Environmental Research Communications

TOPICAL REVIEW

Land pollution research: progress, challenges, and prospects

Ling Gao1, Tianzhen Hu1, Li Li2✉, Maoyuan Zhou1 and Baoqing Zhu3,4 ✉
1 School of Economics, Xiamen University, People’s Republic of China
2 School of Marxism, Fudan University, People’s Republic of China
3 School of Public Affairs, Zhejiang University, People’s Republic of China
4 School of Public Affairs, Zhejiang University, People’s Republic of China
* Corresponding author.

E-mail: gaocen@xmu.edu.cn, w083126@nwafu.edu.cn, lichs@zju.edu.cn, xmuzmy@163.com and swbhtz@hz.cn

Keywords: land pollution, literature measurement, visualization, literature review, citespace

Abstract

This paper comprehensively searched all the literature on the subject of land pollution through the core collection of the Web of Science database, and systematically processed the research literature from 1944 to 2021 using CiteSpace software, and carried out bibliometric analysis and visual presentation, which uncovers the LP research dynamics in detail, and draw the following conclusions: First, through the indicator of betweenness centrality, the basic authors and journals of the subject are obtained; from the perspective of publishing institutions and affiliated countries, the United States is an important research center for LP. Second, keywords such as ‘land use’, ‘air pollution’, ‘impact’, ‘soil pollution’ and ‘management’ are all high-frequency words. The results of keyword clustering and co-citation information in the literature indicate the natural-social dimensions of LP research, such as the use and quality of air, land, and water, as well as urbanization and environmental policies. However, challenges remain and current LP studies are still characterized by a certain degree of fragmentation, which should be enriched by combining land use changes and should require combining experimental results with socioeconomic analysis to propose joint LP remediation approaches. Finally, local and regional forces may strongly influence the LP process, and the drivers of globalization should be emphasized.

1. Introduction

Land is the space carrier of human activities, the most basic production factor for human social and economic development, and the most basic survival resource for urban and rural residents. Since the 1960s, the problem of land pollution (LP) has gradually attracted widespread attention. On the one hand, scholars have paid attention to the causes of LP from the aspects of waste treatment, mining, urbanization, agrochemicals, and soil erosion (Heidi et al. 2008, Guo et al. 2020, Lee et al. 2021). On the other hand, scholars have also explored the impact of LP from the aspects of socio-economic development, ecological environment, and human health, and explored ways to control LP from the aspects of pollution reduction and land restoration (Mone et al. 2004, Jin et al. 2018). Therefore, the challenge of LP is how to solve the relationship between meeting human needs and maintaining the long-term ability of the biosphere to provide goods and services (Foley et al. 2005, Swette and Lambin 2021).

There are two approaches to defining LP in academia: soil pollution in a narrow sense and LP in a broad sense. In a narrow sense, soil pollution and LP are not a term (soil pollution focuses on factory chemicals or sewage and other wastewater). In this article, we will define it more broadly, including garbage and industrial waste, agricultural pesticides and fertilizers, the impact of mining and other industrial firms, the undesirable consequences of urbanization, and the systemic destruction of soil by over-intensive agriculture. As an important factor affecting human health, LP control poses a great challenge to the function of the ecosystem, which has a significant impact on human development (Ma et al. 2020). How to take effective measures to deal with the deteriorating LP, guarantee and improve the quality of land resources, and further understand the dynamic relationship between the natural environment and human life has become one of the urgent problems in contemporary academia.

© 2022 The Author(s). Published by IOP Publishing Ltd
Based on the above background, this research conducted a comprehensive search of all the documents on the subject of 'land pollution' through the core collection of the Web of Science database, and used CiteSpace software to systematically process the research documents from 1944 to 2021 and conduct a bibliometric analysis. LP research dynamics revealed in detail based on visual statistics. This article attempts to address the following issues:

(1) What are the general trends of LP research?

(2) Which common issues in the natural-social dimension of LP research have received attention?

(3) What are the research challenges and future directions?

2. Data and methods

2.1. Data source and data selection
The sample data selected in this paper comes from the core collection of the Web of Science database (https://clarivate.com/webofsciencegroup/solutions/web-of-science-core-collection/), accessed on September 10, 2021. By setting the search subject in the core collection of the Web of Science database as ‘land pollution’, the document type as ‘Article’, the language as ‘English’, and the complete time interval from 1944 to 2021, we found the total volume of published papers issued is 3022, and the final sample is subject to the effective processing of the software. The browsing/processing time is September 11, 2021. The overall trend is shown in figure 1. It should be noted that the first article appeared in 1944. After 1970, the volume of published papers gradually maintained a continuity in time, but the volume of published papers every year was small. Therefore, in order to facilitate the presentation, we aggregate the data from 1944 to 1999 (202 articles in total), and retain the original data for the volume of published papers published from 2000 to 2021. It can be found that the general trend of the volume of research papers on LP from 1944 to 2020 is on the rise.

