers began to increase exponentially (Fig 11), marking the dramatic rise of studies in the field of climate change. Three distinct stages of development were noticed. At the first stage (1990 - 2006), the number of research articles increased slowly, with an increasing rate of approximately 16 papers each year. The increasing rate was 10 times higher at the second stage (2007 - 2014) compared to the first stage, with approximately 162 more papers each year. The number of research articles exceeded 1000 per year since 2011. In the third stage (2015 - 2020), the increasing rate became as high as 441 paper per year. In 2020, the number of research articles in the field of climate change reached 4484. To be noted, the time nodes of three stages coincide with the release of Intergovernmental Panel on Climate Change assessment reports (IPCC-AR, IPCC-AR1 in 1990, IPCC-AR4 in 2007 and IPCC-AR5 in 2014). This suggested that the Intergovernmental Panel on Climate Change (IPCC) significantly promoted the development of the field of climate change and health. The recent release of IPCC-AR6 is anticipated to further stimulate the increase of researches in this field.

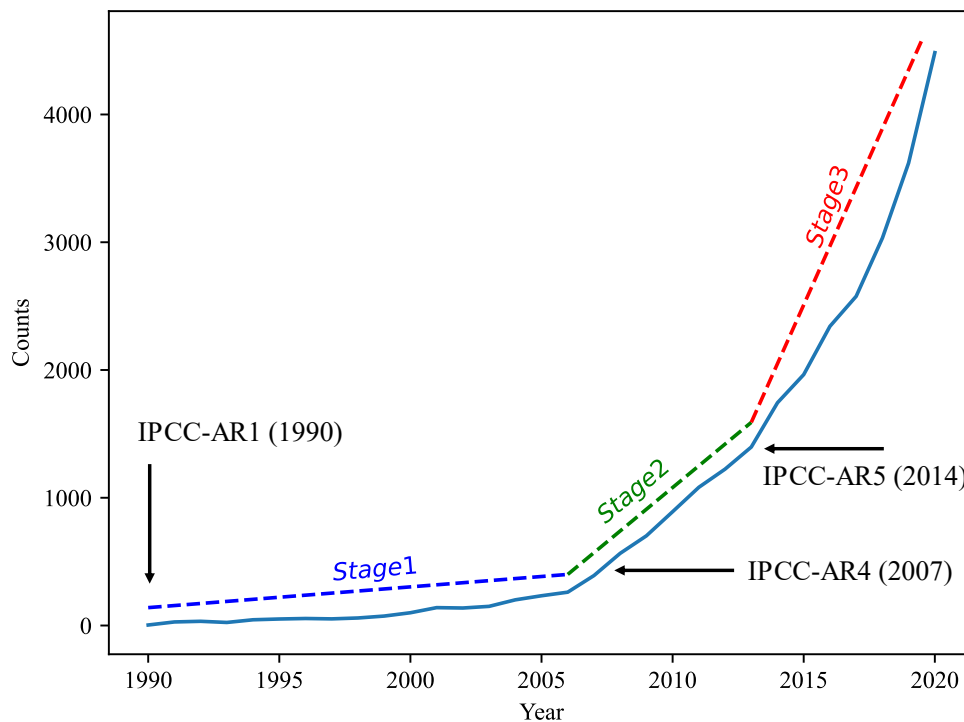


Fig 11 Annual counts of research articles in the field of climate change and health in the Web of Science Core Collection database between 1990 and 2020 (data was obtained on 2nd Nov 2021).

2.3.2 Trend of keywords in each research theme

The frequency-weighted mean appearance time of each cluster is calculated. The earliest and latest mean appearance time of keywords was noticed in research theme 6 (mean = 2014.2, representing keyword of ‘phenology’) and research theme 4 (mean = 2016.2, representing keyword of ‘sustainable development’), respectively. The rug plot showed that there were no new high-frequency keywords after 2018 in research theme 6 and 9

(representing keyword of ‘phenology’), while in research theme 4, quite a few high-frequency keywords emerged in the recent 2 years (Fig 12). This suggested that during 2018 - 2020, the major research topics in research theme 6 and 9 were all traditional ones, but the emergence of new topics were noted in other research themes, especially for research theme 4.

