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ANTHROPOCENE REVIEW

Understanding the Research Interlinkages Between Anthropocene, Millennium and Sustainable Development Goals: A Global Bibliometric Analysis

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Abstract

Sustainable Development Goals (SDGs) are impacted by the Anthropocene's onset, hence critical actions must be taken to develop tailored policies for these goals. This research aims to understand the interaction between anthropogenic activities and SDGs or Millennium Development Goals (MDGs), as well as research trajectories, spatiotemporal development, scientific networks, continuing research issues, and gaps in these fields. The present study compiled the top 500 most referenced publications from 252 different sources from 1992 to 2022 using the Web of Science database. Scientific output in these fields increased from 2016 to 2019, but we found a significant reduction from 2020 onwards. The top three countries generating single-country publications in this field are China, USA, and India. Although human activities have hampered the achievement of SDGs, many small, developing countries are still not involved in the scientific production of this field. Institutions in the USA, China, the UK, and Germany have a greater percentage of international collaborations than other countries. SDGs 3, 6, 7, 11, 12 and 13 are the most researched. The investigation produced helpful information and a full understanding of significant researchers, institutions, current scenario of study, rising trends, and relevant subjects for scholars as well as how that information is translated into actual SDGs attainment.

Keywords Anthropocene · Millennium Development Goals · Sustainable Development Goals · Web of Science · Global

Abbreviations

AIDS	Acquired immune deficiency syndrome
AMSDG	Anthropocene, Millennium and Sustainable Development Goal
CPG	Critical physical geography
GC	Global citation
HIV	Human immunodeficiency virus
IRDS	Internal research documentation system
LC	Local citation
MAG	Microsoft academic graph
MCA	Multiple correspondence analysis
MCP	Multi-country publication
MDG	Millennium development goal
PM	Particulate matter
SCP	Single-country publication
SDG	Sustainable development goal
UN	United Nations
VNR	Voluntary national review
WoS	Web of Science

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1 Introduction

In the foreseeable future, managing the needs of a growing population of 9.7 billion people in areas such as employment, money, energy, food and water, and various other resources will be a major global challenge. To address this predicament, the UN adopted the sustainable development goals (SDG) in 2015 and sought collaborative aims from governments across the world and asked to submit voluntary national reviews (VNR) of SDG every year to create a more sustainable globe by 2030. The 17 SDGs are primarily concerned with the coherent, interdependent progress of the environment, society, and economy. The SDGs, which replace the millennium development goals (MDG) have 17 goals and 169 targets. MDG (1990–2015) had eight goals.

There are a few significant scientific studies that have been crucial, particularly in terms of monitoring real progress, combining the three dimensions of the SDGs, and examining the SDGs' potential for creating a sustainable future. Lu et al. (2015) proposed that economists, social scientists, and scientific experts should create a set of useful indices for monitoring progress on each SDG. The government must provide long-term support and ensure that all SDG data is accessible to the public. To reduce inequality, restrict ecological damage, limit climate change, encourage sustainable consumption, and ensure resilient livelihoods, Bowen et al. (2017) identified three policy challenges, which were major hurdles for sustainability science, society, and the administration. Milan (2017) examined how other SDGs that depend on the water will interact with future residential water demand in cities. Via a global SDG Interactions Knowledge Platform, Nilsson et al. (2018) examined the prospects and challenges of utilising the synergy and trade-off method in SDG research and policy development. Salvia et al. (2019) identified the key SDGs as interpreted by 266 experts from various geographic regions throughout the world and analysed how those objectives relate to the key local problems and barriers of each area. The connections between addressing climate change and attaining the SDGs were investigated by Fuso Nerini et al. (2019). In assessing the detailed performance of attaining the four-dimensional SDGs based on 15 'Belt and Road' countries, Huan et al. (2021) created the Composite SDG Index which supported local coherent planning and national-level decision-making to achieve the SDGs.

The term 'Anthropocene' was first used by the biologist Eugene F. Stoermer (Steffen et al. 2011). Anthropocene can be stated as about or designating the current geological epoch, considered as the time when human activity has had the greatest impact on the climate and the environment (Vignieri 2014). There are different opinions among scientists about the start date of the Anthropocene (Edgeworth et al. 2015). Environmental–human interactions may influence the outcome of achieving the SDG by 2030. Human activities can be both beneficial (e.g., safeguarding and restoring ecosystems, conserving species, etc.) and bad (e.g., pollution, degradation of soils, loss of biodiversity, overcrowding, deforestation, fossil fuel combustion, etc.) for the environment.

Air and water pollution are two of our era's greatest scourges, not only because of their impact on climate change and water but also public health because of rising morbidity and death. The burning of fossil fuels like coal, oil, and gas is the main cause of the surge in human-induced net CO_2 emissions, though cement production and changes in land use account for minor portions of it (Hall et al. 2021). Particulate matter (PM) causes respiratory and cardiovascular disorders, reproductive and central nervous system dysfunctions, and cancer, which is one of them. According to research led by the University of Colorado, anthropogenic activity had increased the quantity of fixed nitrogen on the globe by twofold since 1950 as a result of industrial agriculture and depleted the ozone layer by releasing chlorofluorocarbons (CFCs) on a large scale. The impacts of UV on public health are harmful (such as skin cancer, cataracts, and sunburn), and would all be amplified by ozone depletion (Bais et al. 2018). Similarly, polluted water increases the chance of being affected by cholera, giardia, etc. So, as all the SDGs are interrelated if anthropogenic activities pose a hindrance to achieving SDG 6 and 13, achieving SDG 3 (good health) is also impossible.

Overfishing, climate change, the introduction of exotic species, ocean pollution, ocean acidification, and ocean warming are all examples of human actions that impact marine life and result in the alteration of the geographic distribution of living organisms (Waters et al. 2016). Marine pollution occurs when substances used or spread by people, such as industrial, agricultural, and residential trash, particulates, noise, excess carbon dioxide, or invading creatures, reach the water and cause harm to aquatic wildlife. The mean trophic level of world fisheries has fallen because of the overfishing of high trophic-level species, a phenomenon known as fishing down the food web (Cheung et al. 2009). Nuclear testing has resulted in serious damage to test sites on land and in the immediate marine environment since the late 1940s. For instance, it has been discovered that the release of ^{137}Cs and ^{90}Sr into the world's oceans resulted in their bioaccumulation over time through the food supply chain (Prăvălie 2014). These, in particular, prevent the achievement of SDG 14.1 and SDG 3.

The majority of researchers concurred that human activities have sped up the rate of extinction of species (Sahney et al. 2010; Pimm et al. 2014). According to a study by Ceballos et al. (2020), anthropogenic factors were causing a "biological annihilation" comparable to a sixth mass extinction event. Overconsumption, population expansion, and intensive farming were credited for the collapse of 68% of wildlife populations between 1970 and 2016 (Bullitt-Jonas 2021). Thus, the growing human influence on ecosystems, biodiversity, species extinction, and land use is significantly impeding the fulfilment of various targets of SDG 15.

According to Mahmood et al. (2016), the overuse of pesticides may result in the extinction of biodiversity. Microplastics are a clear indicator of the Anthropocene because humans have been producing millions of tonnes of plastic annually since the early 1950s (Syvitski et al. 2020). A modest amount of scientific research evaluated the intricate connections between environmental elements and their effects on people and the environment, and these studies were linked to most of the SDGs. These are a few of them:

In 2009, Rockstrom and his coworkers developed a new framework of planetary boundaries and stated that such boundaries shouldn't be crossed to prevent humans from generating unacceptably harmful environmental change (Rockström et al. 2009a). Borgwardt et al. (2019) used an environmental risk assessment approach to identify the impact chains connecting to anthropogenic activities, and they also demonstrated how well that information may be utilised to inform stakeholders about trade-offs in the use of different water resources and to support decision-making. The main anthropogenic elements affecting ecosystem services in various regions of China were clarified as essential to managing ecosystems sustainably in a recent study by Fang et al. (2021) and provided a scientific basis for comprehending management policies.

"Significant net benefits in individual well-being and economic growth have resulted from environmental changes," but these gains have come at an increased cost in the form of degraded ecosystem services and the aggravation of poverty for particular groups of people. If these issues are not resolved, future generations will no longer gain as much from ecosystems (Reid et al. 2005). So, there is an increasing significance of studies that connect the Anthropocene and its linkage with development goals (viz. MDG, SDG) (AMSDG from here on).

2 Literature Review on Anthropocene, MDGs and SDGs

There are various types of literature reviews, such as narrative (traditional), critical, overview, scoping, systematic, state-of-the-art, meta-analysis, fast, bibliometric, etc. There are several reasons bibliometrics was used for this research: (a) it is a quantitative approach, implying a higher level of reproducibility; (b) it is based on a broad sense of publications, implying that it can gather a vast collection of articles published; (c) statistical methods could produce pretty realistic appropriations for research domains; and (d) bibliometric analysis could be accomplished using a variety of tools (viz. R, CiteSpace, Pajek, VOSviewer, BibExcel, etc.).

2.1 On Anthropocene

Belli (2016) conducted a bibliometric analysis of the publications and authors in the Anthropocene field, which is controversial and multidisciplinary. He noticed two clusters of co-occurring phrases, expressing approval and disapproval of the Anthropocene, and compared the network's iconic works. Brondizio et al. (2016) explored the term Anthropocene's widespread adoption, interpretative flexibility, emergent narratives, and the disputes it has sparked. Correia et al. (2018) used bibliographical data to track major contributions to the evolution of the multidisciplinary nature of Anthropocene science in scientific literature during the twentieth century. Biermann et al. (2020) proposed a new paradigm called critical physical geography (CPG), which allows scholars to take up the Anthropocene's methodological and conceptual challenges.

2.2 On MDGs and SDGs

Zhu and Hua (2017) performed a bibliometric analysis and discovered that two countries (the USA and the UK) dominated sustainable development research overall, with China having the most publications. To analyze the areas of focus of SDG-related studies in Austria, Körfgen et al. (2018) conducted a study to identify relevant published papers from 13 Austrian universities. The work by Olawumi and Chan (2018), shows how the research field has progressed from the Brundtland Commission report's formulation of ideas to more modern sustainability indicators. The goal of the bibliometric study by Armitage et al. (2020) was to investigate scientific publications linked to SDG 1, 2, 3, 7, 13, and 14 using the Bergen approach and Elsevier approaches. According to Meschede (2020), most research comes from the Social Sciences, Life Sciences, and Biomedicine categories, with SDG 3 being the most prevalent SDG. Sweileh's (2020) study was intended to give policymakers, academicians, and researchers a glimpse of global SDG-related research activities. Payumo et al. (2021) looked at research production and collaboration to support the SDG using bibliometric approaches and network analysis, and they examined ways to detect research collaboration beyond the typical one-time co-authorship. Roy et al. (2022) conducted a bibliometric study to better understand scientific research trends, spatiotemporal progress, scientific cooperation, continuing research interests, and gaps linked to SDG 6. The study's main finding was that countries from the Global South are still falling short in the SDG 6 research area. Finally, they suggested the 'Sustainable Development of Water and Sanitation (SDWS)' framework. We've collated the results of the related literature studies in Table 1.