2.2. Bibliometric methods
We mainly use CiteSpace software to conduct bibliometric research. CiteSpace is a data mining and visualization analysis software jointly developed by Professor Chen Chaomei from the School of Information Science and Technology of Drexel University and WISE Laboratory of Dalian University of Technology. The version we use is CiteSpace 5.7. R2. Compared with the previous version of CiteSpace software, a major advantage of this software version is that there is no need to format the documents in the core collection of the Web of Science database.

5 Curated by a team of in-house Web of Science™ Editors, the Web of Science Core Collection™ contains over 21,100 peer-reviewed, high-quality scholarly journals published worldwide (including Open Access journals) in over 250 sciences, social sciences, and arts & humanities disciplines.

6 CiteSpace software can be used to observe the research trend or dynamics of a certain research field, and it is a bibliometric tool that presents authors, research institutions, keywords, and other aspects in a visual map so that relevant researchers can easily and efficiently grasp the specific or basic situation of the research field.
The specific operation steps of our paper are as follows: select all the 3022 documents filtered in the core collection of the Web of Science database and export them as TXT format files, save them in the Data file and create a new Project file. After running the CiteSpace software, you can get visual maps such as research author, research institution, keyword clustering, keyword emergence, keyword time zone map, document co-citation, author co-citation, etc., and finally, the research trends of LP perform quantitative analysis and visualization, from which the research context, research hotspots and frontier topics of the subject can be derived.

3. Results and visualization of literatures concerning LP research

Running the CiteSpace software to process the keyword ‘land pollution’, the time slice is set to 1 year, and the effective processing results are 2987. We get the following results.

3.1. Analysis of general information

3.1.1. Analysis of authors

Using the Author analysis function of CiteSpace, the author’s co-occurrence network map is obtained, as shown in figure 2. Among them, the size of the font indicates the volume of articles published by the author or the importance of the author (the same below), and the line between the authors indicates the cooperative relationship between each other. The results show that the top three authors by the volume of published papers are: Mark Nieuwenhuijsen, with 16 articles in total, and the first article was published in 2014 (such as Nieuwenhuijsen et al 2014a, 2014b); Jordi Sunyer (tied for the first with Nieuwenhuijsen), both of which were 16 articles, and the first article was published in 2016 (such as Iñiguez et al 2016a, Porta et al 2016b); Bert Brunekreef, 15 articles in total, first published in 2014 (such as Wang et al 2014); Michael Jerrett, 12 articles in total, first published in 2009 (such as Jerrett et al 2009, Su et al 2009); Marianne Hatzopoulou (tied for third with Brunekreef), both of 12 articles, first published in 2016 (such as Shekarrizfard et al 2016, Weichenthal et al 2016).

By analyzing the co-citation and betweenness centrality of key nodes, the author’s co-citation analysis is based on the author as a unit to study the situation where the documents published by multiple authors are cited by other authors at the same time. This can identify authoritative authors with high influence in the field. According to the betweenness centrality indicator, the author’s co-citation map is shown in figure 3. It turns out that among the scholars of environmental pollution research, the top four betweenness centrality indicator of authors are Braden JB (0.14), Cervero R (0.08), Brunekreef B (0.08, tied for second), and Hoek G (0.07).

3.1.2. Analysis of research institutions

Using the Institutional analysis function of CiteSpace, we get the figure of the institutional co-occurrence network, as shown in figure 4.

According to the volume of published papers and centrality indicators, the statistical information of the institution is shown in table 1. It turns out that the top five publications are: Chinese Academy of Sciences (154 articles), University of Chinese Academy of Sciences (72 articles), Beijing Normal University (43 articles), Utrecht University (41 articles), and University of California, Berkeley (34 articles). The centrality index reflects the cooperative relationship between institutions. The presentation of the centrality index in the paper is automatically arranged and generated by the software, so there is a situation where the same centrality involves
Figure 3. Author’s Co-citation Map.