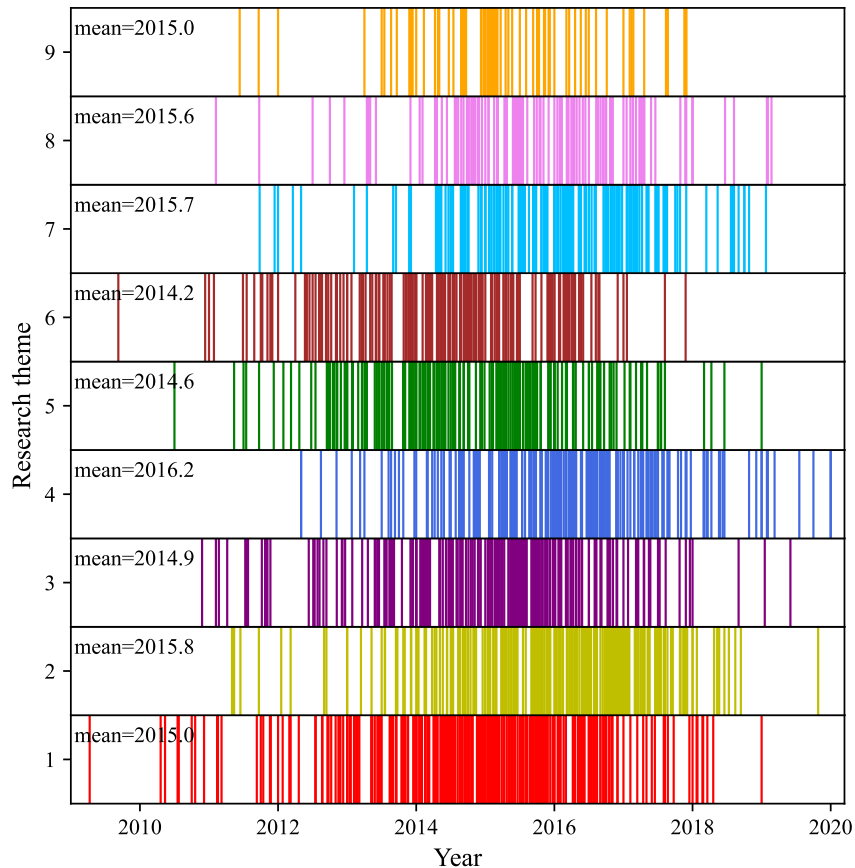


Fig 12 *Rug plot showing the average appearance time of a total of 1673 keywords in 9 different clusters. The mean value within each sub-figure indicates the mean appearance time of all keywords with that research theme.*

2.3.3 Trend of publication number in each research theme

The trend of the number of research articles belonged to each research theme is shown in Fig 13. In general, the number of research articles increased dramatically for all research themes.

2.3.4 Trend of the distribution of publication in each research theme

The trend of the distribution of research articles across 9 research themes was analyzed by the percentage of articles of each research theme from 1991 to 2020. The nMDS plot in Fig 14 revealed that there was no clear research trend at the first 15 years (1991 - 2005), shown as the wide spread of points and the overlapping of color shadow. In the next 15 years (2006 - 2020), a clear trend towards the right-down direction was noted.