After a thorough literature review, we have found some relevant research gaps in the already published bibliometric studies. To begin with, the majority of bibliometric analyses were based on both the retrieved peer-reviewed articles and grey literature. Grey literature often lacks any stringent or significant bibliographic control and reliability of the information. Second, very few studies have discussed both the SDGs and the Anthropocene notion. Third, the majority of bibliometric studies only retrieved publications for a

Table 1 Comparative recent literature about bibliometric analyses of the Anthropocene, MDGs and SDGs (AMSDG)-related research domain

Author(s)	Overview period(s)	Focus domain(s)	Database(s)	Documents
Belli (2016)	2001–2015	Anthropocene	Scopus	1036
Brondizio et al. (2016)	2000–2015	Anthropocene	Web of Science (WoS)	1066
Zhu and Hua (2017)	1987–2015	sustainable development	WoS	59,926 (special selection—626)
Correia et al. (2018)	2001–2016	Anthropocene	WoS	867
Körfgen et al. (2018)	2013–2017	SDGs	Internal research documentation system (IRDS)	28,229 (and 3581 projects)
Olawumi and Chan (2018)	1991–2016	Sustainability; sustainable development;	WoS	2094
Knitter et al. (2019)	2002–2017	anthropocene	WoS	NA
Armitage et al. (2020)	2015–2018	SDGs 1, 2, 3, 7, 13, 14	WoS	500
Biermann et al. (2020)	2002–2019	anthropocene	WoS	2192
Meschede (2020)	2015–2019	SDGs	Scopus, WoS,	4593
Sweileh (2020)	2015–2019	SDG 3	Scopus	18,696
Payumo et al. (2021)	1999–2018	MDGs, SDGs,	Microsoft Academic Graph (MAG)	16,447
Roy et al. (2022)	2015–2021	SDG 6	WoS	289
This study	1992–2022	Anthropocene, MDG, SDG,	WoS	Top 500 (from 1198)

comparably shorter period, which made it challenging to discern the precise evolution of research themes and research trajectories. To fill those gaps and grasp the comprehensive bibliometric view of AMSDG research, we performed our analysis based on only the peer-reviewed literature collected from the Web of Science. So, there was almost no grey literature among the publications we collected. In addition, we retrieved the publications for a very long duration (1992–2022). Besides these, we covered all three topics (Anthropocene, SDG, and MDG) in our study that played an important role in understanding the Anthropocene's consequences (both positive and negative) that mostly render the notion of environmental sustainability practically impossible to achieve, as well as existing policies and rules for achieving SDG. Furthermore, we only included the most significant and top 500 most cited papers from these three categories.

3 Materials and Methods

3.1 Literature Search Tool

To identify and evaluate the hotspots and trends in AMSDG-related research, bibliometrics analysis was used. This study presents the analysis and categorization of scientific works and publications from 1992 to 2022. The Web of Science (WoS) Core Collection was used to find papers during that period in the current study. For the bibliometric analysis, we used the 'bibliometrix' package in R and the VOSviewer software (v. 1.6.16). Using VOSviewer, we conducted a study of bibliographic coupling, citation, co-citation, and co-occurrence. The 'bibliometrix' package (4.0.1) and the 'biblioshiny' function were used to complete the remaining work in R (4.1.2).

3.2 Literature Search Strategy

The data collection was carried out in mid-February, 2022, and all publications from 2022 could not be incorporated.

Search string:

TS = ("anthropocene" OR "anthropogenic" OR "human-induced" OR "man-made" OR "human-caused" OR "human-related" OR "human-made") AND ("millennium development goal*" OR "millennium goal*" OR "millennium development*" OR "millennium target*" OR "sustainable development goal*" OR "sustainable goal*" OR "sustainable development*" OR "sustainable target*" OR "global goal*")

Search period: 1992–01-01 to 2022–02-15

3.3 Inclusion and Exclusion Criteria

Based on the search string it is easily understandable that we have included publications that encompass Anthropocene-related Keywords along with development goals (viz. MDG/SDG). These gave us a total publication count of 1216. From there we removed 2 (reprints). This means we have included all types of publications (i.e., original & review articles, book chapters etc.). Then, we arranged the publications from the highest to the lowest order of citation. From these, we have selected the top cited 500 publications for this study.

As per our understanding, selecting the top 500 highest cited from a pool of 1214 publications makes this selection comprehensive and relevant enough for a bibliometric study.

4 Results and Discussions

4.1 Characteristics of Publication Outputs

500 documents relating to the AMSDG were collected from 252 different sources (journals, books, etc.) which comprised 388 articles (77.60%), 1 data paper article (0.2%), 19 proceedings paper articles (3.80%), 10 editorial materials (2%), 78 reviews (15.60%), and 4 book chapter reviews (0.8%) (Fig. 1a). On average, each document had 47.55 citations, and the average number of citations/year/documents was 6.87 (Fig. 1b). A total number of 35,050 cited references were found. There were 2184 authors and 2445 author appearances, among them 57 authors with single-authored publications and 2127 authors with multi-authored publications. The collaboration index was 4.82, featuring documents/author = 0.229, authors/document = 4.37, and co-authors/document = 4.89. 59 single-author publications were found. There were 1916 author's keywords and 1901 with Keywords plus. The number of publications relating to the AMSDG started at 1 in 1992 and attained its maximum value of 63 in 2019. A significant reduction in the annual production of AMSDG-related documents was found in 2021 (Fig. 1.c).

4.2 Top Output Analysis

4.2.1 Analysis of Sources (Journals)

Figure 1d presents the top twenty most relevant sources ≥ 5 publications output among the 500 selected documents.

From the selected 500 documents under consideration, five leading journals based on maximum citations were listed in Table S1 (Fig. S1). Bradford's law, also known as the Bradford distribution or Bradford's law of scattering, is a trend that forecasts the exponentially decreasing returns of checking for references in scientific journals. According to this research, zone 1 contained 20 journals, showing the most frequently cited scientific journals in this field. The

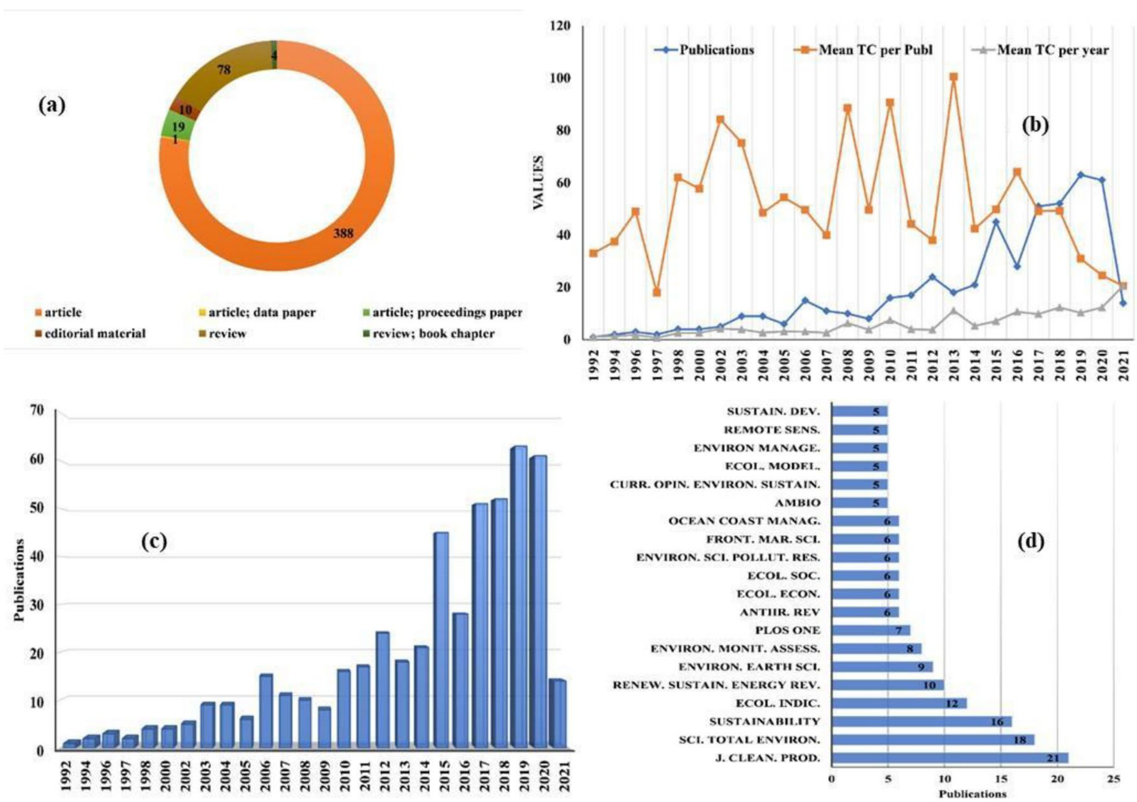

Fig. 1 Characteristic features of publications on Anthropocene, MDG, and SDG-related research. **a** Document types included in this study. 77.6% of documents were articles and 0.8% of documents were book chapter reviews. **b** Mean total citation (TC) characteristics—per publication & year. The Mean total citations per publication had significantly decreased from 2016. **c** Annual publication output. The number of publications relating to the Anthropocene, MDG, and SDG attained its maximum value in 2019, but a significant reduction in annual production was found from 2020 onwards. **d** Most relevant sources. Journals with ≥ 5 publications were shown in the figure

3 leading journals with the maximum frequency were the *J. Clean. Prod.* (21), *Sci. Total Environ.* (18), and *Sustainability* (16) respectively (Fig. S2). Zone 2 and Zone 3 each contained 67 and 165 journals. The top five ranked journals based on Total Citations (TC) were listed in Table S1 under the section of 'sources'. Figure 2a provides the visualisation of the twenty highest-ranked journals having the most local impact by h-index. It also depicts that *J. Clean. Prod.* is in the top position for both m-index and the g-index. According to cumulative production dynamics, among the sources, the five leading journals were the *J. Clean. Prod.*, *Sci. Total Environ.*, *Sustainability*, *Ecol. Indic.*, and *Renewable Sustainable Energy Rev.* (Fig. 2b).

4.2.2 Analysis of Authors

Fractional authorship is a measure used to determine an individual author's contribution to a set of published papers, assuming that all co-authors contributed equally to each document. Based on the fractionalized articles, Kopnina H (2.00), Warner RF (2.00), Wu J (1.99), Kim RE (1.50), and Kohler N (1.50), currently occupy the top five positions in the list of most relevant authors. Figure 2c shows the top twenty most relevant authors based on papers included in this study. We can visualise the twenty best authors based on Local citations in Fig. S3. Among them, the top three authors have twenty citations each. The 'Authors' section of Table S1 provided the five leading authors with the highest local impact (via h-index). Among the authors, the top three authors as per productivity with time were Wu J, Zhang Y, and Li S (Fig. S4).

Using Lotka's Law, we may calculate the frequency of publishing in a selected area during a certain period based on author trends (Allison et al. 1976). According to the findings, 92.5% of the authors had just published one article. With an increasing number of publications, the author's contribution decreases, as shown by 2 (5.3%), 3 (1.1%), 4 (0.5%), 5 (0.4%), and 6 (0.2%) (Fig. S5).