Figure 4. Co-occurrence Map of Research Institutions.
multiple institutions. According to table 2, Utrecht University in the Netherlands and University of Melbourne in Australia are ranked first in terms of centrality, both of which are 0.06. It should be noted that ‘Years’ in the table refers to the time when the author’s or institution’s first article appeared.

3.1.3. Analysis of author’s nations
Using the Nations analysis function of CiteSpace, we get the country co-occurrence network map, as shown in figure 5.

Similarly, according to the volume of published papers and centrality indicators, the relevant statistical information is organized as shown in tables 3 and 4. It can be seen that the US (943 papers), China (790 papers), and the UK (297 papers) ranked the top three in terms of publication volume. The top three countries in terms of centrality are the US (0.32), Netherlands (0.21), and the UK (0.2). It can be found that the US is far ahead not only in the volume of published papers but also in centrality indicators, so it is the most important nation in the study of LP. The total amount of Chinese publications is also very high, but the centrality is not high, which shows that China needs to further strengthen its international cooperation in the publication of documents in the future, and better integrate with the research on worldwide frontier issues.

3.1.4. Analysis of journals
By searching the LP in the database, we can get the journals that focus on this topic. As shown in figure 6, we can find that the top five journals are *Sustainability* (242 papers), *International Journal of Environmental Research and Public Health* (Abbreviation: IJERPH, 193 papers), *Land Use Policy* (108 papers), *Science of the Total Environment* (98 papers) and *Journal of Cleaner Production* (79 papers).

Selecting the Cited Journal option in the CiteSpace node type to perform a ‘journal co-citation’ analysis. From this we have obtained high-impact journals among foreign journals. The results are shown in figure 7. According to the centrality index, relevant statistical information is shown in table 5. And, the information of co-citation frequency is reflected in table 6. It can be found that AMBIO (0.13) ranks first in centrality, so it is an authoritative journal for the study of LP.

| Table 1. Volume of published papers by institutions and centrality (Top10). |
|-----------------------------|-----------------------------|-----------------------------|
| Volume of papers | Institutions | Years |
| 154 | Chinese academy of sciences | 2007 |
| 72 | University of chinese academy of sciences | 2014 |
| 43 | Beijing normal university | 2011 |
| 41 | Utrecht university | 2010 |
| 34 | University of california, berkeley | 2000 |
| 30 | Tsinghua university | 2012 |
| 28 | China university of geosciences | 2018 |
| 27 | University of hong kong | 2001 |
| 27 | Wuhan university | 2017 |
| 26 | University of washington | 2003 |

| Table 2. Centrality of institutions (Top10). |
|-----------------------------|-----------------------------|-----------------------------|
| Centrality | Institutions | Years |
| 0.06 | Utrecht university | 2010 |
| 0.06 | University of melbourne | 2005 |
| 0.05 | University of washington | 2003 |
| 0.05 | University of british columbia | 1999 |
| 0.04 | Chinese academy of sciences | 2007 |
| 0.04 | University of california, berkeley | 2000 |
| 0.04 | Tsinghua university | 2012 |
| 0.04 | Peking university | 2015 |
| 0.04 | Mcgill university | 2013 |
| 0.04 | University of illinois | 1999 |

7 AMBIO is an international environmental and ecological science journal founded by the Royal Swedish Academy of Sciences in 1972. AMBIO’s main topics include environmental impact assessment, biodiversity and its protection, environment and sustainable development, animal and plant ecosystems and global changes, and several major environmental and ecological issues.
3.2. Analysis of topical information

3.2.1. Keyword co-occurrence

Keyword co-occurrence analysis is the most common and effective analysis method for document content. The keywords are the refinement of the core content of the papers. Through the high-frequency co-occurrence of keywords, we can intuitively identify and determine the research context and frontier hot issues of the selected subject area (such as 'Land Pollution' in this article). Select the 'Keyword' option in the CiteSpace node type to

Table 3. Volume of published papers by nations (Top10).

| Volume of papers | Nations         | Years |
|------------------|-----------------|-------|
| 943              | USA             | 1970  |
| 790              | peoples r china | 1996  |
| 297              | England         | 1974  |
| 177              | Canada          | 1980  |
| 176              | Australia       | 1996  |
| 134              | Netherlands     | 1996  |
| 123              | Spain           | 1998  |
| 122              | Germany         | 1998  |
| 106              | Italy           | 2006  |
| 103              | France          | 1993  |

Table 4. Centrality of nations (Top10).

| Centrality | Nations | Years |
|------------|---------|-------|
| 0.32       | USA     | 1970  |
| 0.21       | Netherlands | 1996 |
| 0.2        | England | 1974  |
| 0.19       | Australia | 1996 |
| 0.17       | Germany | 1998  |
| 0.14       | Spain   | 1998  |
| 0.12       | France  | 1993  |
| 0.11       | Greece  | 1992  |
| 0.09       | Sweden  | 1998  |
| 0.08       | Italy   | 2006  |

Figure 5. State Co-occurrence Map.
Figure 6. Volume of papers on LP topics published in the journals.