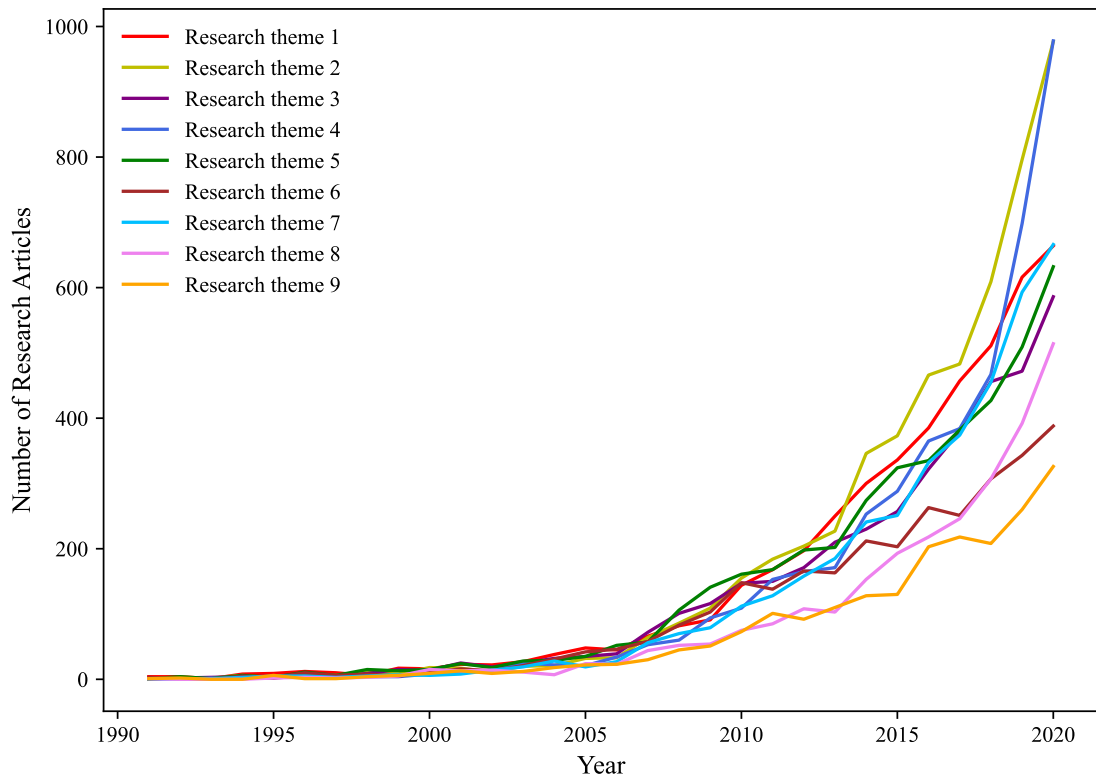


Fig 13 The change of number of research articles belonged to 9 different research themes in the field of climate change and health.