4.2.3 Analysis of Affiliations

The 5 highest-ranked global affiliations for AMSDG-related documents were listed under the 'Affiliations' section in Table S1. Additionally, Fig. 2d provides a more clear visualisation of the twenty-five most relevant affiliations. This implies that China accounts for the vast majority of relevant affiliations related to this field. Only a few other

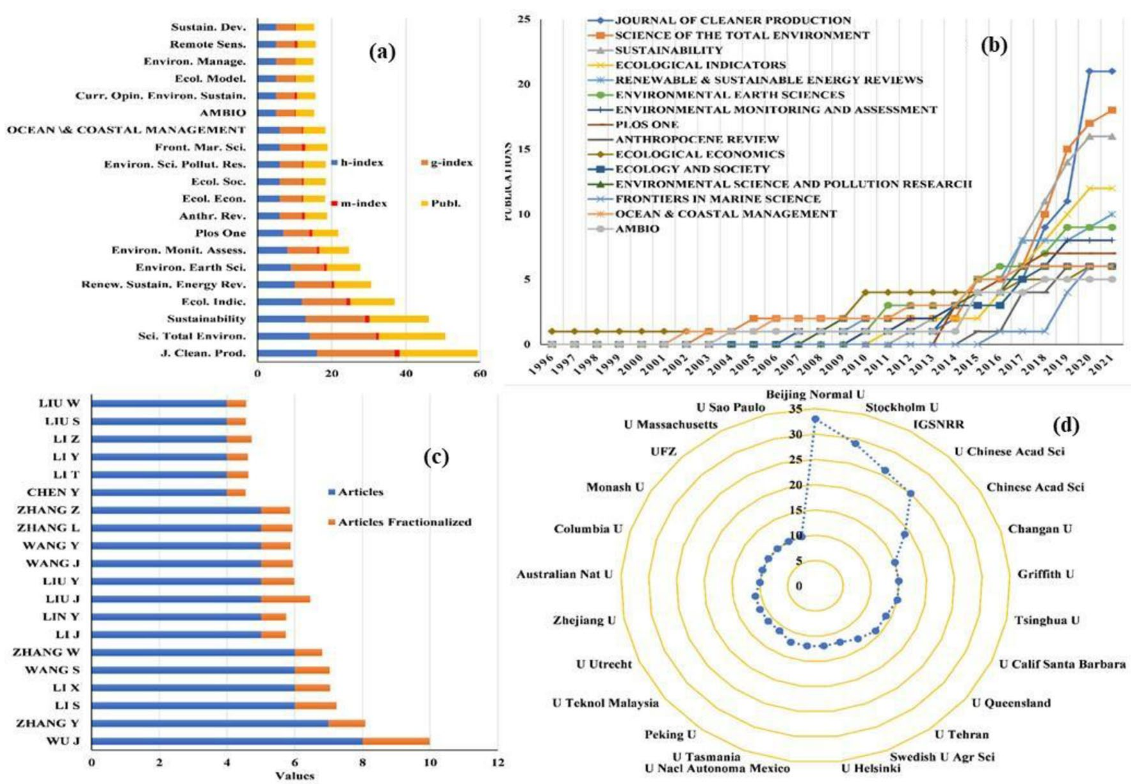

Fig. 2 Analysis of authors, institutions and sources related to Anthropocene, MDG, and SDG research. **a** Local impact of 20 highest ranked sources through m, g & h-index. **b** Cumulative source dynamics of fifteen leading journals. **c** Most relevant authors. **d** Most relevant affiliations. The majority of the top 25 relevant affiliations are primarily from China

universities are listed among the most relevant globally linked institutions.

4.2.4 Analysis of Countries

The five countries that were in the top positions with the highest number of publications (over 100) were China (511), the USA (367), the UK (179), Australia (133), and Germany (106) (Fig. 3a). This signified that 40% of the top five most AMSDG-related document publishing countries were from Asia (China), and 60% were from the USA, Europe, and Australia. Five leading countries to host corresponding authors publishing documents related to this field were listed under the ‘Countries’ section in Table S1. This indicated that among the five leading countries to host corresponding authors, 55.30% were from Asia (China and India) and 44.70% were from the USA, UK, and Australia. We can see the top five countries with ≥ 15 publications, according to Single country publications (SCP) under the ‘countries’ section in Table S1. This indicates that among the top five most AMSDG-related document publishing nations, around 60% are from Asia (India and China) and 40% are from Europe (Australia and UK) and America. Figure S6 presents a visual comparison of the fifteen highest-ranked countries based on single-country publications (SCP) and multiple-country publications. The top 5 countries (with > 1100 Total citations) were listed under the ‘Countries’ section in Table S1. This meant that 48.5% of the top 3 most AMSDG-related

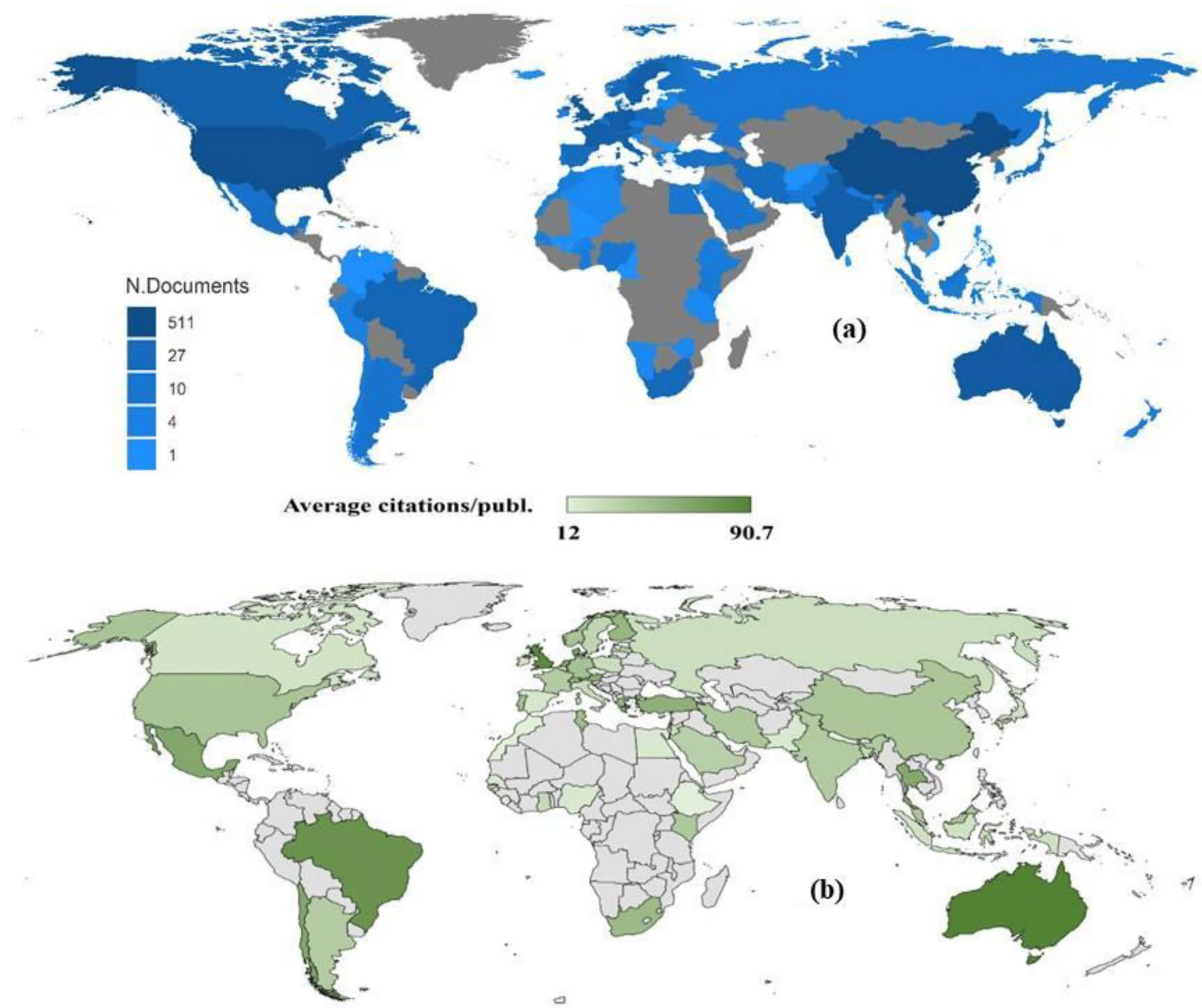

Fig. 3 Spatial distribution of publications. **a** Total scientific production related to Anthropocene, MDG, and SDG. The darker the colour, the more productive the country is for publishing documents in this field. China is the most productive country in terms of publishing, followed by the USA and the UK. **b** Distribution of citations. The top 3 most Anthropocene, MDG, and SDG-related publishing countries with the highest average citation count are London, Australia, and Brazil

publishing countries with the highest total citation count were from Asia (China), whereas 51.5% are from Europe and Australia. However, in terms of average article citations, the top eleven (60 citations per average article) countries were Australia (90.7), the UK (85.7), Brazil (78.2), Denmark (70.7), South Korea (66.5), Netherlands (66.3), Mexico (64.2), Chile (64.00), Malta (64.00), Thailand (62.5), and Austria (60.6). This signified that among the top 11 most AMSDG-related articles cited on average, 50% are from Europe (Fig. 3b).

4.2.5 Analysis of Publications

The top five documents from each of these five categories, viz. Global citations (GC), Total Citations per year (TCpy), Local citations (LC), Local Global citations ratio (LC/GC, in %), and Locally cited references, were listed in the 'Publications' section in Table S1. When the ratio of local to global citations (i.e., LC/GC in%) was considered, it showed that 3 leading academics had received more local citations for their papers, showing that their papers are important both locally and globally. Using reference publication year (RPY) spectroscopy, we may see the year the oldest references were published. The top five most distant years of citation in our study were 1798 (1), 1817 (1), 1833 (1), 1841 (1), and 1861 (1). Every year since 1957, there had been at least ten citations. Starting from 1983 up to 2014, there were > 100 citations every year. 2014 was the year with the most citations (2080) (Fig. S7). It formed five clusters from the network of global citation and local citation score coupling. There were 81 (cluster 1), 91 (cluster 2), 66 (cluster 3), 4 (cluster 4), and 8 (cluster 5) documents in each of these clusters (Fig. S8).

4.3 Academic Cooperation

Through intriguing research collaborations, academic researchers from different countries with similar expertise have been found to communicate and contribute considerably to AMSDG-related research. The world's 10 leading countries having multi-country collaboration for publications in this domain, with a frequency of > 9, were the USA, China, the UK, South Africa, Australia, Germany, Norway, Italy, Spain, and Canada. So, countries in Europe and America had a higher collaboration than countries in Asia, South Africa and Australia (Fig. 4a). Table 2 presents the academic cooperation of countries, authors, and institutions showing the clusters also. Collaboration networks of countries depicted that countries with a high level of international collaboration were concentrated in these three clusters, as shown by the data (Clusters 1, 2, and 3). As we have seen from the collaboration network of authors, most of the authors with multi-country publications were found in cluster 1. Moreover, it was evident from the collaboration network of institutions that clusters 1 and 2 represented the majority of the institutions engaging in multi-country collaboration.

Bibliographic coupling is a common metric that builds a similar relationship between publications using citation analysis. When two documents refer to the same third work, then it is called bibliographic coupling. It shows that the two documents are probably about the same thing (Jarneving 2007). If two documents share one or more citations, they are considered bibliographically related. The more references to other works two papers share, the higher their coupling strength. Likewise, two authors are bibliographically connected if they both have a reference to the same work in their cumulative reference lists, and the strength of their coupling grows with the increasing number of citations to other publications they share (Glänzel and Czerwon 1996). We collated the bibliographic coupling of AMSDG-related research for nations, sources, authors and documents in Table S2. In the bibliographic network of authors, there were 4 clusters. Five authors were in cluster 1. Clusters 2, 3, and 4 had four authors each. There were 4 clusters in the bibliographic coupling network of countries. Clusters 1 and 2 each had 11 countries. Cluster 3 had 7 countries and Cluster 4 had 3 countries. Countries like China, the United States, and Australia had the most bibliographic connections, while the far-flung countries of South Korea and Iran had the fewest (Fig. 4b). Five clusters were present in the bibliographic coupling network of documents. Cluster 1 had seven documents, Cluster 2 had five documents, Cluster 3 had four documents, and Clusters 4 & 5 each had two documents. This is clear from Fig. S10, which shows very poor bibliographic linkages among the documents. In the bibliographic network of organizations, there were five clusters. Clusters 1 & 2 each had 8 organizations. Clusters 3 & 4 each had five organizations In contrast to other bibliographic networks, the institutional graph of Fig. S11 demonstrates how this collaboration represents a highly centralised arrangement, congested with complex institutional interlinkages in a developed centre, which then permeates a series of less well-connected organisations mainly connected to the network via their links. 2 clusters were present in the bibliographic coupling network of sources. Cluster 1 had 15 journals and Cluster 2 had 6 journals. The bibliographic network of sources remains quite diffused, which means sources shown in Fig. S12 have a comparatively lesser bibliographic connection and the common citations shared by those sources are lesser. We can get a more detailed visualization of the bibliographic network of documents, organizations, and sources from Fig. S10-12 respectively.

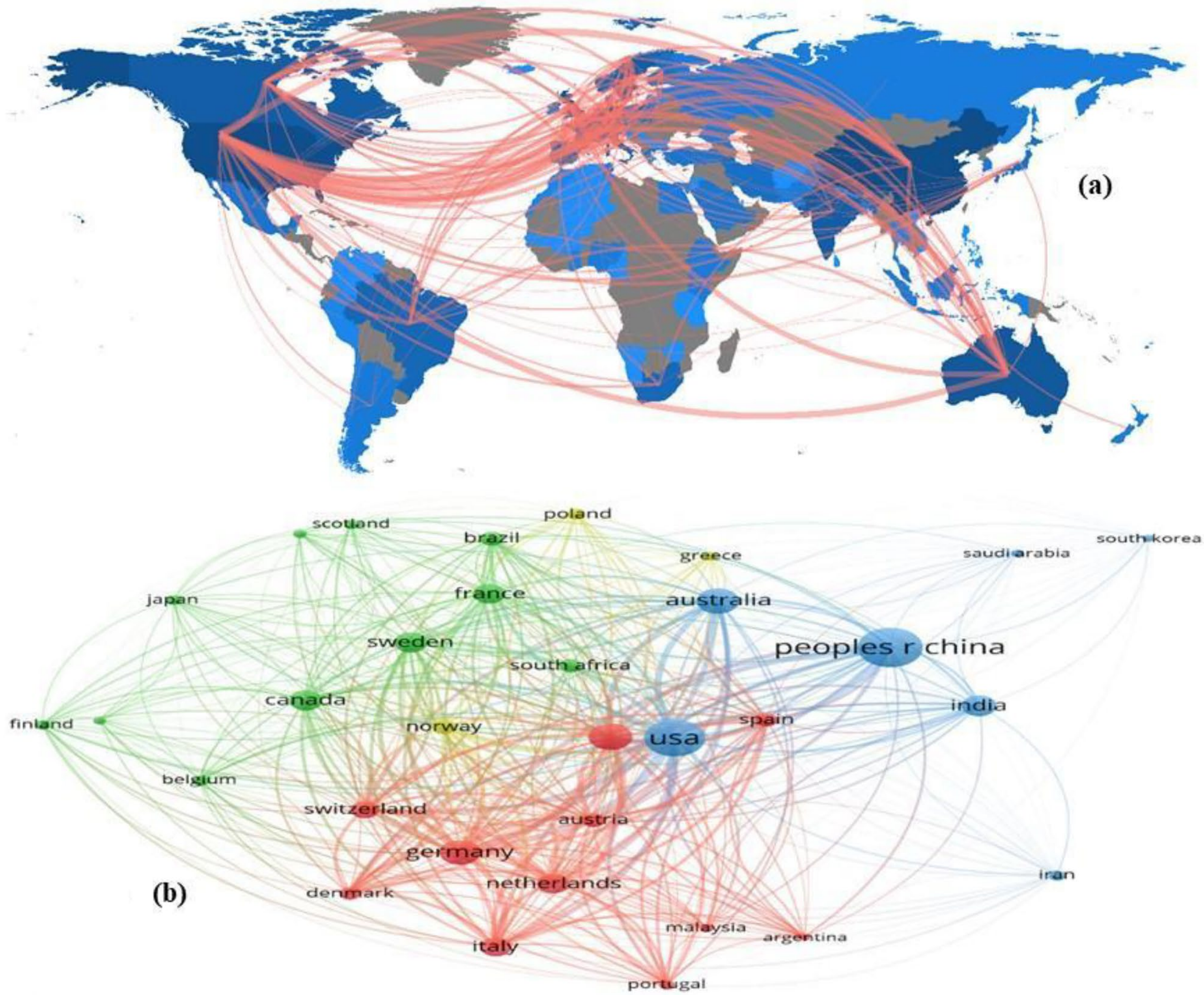

Fig. 4 Analysis of countries and academic cooperation related to Anthropocene, MDG, and SDG research. **a** Global collaboration of publications on AMSDG. Countries in Europe had the highest research collaborations with the USA, China, Brazil, and Australia, with extensive linkages. **b** Bibliographic coupling network of the countries. The maximum number of bibliographic linkages were found in countries like China, the USA, and Australia in the middle of the map, while the fewest connections were found in the outermost nations like South Korea and Iran

4.4 Keyword Analysis

The top 10 most often used words, according to Keywords Plus, were: ‘climate-change’ (60), ‘sustainable development’ (41), ‘management’ (40), ‘impacts’ (34), ‘impact’ (32), ‘biodiversity’ (31), ‘conservation’ (27), ‘land-use’ (26), ‘anthropocene’ (25), and ‘China’ (23). ‘Sustainable development’ (477), ‘climate change’ (184), ‘development goals’ (92), ‘ecosystem services’ (88), and ‘anthropogenic activities’ (65) were the five most frequently used words from the analysis of abstracts. From the analysis of the author keywords, ‘sustainable development’ (74), ‘climate change’ (41), ‘sustainability’ (32), ‘Anthropocene’ (18), and ‘sustainable development goals’ (17) were the five most often used words. As per the title analysis, the five most frequently used words were: ‘sustainable development’ (57), ‘climate change’ (31), ‘development goals’ (16), ‘river basin’ (13), and ‘ecosystem services’ (12). Cumulative word dynamics can explore further temporal trends. According to Keywords Plus's examination of cumulative word dynamics, 'management' was the most commonly used word from 1994 to 2016, but it was surpassed by 'climate change' from 2017 onwards. 'Climate change', 'management', and 'impacts' are the most frequently used terms in that order. The keywords—'climate change', 'management', and 'impacts' are on the rise. 'Model' and 'conservation' are falling in popularity. From the analysis of the author's keywords of cumulative word dynamics, ‘biodiversity', ‘climate change’, ‘China’, and ‘management’

Table 2 Analysis of academic cooperation of the Anthropocene, MDG and SDG (AMSDG)-related research

Features	Number of clusters	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Countries	4	USA, China, Germany, Italy, Canada, Sweden, France, Switzerland, India, Denmark, Finland, Iran, Poland, Japan, South Korea, Ethiopia, Czech Republic New Zealand	UK, South Africa, Australia, Netherlands, Austria, Brazil, Nepal, Mexico, Belgium, Malaysia, Nigeria, Kenya, Indonesia	Spain, Norway, Argentina, Chile, Portugal, Greece	Turkey, Russia
Authors	4	Wu J, Lin Y, Wang X	Zhang Y, Li G	Zhang Y, Li G	Zhang Z, Luo Y
Institutions	4	BNU, UCAS, IGSNRR, CAS, RADI,	SU, ANU, CU, MON, OU, ASU, HUB,	PKU, THU, TJU,	UCSB

BNU Beijing Normal University, *UCAS* The University of the Chinese Academy of Sciences, *IGSNRR* The Institute of Geographical Sciences and Natural Resources Research, *CAS* The Chinese Academy of Sciences, *RADI* The Institute of Remote Sensing and Digital Earth, *SU* Stockholm University, *ANU* Australian National University, *CU* Columbia University, *MON* Monash University, *OU* The University of Oxford, *ASU* Arizona State University, *HUB* Humboldt University, *PKU* Peking University, *THU* Tsinghua University, *TJU* Tianjin University, *UCSB* University of California, Santa Barbara

are the most frequently used terms. The keywords—'climate change', 'development', and 'planetary boundaries' are on the rise. 'Ecosystem', ‘habitat’, and 'environment' on the other side, are falling in popularity. According to the analysis of abstracts of cumulative word dynamics, ‘climate change’, ‘water quality', ‘ecosystem services’ and ‘water resources’ are the most commonly used terms. As per the title examination of cumulative word dynamics, ‘climate change’, ‘development goals’, ‘ecosystem services’, and ‘river basin’ are the most frequently used words. On the other hand, 'global warming', ‘groundwater sanitation’, and 'greenhouse gas' on the other side, are falling in popularity.

A co-occurrence network is a group of terms linked based on their recurrence in the same text unit. Networks are created by combining pairs of phrases using a collection of co-occurrence criteria. Co-occurrence networks are a common technique to see how people, organizations, concepts, and other things in a text are connected. The emergence of electronically stored text that is a text-mining complaint has made the development and visualization of co-occurrence networks possible. From the examination of the co-occurrence word network of keyword plus (Fig. 5), there were five clusters. The three most frequently occurring co-words of significant clusters were: ‘climate change’ (occurrence = 59), ‘management’ (39), and ‘quality’ (21) in cluster 1; ‘China’ (23), ‘urbanization’ (16), and ‘pattern’ (15) in cluster 2; ‘water’ (19), ‘pollution’ (15), and ‘river’ (14) in cluster 3; ‘impact’ (30), ‘model’ (23), and ‘consumption’ (14) in cluster 4; ‘biodiversity’ (31), ‘land-use’ (26), and ‘conservation’ (25) in cluster 5 (Fig. S13). From the analysis of author keywords, they were: ‘ecosystem services’ (12), ‘China’ (12), and ‘biodiversity’ (12) in cluster 1; ‘planetary boundaries’ (11), ‘resilience’ (8), and ‘groundwater’ (7) in cluster 2; ‘climate change’ (44), ‘adaption’ (7), and ‘renewable energy’ (6) in cluster 3; ‘remote sensing’ (8), ‘social-ecological system’ (7), and ‘urbanization’ (6) in cluster 4 (Fig. S14). As presented in Fig. (5), all keywords, were: ‘management’ (45), ‘impact’ (30), and ‘land-use’ (27) in cluster 1; ‘climate change’ (44), ‘adaption’ (19), and ‘framework’ (18) in cluster 2; ‘biodiversity’ (40), ‘China’ (34), and ‘ecosystem services’ (33) in cluster 3; ‘sustainability’ (45), ‘environment’ (23), and ‘consumption’ (16) in cluster 4; ‘impacts’ (35), and ‘resources’ (11) in cluster 5.