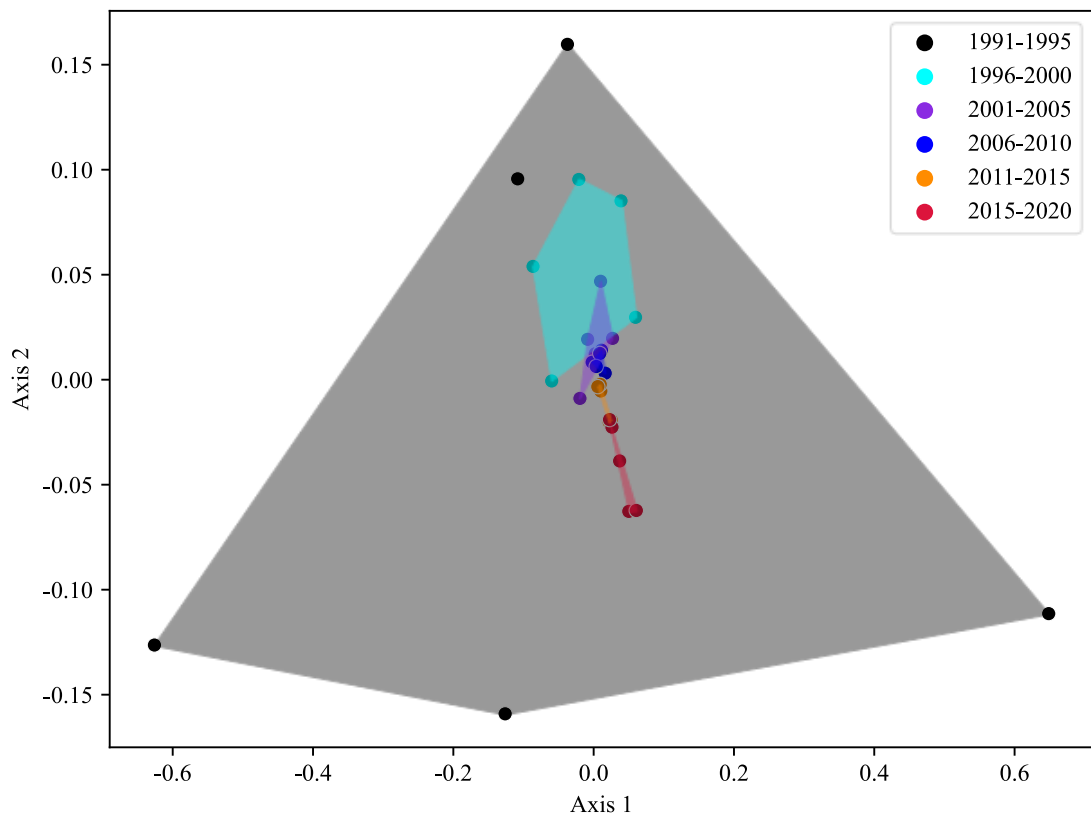


Fig 14 *The non-metric multidimensional scaling (nMDS) plot based on the percentage of research articles of 9 different research themes. Each point represents a year between 1991 and 2020 and is marked with 6 different colors based on the year it represented.*

Further analysis on the distribution of research articles across 9 research themes between 2006 and 2020 showed a significant separation of points across Axis 1 (Fig 15). The bubble nMDS plots revealed that during 2006 - 2020, the percentage of research articles of research themes 2 (representing keyword of 'risk assessment and adaptation'), 4 (representing keyword of 'sustainable development'), 7 (representing keyword of 'extreme heat') and 8 (representing keyword of 'air pollution') increased significantly as time increased ($p < 0.05$). On contrast, the percentage of research articles of research themes 3 (representing keyword of 'ocean'), 5 (representing keyword of 'infectious disease') and 6 (representing keyword of 'phenology') decreased significantly as time increased ($p < 0.05$). The percentage of research articles of research themes 1 (representing keyword of 'drought') and 9 (representing keyword of 'ecosystem change') was not significantly changed as time increased ($p > 0.05$). This suggested that the climate change risk governance and sustainable development under climate change are becoming hotter and have attracted increasing attention. Relative to its impact on ocean, infectious disease and phenology, more studies were conducted to investigate the health impact of climate change due to increased extreme weather events and its association with air pollution in the recent years. As weather/climate extremes are becoming more frequent and have exerted severe impacts on many fields including human health, the issue of climate change adaption has become a major task besides climate mitigation for the goals of sustainable development. It's anticipated to have more cross-cutting research to be prioritized on climate adaptation, such as the development and implementation of multi-hazard early warning system.

3 Future research priorities and recommendations

Future priorities were summarized based on the expert discussion and recommendation in the three high-level forums/workshops hosted by the IRDR International Centre of Excellence on Risk Interconnectivity and Governance on Weather/Climate Extremes Impact and Public Health (ICoE-RIG-WECEIPHE) at Fudan University. The first one is Climate Change and One Health Forum hosted on 4th June 2021, which was a session of Pujiang Innovation Forum 2021 and a pre-session of IRDR conference 2021. More information about this forum can be found at http://en.pujiangforum.cn/en/en_agenda_show.aspx?channel_id=21&cateid=347&id=133 and <https://www.shine.cn/news/metro/2105289737/>. The second one is 1st Chemical Weather and Chemical Climate Youth Forum hosted on 24th - 26th Sep 2021. The third one is Air Quality and Health Workshop hosted on 30th Nov 2021. More information about this workshop can be found at <https://www.irdrinternational.org/news/882>. To be noted, two scientific papers led by the authors of this working paper were published as the outcome of these discussion. Parts of following statements were from the published papers (Zhang et al. 2021; Ouyang et al. 2022).