4.5 Research Trajectories

According to Keywords Plus, the latest trending topics with the highest frequency were—’contaminations’ (8), 'wastewater' (7), 'health' (7), 'CO_2 emissions' (6), and 'land use' (50) in 2020. In 2019, 'system'(15), 'area' (13), 'fresh-water’ (11), 'classification' (9), and 'ecosystem' (9) were included in the list. In 2018, they were ‘climate change’ (60), ‘land-use’ (26), 'Anthropocene' (25), 'China' (23) and 'ecosystem services' (20) (Fig. S9). Through the analysis of the contents of the abstract, the most trending terms were—‘climate action’ (7), ‘biomass energy’ (6), ‘ecological integrity’ (5), ‘positive impact’ (5), and ‘water pollution’(5) in 2021; ‘water stress’ (20), ‘planetary boundaries’ (19), ‘water cycle’ (15), ‘ecological security’(14), and ‘water security’ (14) in 2020; and ‘energy consumption’ (25), ‘heavy metals’ (25), ‘land degradation’ (22), ‘goals SDGs’ (21), and ‘air quality’ (19) in 2019 (Fig. S15). It presented an overview of the changing nature of AMSDG-related research, particularly in recent years. According to the authors' keywords analysis, trending terms were: ‘human activities’ (6) in 2020; ‘planetary boundaries’ (9), and ‘land degradation’ (5) in 2019; and ‘sustainability’ (32), ‘sustainable development goals’ (17), ‘land use’ (10), ‘ecosystem’ (8), and ‘remote-sensing’ (8) in 2018 (Fig. S16). Last, from the analysis of titles, the most trending terms were—‘human activities’ (7), and ‘heavy metals’ (5) in 2020; ‘ecosystem services’ (12) in 2019; ‘development goals’ (16), ‘remote sensing’ (6), ‘water quality’ (6),

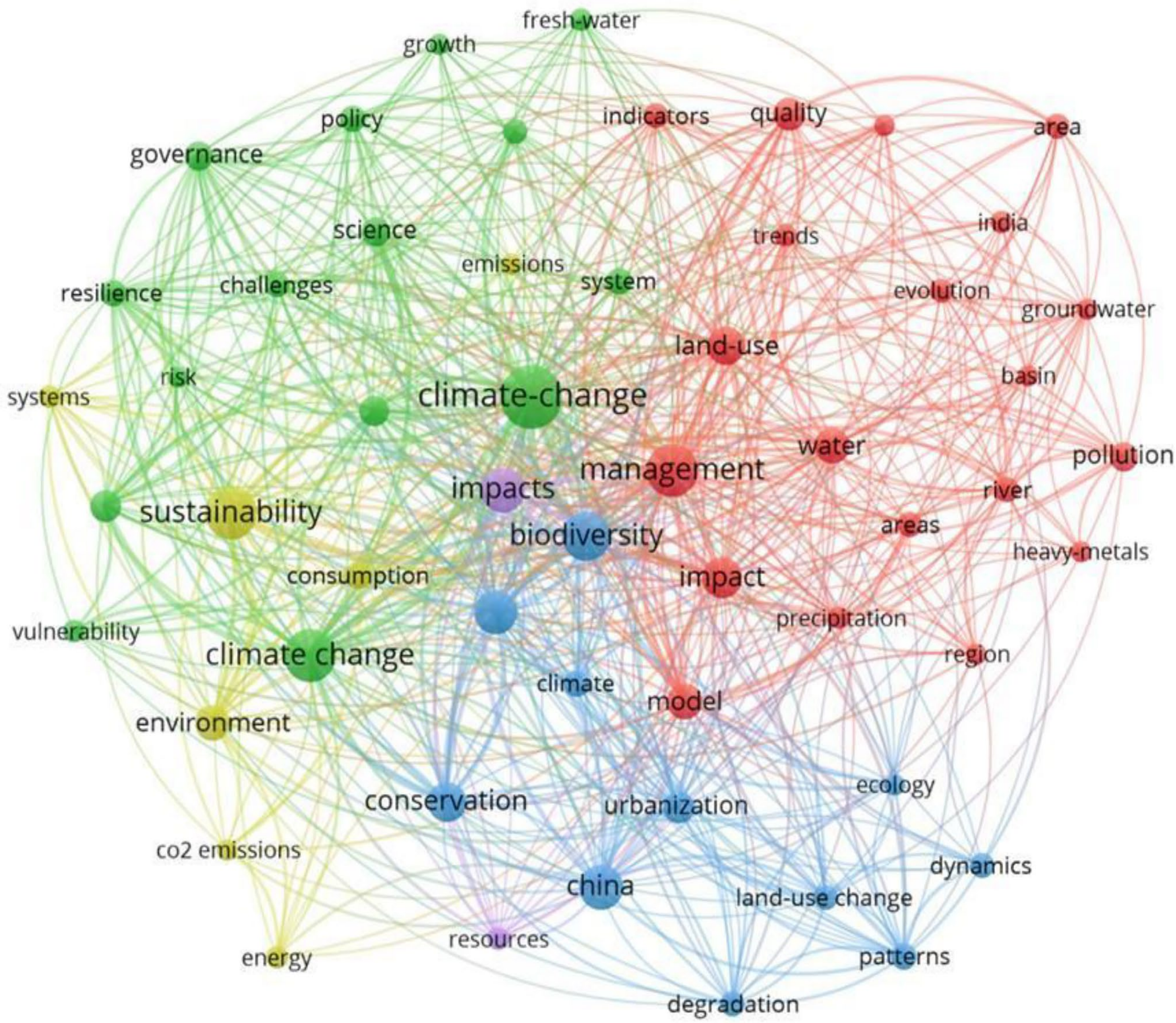

Fig. 5 Co-occurrence network of all keywords. Five colours represent five major clusters. The larger the nodes, the more linkages there are, based on the recurrence of the words in the same text unit

'environmental sustainability' (5), and 'groundwater quality' (5) in 2018 (Fig. S17). The following basic themes emerged from the thematic network analysis: 'climate change', 'sustainable development', and 'anthropocene' (from keyword plus); 'sustainable development', 'united nations', 'human activities', 'anthropogenic activities', 'goals SDGs' and 'development goals' (from abstracts); 'climate change', 'resilience', 'adaption', 'planetary boundaries', 'ecosystem services', 'anthropocene', 'development', 'urban', 'biodiversity', 'management', 'renewable energy' and 'sustainable development goals' (from author keywords); and 'particulate matter', 'ground chemistry', 'heavy metals', 'ecological risk', 'sustainable development', 'development goals', 'climate change', 'ground water quality', 'environmental sustainability', 'north China', 'land use land', 'planetary boundaries', 'river delta', 'basin China', 'river basin', 'ecosystem services' and 'human activities'(from the title). Arising motor themes were—'quality', 'water', and 'framework' (from keyword plus); 'land cover', 'land degradation', and 'remote sensing' (from abstracts); 'environmental', 'environment', 'assessment', 'monitoring', 'sustainable development', and 'sustainability' (from author keywords); 'urban development', 'landscape fragmentation', and 'time series' (from titles). The niche themes that arise are– 'climate', 'dynamics', 'patterns', 'consumption', 'indicators', and 'systems' (from keyword plus); 'anthropogenic sources', 'human activity', 'air pollution', 'heavy metals', 'natural systems', and 'policy makers' (from abstracts); 'capital', 'accounting', 'degradation', 'catchment', 'classifications', 'ground water', 'anthropogenic', 'India', 'climate scenarios', 'Mediterranean basin', 'scenarios' and 'assets' (from author keywords); 'central amazon', 'energy water', 'environmental change', and 'hierarchy process' (from titles). The emerging themes are– 'management', 'model', 'river', 'conservation', 'biodiversity', and 'land use' (from keyword plus); 'climate change', 'global warming', and 'greenhouse gas' (from abstracts); 'China', 'ecosystem', 'land use', 'social-ecological systems', 'human activity', and 'urbanization' (author keywords); 'northwestern China', 'water resources', 'global environmental', 'air pollution', 'environmental change', 'st century' and 'renewable energy' (from titles) (Figs. 6a & S18–S19).

The term 'thematic evolution' refers to the evolution of a group of themes over time even across the sub-phases. We divided the total number of phases (1992–2022) into two intervals, 1992–2007 and 2008–2022 to distinguish temporal trends. Themes that were prevalent in AMSDG-related research from 1992 to 2007 are–'human', 'development', 'reserved', 'change', 'anthropogenic' (from abstracts); 'health', 'sustainable development', 'biodiversity', 'conservation', 'dynamics', 'emission', 'catchment', 'environment' and 'health' (from keyword plus); 'assessment', 'sustainable development', 'water', 'sustainability', 'China' (from author keywords); 'water', 'challenges', 'future', 'sustainable', 'assessment', 'energy', 'management', 'coastal', 'ecological' (from the title). The current themes (2008–2022) that are predominantly present in this research field, are– 'development', 'environmental', 'rights', 'management' (from abstracts); 'sustainable development', 'sustainability', 'China', 'biodiversity', 'development' (from author keywords); 'water', 'impacts', 'impact', 'climate-change', 'conservation' (from keyword plus); 'China', 'environmental', 'development', 'ecological', 'management' (from titles). Themes like 'environment', 'biodiversity', 'health', and

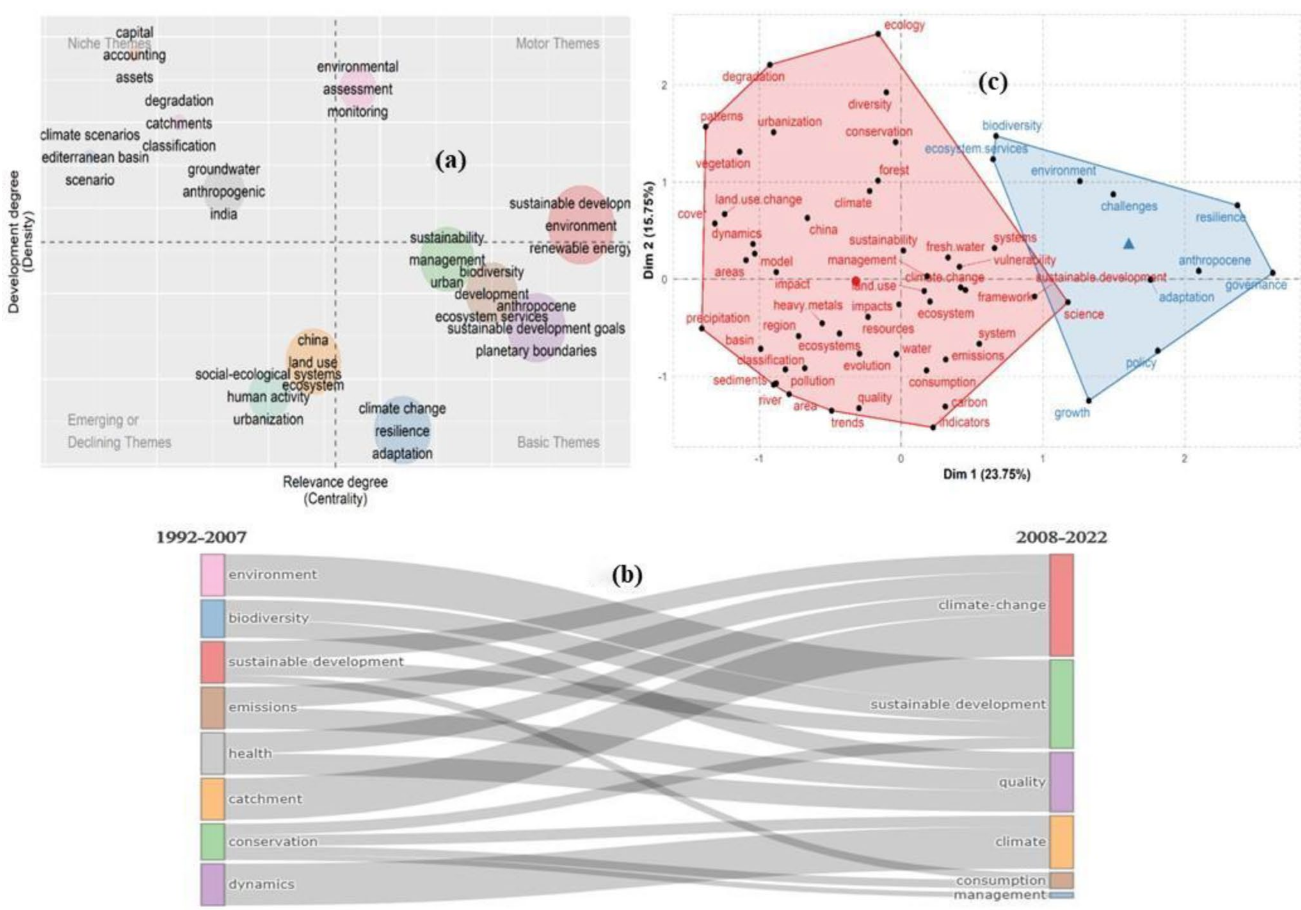

Fig. 6 Analysis of Keywords and research trajectories related to Anthropocene, MDG, and SDG (AMSDG). **a** Thematic map from analysis of the Author's keywords. Niche themes, motor themes, basic themes, and emerging or declining themes of the Author's keywords are visible in the figure. **b** Temporal trend of thematic development of AMSDG research (keyword plus). It's clear that the theme of 'sustainable development' has been consistent from 1992 to 2022 and has even become more prominent in the recent period. **c** Concept structure map of keywords from Multiple Correspondence Analysis (MCA) analysis. Two (Red and blue) colours represent two clusters in two dimensions (23.75% and 15.75%) for keywords

'conservation' were prevalent in the 1992–2007 time period but absent in the 2008–2022 time period. New themes like ' climate change', 'quality', 'consumption', and 'management' are trending in the 2008–2022 time period but were absent in the earlier period (from keyword plus) (Fig. 6b).

MCA (Multiple Correspondence Analysis) is a method for finding and clarifying underlying principles in nominal category data. Two clusters arise in two dimensions (23.75% and 15.75%) from the conceptual structure map of most cited documents created using MCA. Similarly, there are two clusters in two dimensions (23.75% and 15.75%) for keywords (Fig. 6.c), and two clusters in two dimensions (23.75% and 15.75%) for documents with the highest citations. Topic dendrograms can also illustrate this (Fig. S20).

We have created three field plots for nations, best-performing affiliations and AMSDG-related documents publishing sources. It shows nations on the left side, publishing sources in the middle and affiliations on the right side. This implies that China accounts for the vast majority of publications and affiliations related to the AMSDG research while a handful of nations like Poland, Canada, Austria, Brazil, and Denmark fall into the bottom categories (Fig. 7a). We have also composed three-field plots of reference-author and keywords plus (Fig. S21).

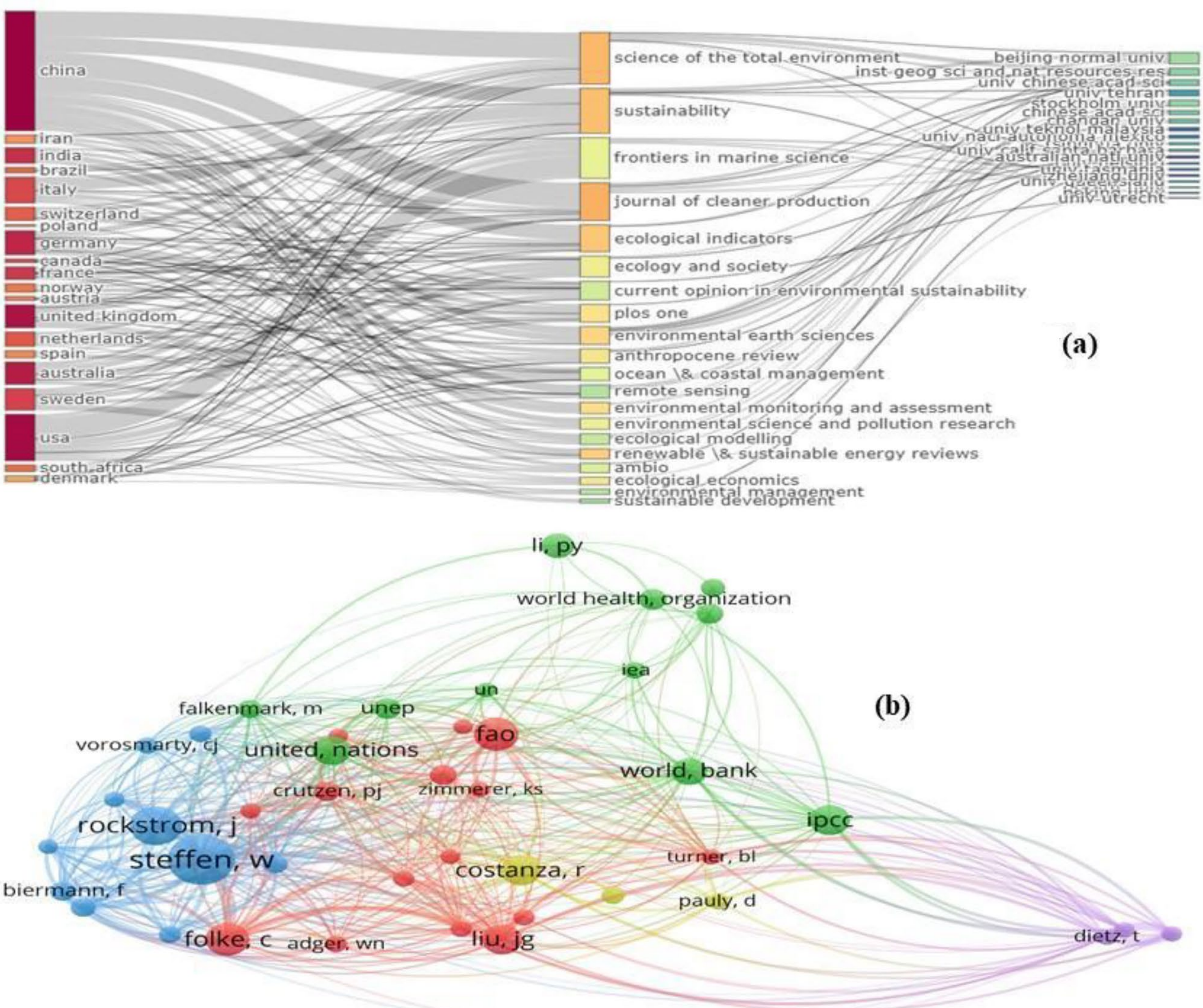

Fig. 7 Analysis of research trajectories, affiliations, and authors. **a** Temporal trend of thematic development of Anthropocene, MDG, and SDG (AMSDG) related research. Three-field plots showing nations on the left side, publishing sources in the middle and best-performing affiliations on the right side. China accounts for the vast majority of publications and affiliations related to the AMSDG research. b Co-citation network of the authors. Five colours represent five different clusters of co-cited authors

4.6 Citation analysis

Five clusters were present in the citation network of organizations. 9 institutions were in Cluster 1, 8 institutions are in Cluster 2, 6 institutions were in Cluster 3, 2 institutions were in Cluster 4, and 1 institution was in Cluster 5. As seen from these five clusters, the Chinese Academy of Sciences, The University of California, Santa Barbara, Stockholm University, Zhejiang University, and the University of Amsterdam were the most cited organizations related to AMSDG-related study (Fig. S22).

Co-citation analysis is the technique of locating pairs of publications that are credited in the same source article. When a significant number of authors co-cite consistent pairs of publications, clusters of research arise. The theme of such clusters of co-cited publications is likely to be the same. It's a method for exploring the cognitive structure of a scientific field. For the authors, there were five clusters. 15 authors were in Cluster 1, 11 authors in Cluster 2, 10 authors in Cluster 3, and Clusters 4 and 5 each had three authors. Report materials that have been approved by the institutions have been excluded. The top three authors from each cluster in terms of betweenness were Folke C (572), Liu JG (455), and FAO (311) in cluster 1; Falkenmark M (156), Li PY (34), and Rao NS (15) in cluster 2; Steffen W (882), Rockstrom J (628), and Galaz V (424) in cluster 3; Costanza R (324), Pauly D (139), and Junk WJ (16) in cluster 4; Jorgenson AK (446), Dietz T (435), and York R (429) in cluster 5 (Fig. 7b). We can regard the UN, WHO, World Bank, IPCC (Intergovernmental Panel on Climate Change), IEA (International Energy Agency), and UNEP (United Nations Environment Programme) as the six most essential institutions working on AMSDG-related research publications. Likewise, if the co-citation network of sources is considered, there are five clusters. 12 journals were in Cluster 1 (red), 7 journals in Cluster 2 (violet), 11 journals in Cluster 3 (green), 8 journals in Cluster 4 (yellow), and 10 journals in Cluster 5 (sky blue) (Fig. S23). Three important journals from each cluster in terms of betweenness were *Sci. Total Environ.* (13,850), *Environ. Sci. Technol.* (7788), and *Environ. Pollut.* (5859) in cluster 1; *J. Clean. Prod.* (8459), *Ecol. Econ.* (8467), and *Ecol. Indic.* (4944) in cluster 2; *Science* (24,573), *Glob. Environ. Change* (9772), and *Ecol. Soc.* (8010) in cluster 3; *Plos One* (8891), *Glob. Change Biol.* (9460), and *Conserv. Biol.* (6204) in cluster 4; *J. Hydrol.* (5426), *Remote Sens. Environ* (5115), and*Clim. Change* (6026) in cluster 5. From the analysis of a co-citation network of references, we got five clusters. The best reference from each cluster based on the link strength was Foley JA, 2005, *Science* (from the red cluster); Costanza R, 1997, *Nature* (from the yellow cluster); Steffen W, 2007, *Ambio* (from the violet cluster); Rockstrom J, 2009, *Nature*; (from sky blue cluster); and Crutzen PJ, 2002, *Nature*; (from the green cluster) (Fig. S24).

We can understand which works were quoted more frequently by other works across periods by studying historiography (i.e., annually). This was calculated using the local citation score (LCS) and the global citation score (GCS). As per the local citation score, the five leading papers that were cited most by other works from the period of 1992 to 2022 were Griggs D, 2013, *Nature*; Subba Rao N, 2006, *Environ. Geol.*; Griggs D, 2014, *Ecol. Soc.*; Newbold T, 2016, *Science*; and Johnson CN, 2017, *Science*. The top five articles that were cited the most by other works from 1992 to 2022, according to global citation score are Griggs D, 2013, *Nature*; Monteiro CA, 2018, *Public Health Nutr.*; Newbold T, 2016, *Science*; Liu Haibin LH, 2010, *Resour Conserv Recycl*; and Weiss DJ, 2018, *Nature* (Fig. S25).

6 clusters emerged from the citation analysis of countries. Cluster 1 had 7 countries. Clusters 2, 3, and 4 in each country. Cluster 5 had 4 countries and Cluster 6 had 2 countries. USA, Germany, Australia, China, India, and Italy were the most cited countries from these 6 clusters (Fig. S26).