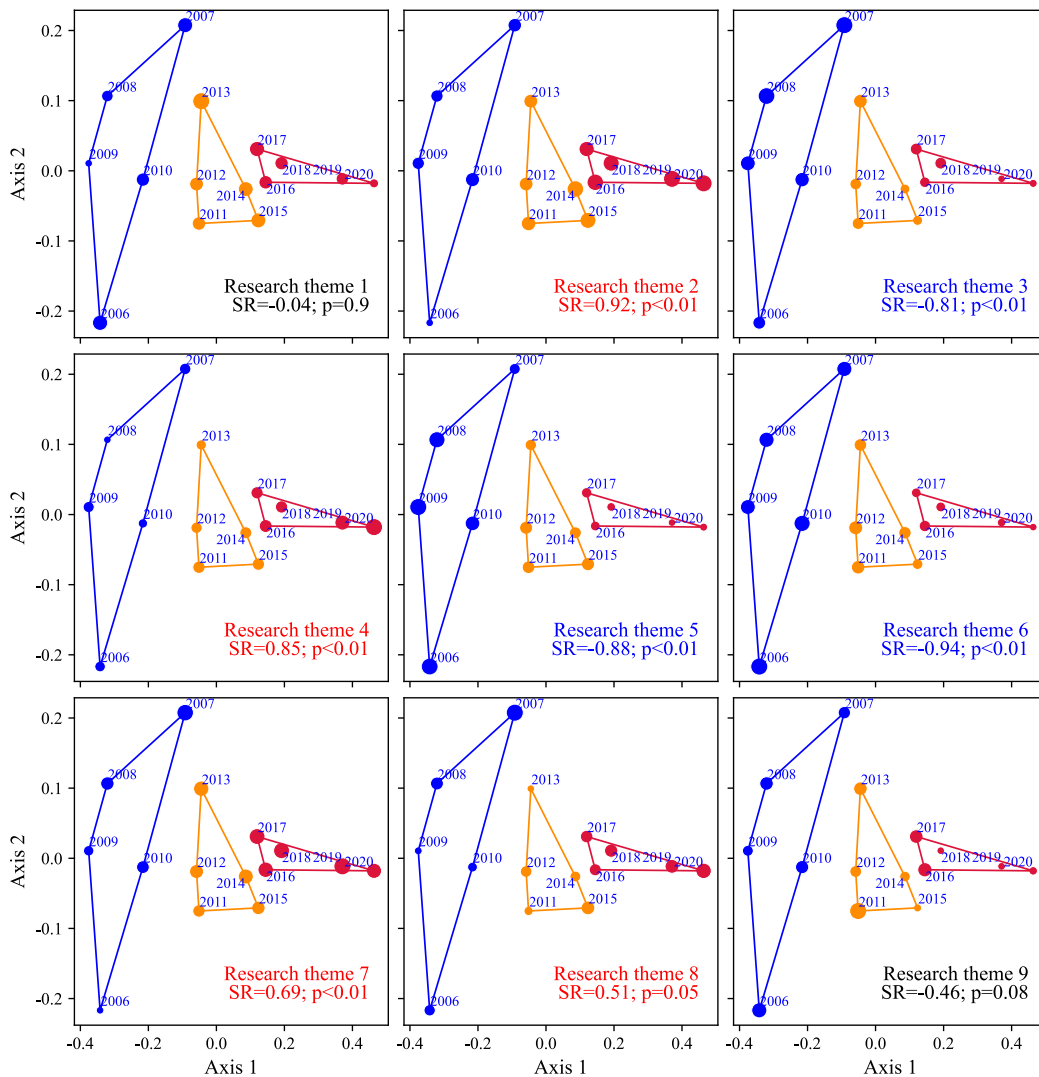


Fig 15 The bubble non-metric multidimensional scaling (nMDS) plot based on the percentage of research articles of 9 different research themes. Each point represents a year between 2006 and 2020 and is marked with 3 different colors based on the year it represented. Within each subplot, larger bubbles indicate a relatively higher percentage of research articles of the research theme stated in the subplot. Bubble sizes are not comparable between subplots. The Spearman's rank correlation coefficient (SR) and p value between Axis 1 values and the percentage of each research theme are shown in the Figure.

As revealed by the trend of research themes in section 2.3.2, extreme weather and air pollution are attracting increasing attention in recent years. Future research priorities highlighted by experts in these two research themes include,

- (1) Understand the occurrence and development mechanisms of extreme weather and climate events to improve the early warning and forecasting capabilities of these events.

- (2) Strengthen the risk interconnectivities research on extreme weather and climate events and their derived disasters for better risk governance.
- (3) Develop high-resolution model which couples the air pollution and climate change, with a better representation of the non-linear relationship between chemical substances in the atmospheric environment.
- (4) Develop digital tools and infrastructure for bettering monitoring pollution and greenhouse gas emission.
- (5) Conduct an all-cause assessment on health impact of climate change and environment conditions to guide risk governance.
- (6) Investigate the co-benefit of climate change mitigation and air quality improvement and formulate policies to maximize the co-benefits.
- (7) Understand the spatial difference and identify the best adaptation strategies for local regions.

In addition, experts pointed out that climate change were affecting our lives and living environments from all aspects and a united, holistic action and a paradigm shift from response to prevention is very needed to respond to the climate change crisis ([Zhang et al. 2021](#)). The One Health approach emphasizes the importance of considering the environment health, animal health and human health as a whole as they are linked together. Currently, the research focus on ecosystem change (research theme 9) is relatively low, more attention should be paid to this research theme. Experts also warned about emerging risks of infectious diseases, as the distribution and transmission of diseases may change significantly in the context of climate change, making previously low-probability events common.

The importance of data sharing and international cooperation were also highlighted, as climate change is a global threat beyond national borders. Experts called for more investments to support the interdisciplinary and innovation research in the field of climate change and health, to enhance the risk governance capacities through early detection, early identification, early warning and early response. It is also noted that combating climate change is not only a scientific issue, but also requires multi-stakeholder participation. Raising public's risk awareness and perception of climate change and promoting green and low-carbon behaviors are of great importance and are considered to be a key priority of all governments.

4 Conclusion

In this paper, we have identified 9 major research themes in the field of climate change and health, that is (1) impacts of drought and its derived disasters on the forest and vegetation, (2) climate change risk assessment and adaptation, with major focus on aspects including adaptation, vulnerability and resilience, (3) the impact of global

warming on marine biota (especially coral reefs) and ocean circulation, (4) the threats and paths of sustainable development in the context of climate change, with special focus on food, water, energy and environment, (5) the impact of climate change on the distribution and transmission of infectious diseases, (6) the impact of climate change on plants and animals at species-level and population-level, (7) the risks associated with the extreme weather/climate events, (8) the health impacts of air pollution and the interaction between air pollution events and local climate, (9) the impact of ecosystem function loss and biodiversity reduction. The number of published articles increased in the past 30 years for all 9 research themes. Relative percentage of articles in each research themes indicated that research themes 2, 4, 7 and 8 were getting hotter in the past 15 years, while relatively reduced attentions were paid to research themes 3, 5 and 6.

Future research should focus more on (i) the interconnectivity of multi-risks and incorporate One Health approach into the risk governance; (ii) a deepened identification of all causes of the relation facts and its interaction of climate change, environment and public health is needed; (iii) co-benefit should be obtained in developing and implementing an integrated pathway in tackling health burden, air pollution, biodiversity losses and greenhouse gases emission at the same time. Identified future priorities in the field of climate change and health and recommendations for climate change risk reduction are mission-orientated actions, which could serve as the supplementary action plan in response to the research priorities identified in the new Global Risk Research Framework (IRDR, 2021), especially for Priority 1 (understand risk creation and perpetuation in the contemporary risk landscape: systemic, cascading and complex risks), Priority 4 (understand the implications of new thinking on hazards), Priority 5 (harness technologies, innovations, data and knowledge for risk reduction), Priority 6 (support regional and national science and knowledge for policy and action) and Priority 9 (foster a transdisciplinary approach and multi- stakeholder collaboration for solutions to risk challenges).

5 References

- Coakley, S. M. (1979). Climate variability in the Pacific Northwest and its effect on stripe rust disease of winter wheat. *Climatic Change*, 2(1): 33-51.
- Hammer Ø, Harper DA, Ryan PD (2001). PAST: paleontological statistics software package for education and data analysis. *Palaeontologia electronica*, 4(1):9.
- Hirst, J. M., & Stedman, O. J. (1960). The epidemiology of *Phytophthora infestans*: I. Climate, ecoclimate and the phenology of disease outbreak. *Annals of Applied Biology*, 48(3): 471-488.
- Integrated Research on Disaster Risk. (2021). A Framework for Global Science in support of Risk Informed Sustainable Development and Planetary Health [eds Handmer, John; Vogel, Coleen; Payne, Ben; Stevance, Anne-Sophie; Kirsch-Wood, Jenty; Boyland, Michael; Han, Qunli; Lian, Fang]; Paris, France, International Science Council; Geneva, Switzerland, United Nations Office for Disaster Risk Reduction; Beijing, China, Integrated Research on Disaster Risk. DOI: 10.24948/2021.07.