4.7 Discussion

This study shows how research on the AMSDG has advanced in the years after the UN SDG and MDG were formed throughout the world. A summary of research in the aforementioned field was offered, including authors' information, organizations, journals, countries, articles, keywords, research advancements, and so forth. The findings showed that quantitative analysis and data presentation regarding research publications over a broad array of topics, journals, and countries all reflected growth rates in the specific study field, which was quite similar to the conclusion of studies performed by Olawumi and Chan (2018) and Payumo et al. (2021).

In terms of corresponding authors (from 52 countries) and multi-country publications (MCP), China, the USA, and the UK were the top three countries (52 countries). This signified that just a few nations have taken part in this study which was also reflected in the study of Meschede (2020). Although human activities have impeded the fulfilment of SDG, many small, less economically developed nations are still not sufficiently involved in AMSDG research that ultimately would help in human development. Three universities were at the top of the list of affiliations that had produced AMSDG-related scientific publications: Beijing Normal University (China), Stockholm University (Sweden), and the Institute of Geographical Sciences and Natural Resources Research (China). This finding and the results derived from the studies of Olawumi and Chan (2018) and Zhu and Hua (2017) are somewhat identical. Wu J, Zhang Y, and Li S were the most productive of the 2185 writers involved in AMSDG-related research papers. *J. Clean. Prod., Sci. Total Environ.*, and *Sustainability* were three of the most productive sources of AMSDG-related academic articles. In previous years, these journals also experienced strong citation bursts and co-citation frequency. Olawumi and Chan (2018) and Wang et al. (2019) mentioned several high-impact journals that give significant insights into sustainability research, which is consistent with our evaluation of the most productive journals. China, the USA, and India were the top three nations producing single-country publications (SCP) in this subject, out of 52. *Science, Nature*, and *Sci. Total Environ.* were the most co-citing sources in the AMSDG-linked domain, out of the 50 sources of co-citations. This outcome is consistent with the keyword analysis in the study of Olawumi and Chan (2018). Rockström et al.'s (2009b) study were one of the most cited studies according to co-citation analysis of references as well as authors, which was also evidenced by the study of Zhu and Hua (2017).

Herrera-Calderon et al. (2021) found in their article that institutions are the knowledge-generating entities for the SDG. Similarly, according to our findings, the institutions engaged in the publishing of these publications are mainly research centres and universities, which play an essential role as knowledge-generating bodies in the AMSDG-related fields. Universities are now graded based on the amount of SDG-related research they produce. Recently, numerous academic organizations throughout the world have developed a strategy to eliminate undernourishment through social programs (Chang and Lien 2020), projects, and curricula that are led to integrate the SDG in some courses to achieve SDG 2 (Leal Filho et al. 2019). For example, in 2019, the Universidad de Chile and the FAO signed a contract to establish the Forest Engineering School, provide technical help for the food processing industry through the Faculty of Agronomy, and implemented training programs in the agriculture research institutions and more in food security (FAO 2021). Like, the Pacific Alliance promoted commercial development and common aspects such as poverty reduction and inequality reduction between member countries, but there are a few shortfalls that could stymie progress, like funding in science and innovation and political assessments to reach this goal (Salvia et al. 2019). The above-said initiatives are some noticeable steps that are already taken by different bodies throughout the world in achieving SDG and in uplifting SDG research.

Scientific output in the fields of the AMSDG increased in a linear and rising manner from 2016 to 2019. This conclusion is comparable to that of Sweileh (2020), who examined articles relevant to the aim of good health and well-being (2015–2019). But if we look at annual scientific production from 2020 onwards, a significant reduction in the annual production of AMSDG-related documents was found. Eventually, it is very important to know the reasons for the lack of research in this field, i.e., the underlying reasons for the disinterest of the authors in this field, otherwise, the major obstacles in the way of SDG development will remain unknown which will ultimately prevent SDG achievement and necessary policy-making.

The global perspective and collaboration are crucial aspects of the SDG. According to the findings of the current study, the strength and amount of research collaboration in AMSDG-related research vary by geographic location. As seen in the results, Beijing Normal University, the University of the Chinese Academy of Sciences, the Institute of Geographical Sciences, Stockholm University, Australian National University, Columbia University, Monash University, and the University of Oxford were mainly involved in multi-country collaboration regarding research in this field. Based on the current study, the USA, China, the UK, Germany, Norway, Italy, Spain, and Canadian institutions had a higher share of international collaborations than nations in Asia, South Africa, and Australia. This study's scientific collaboration among countries is identical to Meschede (2020). Policymakers in areas with poor research outcomes in the Anthropocene and SDG should promote and facilitate collaborative research with researchers from the USA, Europe, and China. This type of research partnership is thought to garner more funding and increase the possibility of publishing high-impact papers (Didegah and Thelwall 2013; Herrera-Calderon et al. 2021). Based on our findings, we agree with Didegah and Thelwall that articles co-authored by authors from many organizations receive much more citations than papers co-authored by writers from a single organization (Didegah and Thelwall 2013). Our findings also indicate that, both at the author and organizational level, collaboration rates have risen over time, which is also reflected in the study by Payumo et al. (2021). This increase in collaboration could be explained by higher research funding, the availability of other supplies like infrastructure and labour, as well as potential changes in the types of research questions investigated and methodologies employed, which may make SDG even more flexible and adaptable to cooperative research (Wagner 2018, Adams 2013). Spatial proximity persists as a significant motivator for cooperative SDG research, supporting the conclusions of Glänzel and Schubert (2005).

Based on the retrieved literature, the most researched SDGs were health (SDG 3), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11), responsible consumption and production (SDG 12), and climate action (SDG 13). This result is partially similar to that of Salvia et al. (2019). In general, based on our study, socio-economic goals are represented rather well, whereas environmental objectives are only marginally incorporated into policy initiatives. The findings of the 2018 study by Korfgen et al., where social goals prevail because fundamental human needs are supported by environmental systems, our study also showed this tendency. According to Keywords Plus, the terms "climate change," "sustainable development," "management," "impacts," "impact," "biodiversity," "conservation," "land use," "anthropocene," "ecosystem services," and "anthropogenic activities" were the most often used. This shows that most trending research topics are related to the environment and anthropogenic effects on SDG. Climate change and global warming are big worldwide challenges to life and the economy on Earth. Conflicts around the Anthropocene notion can assist the investigators in developing new conceptual formulations and integrative approaches needed to produce useful information that is consistent with globalization and sustainability challenges.

4.8 Limitations

There are a few drawbacks to this study, and these should be considered while reading. To begin with, the present study only looked at peer-reviewed literature and excluded grey literature, which occasionally contained critical information on progress toward achieving the MDG or SDG. Second, only publications from WoS databases were used in our investigation. The number of publications produced by nations or regions having regional journals that haven't been listed in WoS was negatively impacted by this. Third, the present study's strategy did not discriminate between publications that concentrated on the AMSDG and those that just included the phrase. Likewise, the inverse is also true. A paper might tackle a subject like health without referencing the SDG. Fourth, the records for 2022 were incomplete because we ran our query after mid-2022. Fifth, a different methodological approach from ours could produce a different outcome. Because the approach/method typically makes a significant impact. Various methods can change the final country rankings and different interpretations of the SDGs and points of relevance view can be influenced by search term selection, how they are integrated, and query structure.

4.9 Policy and future recommendations

This study can be helpful to understand the effects of anthropogenic activities on MDG, SDG and steps or initiatives taken to achieve SDG. This work may be used as a guide to undertake new studies in anthropogenic activities and sustainability research from a bibliometric standpoint, expanding to additional sources and information systems, as a recommendation. This research aids government agencies in formulating research policies and implementing them by identifying the major contributors and institutions with whom they might contact to help them develop policies that promote long-term sustainability. The research yielded useful information and a thorough awareness of the important researchers, institutions, current scenario of the subject of study, rising trends, and important topics for scholars. In addition, the research assisted in the critical discoveries to improve the execution of a comprehensive approach to attain holistic sustainability, which is extremely helpful to both human civilization and the mother planet. Junior researchers will use the data of this study to identify gaps and advancements in sustainability research, and academics will collaborate with other researchers in their fields. To have a uniform SDG roadmap for every nation is impractical. So, each nation must create its customized policies and standards while keeping an overall objective at the forefront. Governments should take the initiatives to make the datasets or databases related to different indicators of the SDG updated and also openly accessible, which will facilitate the smooth progress of research. Besides these, policies and governance should be stringent. Furthermore, policies should be made based on the opinions of three stakeholders (academics, policymakers, and common people) that will provide the real-world scenario to better achieve environmental sustainability as well as SDGs. So, further investigation might focus on the knowledge transfer between academic and non-academic stakeholders, customised policy making, and tracking the implementation of SDG policies in the real world (Olawumi and Chan 2018). Other areas for future research based on current studies could include the use of sustainability knowledge in waste management, carbon footprint reduction, campus sustainability, sustainable infrastructure, sustainable smart city formation, green neighbourhoods, and the development of country-specific sustainability evaluation indexes (Olawumi and Chan 2018).

5 Conclusion

The MDGs signalled a significant and successful worldwide mobilisation strategy to achieve several crucial socioeconomic goals around the globe. Though the global environmental goals needed to have more visibility in a world already plagued by severe climate change and some other severe ecological evils primarily driven by anthropogenic activity. The result was the introduction of the Sustainable Development Goals (SDGs), an innovative roadmap that offers an opportunity to apply the lessons discovered during the previous phase and concentrate on creating a sustainable world where environmental sustainability, social equality, and economic progress are given equal weight (Díaz-López et al. 2021).

Despite the promising potential of that SDG planning, we observed more discussion about integrated research than actual implementation (Biermann et al. 2020). So, understanding the benefits and drawbacks of various knowledge areas and SDG methods is thus necessary, with the idea of the Anthropocene acting as a connecting thread.

The outcomes of our study have implications for how well we comprehend the current scenario of collaboration and how to draw out stable, long-term collaborations, which will ultimately lead to the fulfilment of SDG 17. This study enables the development of research policies, significantly improving the subject of government actions. The research results also assist in identifying research gaps in the existing Anthropocene, MDG, and SDG-related literature and, as a result, offer suggestions for future studies.

Finally, we may infer that scientific knowledge on the social side, as well as societal knowledge on the theoretical underpinnings, are both crucial. More studies might look at the rate of beneficial and detrimental effects of anthropogenic activities on SDG and the transfer of that knowledge into actual SDG achievement.

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Author contributions NG: Conceptualization, Writing—Original Draft, Writing—Review & Editing, Visualization, AR: Conceptualization, Methodology, Software, Formal analysis, Data Curation, Writing—Original Draft, Visualization, KP: Writing—Review & Editing, Supervision, Project administration.

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Data availability Data will be available on request.