- Intergovernmental Panel on Climate Change. (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Lösschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.
- Ouyang, H., Tang, X., Kumar, R., et al. (2022). Toward Better and Healthier Air Quality: Implementation of WHO 2021 Global Air Quality Guidelines in Asia. *Bulletin of the American Meteorological Society*, 103(7): E1696-E1703.
- Post, J. D. (1984). Climatic variability and the European mortality wave of the early 1740s. *The Journal of interdisciplinary history*, 15(1): 1-30.
- Romanello, M., McGushin, A., Di Napoli, C., et al. (2021). The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. *The Lancet*, 398(10311): 1619-1662.
- United Nations Disaster Risk Reduction. (2015). Sendai Framework for Disaster Risk Reduction 2015-2030.
https://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf.
- United Nations Environment Programme. (2022) Frontiers 2022: Noise, Blazes and Mismatches. <https://www.unep.org/resources/frontiers-2022-noise-blazes-and-mismatches>
- United Nations Framework Convention on Climate Change. (2015). Paris Agreement.
https://unfccc.int/sites/default/files/english_paris_agreement.pdf.
- United Nations. (2015). The 2030 Agenda for Sustainable Development.
<https://sdgs.un.org/goals>
- United Nations. (2020). <https://www.un.org/sg/en/content/sg/statement/2020-12-12/secretary-generals-remarks-the-climate-ambition-summit-bilingual-delivered-scroll-down-for-all-english-version>
- World Economic Forum. (2022). The Global Risks Report 2022, 17th Edition.
https://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2022.pdf
- Zhang, R., Tang, X., Liu, J., et al. (2022). From concept to action: a united, holistic and One Health approach to respond to the climate change crisis. *Infectious Diseases of Poverty*, 11(1): 17.

Indications of contributions to Global Risk Research

Framework and UN Agendas

1. How does this study contribute to Global Risk Research Framework Priorities?

Climate change is one of the biggest threats to human in 21st century. Climate change affects all aspects of our lives, including marine, freshwater and terrestrial ecosystems and ecosystem services, water and food security, settlements and infrastructure, health and wellbeing, and economies and culture (IPCC, 2022). Therefore, understanding the health risks of climate change is the fundamental basis for the corresponding risk governance for building resilience and sustainability of social and economic development. This study identifies the research focus and trends in the field of climate change, which can increase our understanding of the compounding, cascading risks of climate change on health (Research Priority 1). The future priorities presented in this study can be a support to Research Priority 5, 6 and 9.

2. How does this study contribute to SFDRR targets?

The future priorities presented in this study have the potential to contribute to several Sendai Framework targets. Better understanding of the health risks associated with climate change can significantly reduce related loss and damage and enhance the risk governance (targets A, B, D, F, and G). In addition, this study could provide support to Priorities 1, 2 and 4, by increasing the understanding of disaster risks induced by climate change, enhancing disaster preparedness and strengthening risk governance.

3. How does this study contribute to SDGs?

This study has direct relevance to Sustainable Development Goal target 1 (No Poverty), especially its target 1.5: by 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters; SDG target 3 (Good health and well-being), especially its SDG target 3.3: by 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, waterborne diseases and other communicable diseases; SDG target 3.4: by 2030, reduce by one third premature mortality from noncommunicable diseases through prevention and treatment and promote mental health and well-being; SDG target 3.9: by 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination; SDG target 13 (Climate Action), especially its SDG target 13.1: strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries; SDG target 13.3: improve education,

awareness raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning. In particular, this study highlights the importance of sustainable development as an aim of climate change risk governance.

4. How does this study contribute to Paris Agreement?

Climate change poses some of the greatest global health risks that we have ever seen. The Paris Agreement is a fundamental public health agreement, potentially the most important public health agreement of the century. If we don't meet the climate challenge, if we don't bring down greenhouse gas emissions, then we are undermining the environmental determinates of health on which we depend: we undermine water supplies, we undermine our air, we undermine food security. The adoption of Paris Agreement marked the international commitment to combat climate change and adapt to its effects including its impact on human health. Health is mentioned three times in the core text of the agreement, which refers to the “co-benefits” of tackling health and climate change at the same time. The research gaps and future priorities presented in this paper could enhance our understanding of the risks of climate change, stimulating the actions towards climate change mitigation and promoting the actions towards climate change risk governance and adaptation.