Declarations

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

References

Adams AC (2013) Sustainability reporting and performance management in universities: Challenges and benefits. Sustain Account 4(3):384–392. https://doi.org/10.1108/SAMPJ-12-2012-0044

Allison PD, de Solla PD, Griffith BC, Moravcsik MJ, Stewart JA (1976) Lotka's law: a problem in its interpretation and application. Soc Stud Sci 6(2):269–276. https://doi.org/10.1177/030631277600600205

Armitage CS, Lorenz M, Mikki S (2020) Mapping scholarly publications related to the Sustainable Development Goals—do independent bibliometric approaches get the same results. Quant Sci Stud 1(3):1092–1108. https://doi.org/10.1162/qss_a_00071

Bais F, Luca RM, Bornman JF et al (2018) Environmental effects of ozone depletion, UV radiation and interactions with climate change: UNEP Environmental Effects Assessment Panel, update 2017. Photochem Photobiol Sci 17(2):127–179. https://doi.org/10.1039/c7pp90043k

Belli S (2016) Mapping a controversy of our time: The Anthropocene. Riv Filos 22(3):33–49. http://www.losguardo.net/en/mapping-a-controversy-of-our-time-the-anthropocene-2/. Accessed 8 Dec 2022

Biermann C, Kelley LC, Lave R (2020) Putting the Anthropocene into practice: Methodological implications. Ann Am Assoc Geogr 111(3):808–818. https://doi.org/10.1080/24694452.2020.1835456

Borgwardt F, Robinson L, Trauner D et al (2019) Exploring variability in environmental impact risk from human activities across aquatic ecosystems. Sci Total Environ 652:1396–1408. https://doi.org/10.1016/j.scitotenv.2018.10.339

Bowen KJ, Cradock-Henry NA, Koch F, Patterson J, Häyhä T, Vogt J, Barbi F (2017) Implementing the "Sustainable Development Goals": towards addressing three key governance challenges—collective action, trade-offs, and accountability. Curr Opin Environ Sustain 26:90–96. https://doi.org/10.1016/j.cosust.2017.05.002

Brondizio ES, O'Brien K, Bai X et al (2016) Re-conceptualizing the Anthropocene: a call for collaboration. Glob Environ Change 39:318–327. https://doi.org/10.1016/j.gloenvcha.2016.02.006

Bullitt-Jonas M (2021) Climate change, addiction, and spiritual liberation. Religions 12(9):709. https://doi.org/10.3390/rel12090709

Ceballos G, Ehrlich PR, Raven PH (2020) Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction. PNAS 117(24):13596–13602. https://doi.org/10.1073/pnas.1922686117

Chang YC, Lien HL (2020) Mapping course sustainability by embedding the SDGs inventory into the university curriculum: a case study from national university of Kaohsiung in Taiwan. Sustainability 12(10):4274. https://doi.org/10.3390/su12104274

Cheung WW, Lam VW, Sarmiento JL, Kearney K, Watson R, Pauly D (2009) Projecting global marine biodiversity impacts under climate change scenarios. Fish Fish 10(3):235–251. https://doi.org/10.1111/j.1467-2979.2008.00315.x

Correia RA, Correia ZC, Malhado AC, Ladle RJ (2018) Pivotal 20th century contributions to the development of the Anthropocene concept. Curr Sci 115(10):1871–1875. https://doi.org/10.18520/cs/v115/i10/1871-1875

Díaz-López C, Martín-Blanco C, De la Torre Bayo JJ, Rubio-Rivera B, Zamorano M (2021) Analyzing the scientific evolution of the sustainable development goals. Appl Sci 11(18):8286. https://doi.org/10.3390/app11188286

Didegah F, Thelwall M (2013) Which factors help authors produce the highest impact research? Collaboration, journal and document properties. J Informet 7(4):861–873. https://doi.org/10.1016/j.joi.2013.08.006

Edgeworth M, de Richter BD, Colin W, Peter H, Neal C, Price SJ (2015) Diachronous beginnings of the Anthropocene: The lower bounding surface of anthropogenic deposits. Anthr Rev 2(1):33–58. https://doi.org/10.1177/2053019614565394

Fang L, Wang L, Chen W, Sun J, Cao Q, Wang S, Wang L (2021) Identifying the impacts of natural and human factors on ecosystem service in the Yangtze and Yellow River Basins. J Clean Prod 314:127995. https://doi.org/10.1016/j.jclepro.2021.127995

Food and Agriculture Organization of the United Nations (FAO) (2021) FAO and University of Chile will promote sustainable development in the agri-food sector. FAO. https://www.fao.org/news/story/en/item/1176233/icode/. Accessed 6 Dec 2022

Fuso Nerini F, Sovacool B, Hughes N et al (2019) Connecting climate action with other sustainable development goals. Nat Sustain 2(8):674–680. https://doi.org/10.1038/s41893-019-0334-y

Glänzel W, Czerwon H (1996) A new methodological approach to bibliographic coupling and its application to the national, regional and institutional level. Scientometrics 37(2):195–221. https://doi.org/10.1007/bf02093621

Glänzel W, Schubert A (2005) Analysing scientific networks through co-authorship. In: Moed HF, Glänzel W, Schmoch U (eds)

Handbook of quantitative science and technology research. Springer, Dordrecht, pp 257–276 (**ISBN 978-1-4020-2755-0**)
Hall BD, Crotwell AM, Kitzis DR, Mefford T, Miller BR, Schibig MF, Tans PP (2021) Revision of the World Meteorological Organization Global Atmosphere Watch (WMO/GAW) CO2 calibration scale. Atmos Meas Tech 14:3015–3032. https://doi.org/10.5194/amt-14-3015-2021
Herrera-Calderon O, Yuli-Posadas RÁ, Peña-Rojas G, Andía-Ayme V, Hañari-Quispe RD, Gregorio-Chaviano O (2021) A bibliometric analysis of the scientific production related to "zero hunger" as a sustainable development goal: trends of the pacific alliance towards 2030. Agric Food Secur 10(1):1–15. https://doi.org/10.1186/s40066-021-00315-8
Huan Y, Liang T, Li H, Zhang C (2021) A systematic method for assessing progress of achieving sustainable development goals: a case study of 15 countries. Sci Total Environ 752:141875. https://doi.org/10.1016/j.scitotenv.2020.141875
Jarneving B (2007) Bibliographic coupling and its application to research-front and other core documents. J Informetr 1(4):287–307. https://doi.org/10.1016/j.joi.2007.07.004
Knitter D, Augustin K, Biniyaz E, Hamer W, Kuhwald M, Schwanebeck M, Duttmann R (2019) Geography and the Anthropocene: critical approaches needed. Prog Phys Geogr 43(3):451–461. https://doi.org/10.1177/0309133319829395
Körfgen A, Förster K, Glatz I, Maier S, Becsi B, Meyer A, Kromp-Kolb H, Stötter J (2018) It's a Hit! Mapping Austrian research contributions to the sustainable development goals. Sustainability 10(9):3295. https://doi.org/10.3390/su10093295
Leal Filho W, Shiel C, Paço A et al (2019) Sustainable Development Goals and sustainability teaching at universities: Falling behind or getting ahead of the pack? J Clean Prod 232:285–294. https://doi.org/10.1016/j.jclepro.2019.05.309
Lu YL, Nakicenovic N, Visbeck M, Stevance AS (2015) Policy: five priorities for the UN sustainable development goals. Nature 521(7550):28–28. https://doi.org/10.1038/520432a
Mahmood I, Imadi SR, Shazadi K, Gul A, Hakeem KR (2016) Effects of pesticides on environment. In: Hakeem K, Akhtar M, Abdullah S (eds) Plant, soil and microbes. Springer, Cham, pp 253–269
Meschede C (2020) The sustainable development goals in scientific literature: a bibliometric overview at the meta-level. Sustainability 12(11):4461. https://doi.org/10.3390/su12114461
Milan BF (2017) Clean water and sanitation for all: interactions with other sustainable development goals. Sustain Water Resour Manag 3(4):479–489. https://doi.org/10.1007/s40899-017-0117-4
Nilsson M, Chisholm E, Griggs D et al (2018) Mapping interactions between the sustainable development goals: lessons learned and ways forward. Sustain Sci 13:1489–1503. https://doi.org/10.1007/s11625-018-0604-z
Olawumi TO, Chan DW (2018) A scientometric review of global research on sustainability and sustainable development. J Clean Prod 183:231–250. https://doi.org/10.1016/j.jclepro.2018.02.162
Payumo J, He G, Manjunatha AC, Higgins D, Calvert S (2021) Mapping collaborations and partnerships in SDG research. Front Res Metr Anal 5:612442. https://doi.org/10.3389/frma.2020.612442
Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO (2014) The biodiversity of species and their rates of extinction, distribution, and protection. Science 344(6187):1246752. https://doi.org/10.1126/science.1246752
Prăvălie R (2014) Nuclear weapons tests and environmental consequences: a global perspective. Ambio 43(6):729–744. https://doi.org/10.1007/s13280-014-0491-1
Reid WV, Mooney HA, Cropper A et al (2005) Ecosystems and human well-being-synthesis: a report of the Millennium Ecosystem Assessment. Island Press, Washington, DC, pp 3–20 (**ISBN 1-59726-040-1**)
Rockström J, Steffen W, Noone K et al (2009a) A safe operating space for humanity. Nature 461(7263):472–475. https://doi.org/10.1038/461472a
Rockström J, Steffen W, Noone K et al (2009b) Planetary boundaries: exploring the safe operating space for humanity. Ecol Soc 14(2). http://www.jstor.org/stable/26268316
Roy A, Basu A, Su Y, Li Y, Dong X (2022) Understanding recent trends in global sustainable development goal 6 research: scientometric, text mining and an improved framework for future research. Sustainability 14(4):2208. https://doi.org/10.3390/su14042208
Sahney S, Benton MJ, Ferry PA (2010) Links between global taxonomic diversity, ecological diversity and the expansion of vertebrates on land. Biol Lett 6(4):544–547. https://doi.org/10.1098/rsbl.2009.1024
Salvia AL, Leal Filho W, Brandli LL, Griebeler JS (2019) Assessing research trends related to sustainable development goals: local and global issues. J Clean Prod 208:841–849. https://doi.org/10.1016/j.jclepro.2018.09.242
Steffen W, Grinevald J, Crutzen P, McNeill J (2011) The Anthropocene: conceptual and historical perspectives. Philos Trans R Soc A 369(1938):842–867. https://doi.org/10.1098/rsta.2010.0327
Sweileh WM (2020) Bibliometric analysis of scientific publications on "sustainable development goals" with emphasis on "good health and well-being" goal (2015–2019). Glob Health 16:68. https://doi.org/10.1186/s12992-020-00602-2
Syvitski J, Waters CN, Day J et al (2020) Extraordinary human energy consumption and resultant geological impacts beginning around 1950 CE initiated the proposed Anthropocene Epoch. Commun Earth Environ 1(32):32. https://doi.org/10.1038/s43247-020-00029-y
Vignieri S (2014) Vanishing fauna. Science 345(6195):392–395. https://doi.org/10.1126/science.345.6195.392
Wagner DA (2018) Technology for education in low-income countries: Supporting the UN sustainable development goals. In: Lubin I (ed) ICT-supported innovations in small countries and developing regions: perspectives and recommendations for international education. Springer, Cham, pp 51–74 (**ISBN 978-3-319-67657-9**)
Wang M, Liu P, Gu Z, Cheng H, Li X (2019) A scientometric review of resource recycling industry. Int J Environ Res Public Health 16(23):4654. https://doi.org/10.3390/ijerph16234654
Waters CN, Zalasiewicz J, Summerhayes C et al (2016) The Anthropocene is functionally and stratigraphically distinct from the Holocene. Science 351(6269):2622. https://doi.org/10.1126/science.aad2622
Zhu J, Hua W (2017) Visualizing the knowledge domain of sustainable development research between 1987 and 2015: A bibliometric analysis. Scientometrics 110:893–914. https://doi.org/10.1007/s11192-016-2187-8