Figure 7. The journals Co-citation map.

Table 5. Co-citation centrality of journals (Top 10).

| Centrality | Journals              | Years |
|------------|-----------------------|-------|
| 0.13       | Ambio                 | 1981  |
| 0.08       | Science               | 1992  |
| 0.08       | Atmos Environ         | 1976  |
| 0.08       | Environ Plann A       | 1979  |
| 0.08       | Am J Agr Econ         | 1990  |
| 0.08       | Ann Ny Acad Sci       | 1974  |
| 0.07       | Environ Plann B       | 1995  |
| 0.06       | Urban Stud            | 1996  |
| 0.06       | Q J Econ              | 1979  |
| 0.06       | Arch Environ Health   | 1974  |
get the keyword co-occurrence graph, and the result is shown in figure 8. Among them, ‘land use’ (552 times), ‘pollution’ (540 times), ‘air pollution’ (469 times), ‘impact’ (410 times), and ‘management’ (259 times) are all high-frequency words. Furthermore, by focusing on centrality information, we found that the top three are ‘pollution’ (0.16), ‘agriculture’ (0.09), ‘air pollution’ (0.08) and ‘climate change’ (0.08, tied for third).

3.2.2. Keyword burstiness
CiteSpace can do burstiness analysis of keywords, which can well grasp the research hotspots of specific selected topics in a certain year. From the perspective of the time evolution of keywords, if the frequency of occurrence of a keyword in a certain year increase, it means that the topic represented by the keyword is a hot spot in that year. This type of keyword is called a burst term. Furthermore, by focusing on centrality information, we found that the top three are ‘pollution’ (0.16), ‘agriculture’ (0.09), ‘air pollution’ (0.08) and ‘climate change’ (0.08, tied for third).

3.2.3. Keyword clustering
Although the direction of the selected topic is determined, the keywords in different journal articles are trivial and independent, so it is necessary to perform cluster analysis on these keywords. Cluster analysis can not only systematically integrate and classify decentralized keywords, but also help researchers to understand the detailed research directions involved in this subject area conveniently and intuitively. Keyword clustering analysis is one of the characteristic functions of CiteSpace. It provides three algorithms: LSI, LLR, and MI. The results of the three algorithms are not the same. The LLR algorithm is more commonly used. The clustering results of LP studies are summarized as shown in table 8.
Table 8 clearly reflects the clustering results of the LP study. Among them, there are 12 first-level clustering results. Due to limitations of paper, the author selected 10 related keywords for the second-level clustering results. Correspondingly, the index value for evaluating the clustering result is reflected in the Q Value and the S Value. According to the corresponding interval of the value, it can be found that the overall clustering structure of this paper is significant (Q = 0.4524 > 0.3), and the clustering result is reliable (S = 0.7551 > 0.7).8

From the clustering results in table 8, it can be found that the current research covers different aspects of the natural environment and ecological pollution research more comprehensively, and partly involves the dimensions of human social development. It should be pointed out that the results of LP research involved in the natural ecological environment are more abundant, such as ‘air pollution’ (Mayer 1999, Brunekreef and Holgate 2002, Chen et al 2017), ‘water quality’ (Olmstead 2010, Tyagi et al 2013, Boyd 2019), ‘soil conservation’ (McConnell 1983, Blanco and Lal 2008, Hellin 2019), ‘air quality’ (Jones 1999, Jacob and Winner 2009, Wolkoff 2018), ‘land cover’ (Lambin et al 2001, Lambin et al 2003, Wulder et al 2018) and other topics. These issues are essentially closely related to the production and living activities of human society. Therefore, the natural issues in the world today are, to a great extent, natural-social issues.

Table 7. Keyword burstiness information (Top10).

| Keywords          | Burst strength | Starting year | End year |
|-------------------|----------------|---------------|----------|
| Agriculture       | 13.32          | 1992          | 2021     |
| Pollution         | 11.92          | 1998          | 2021     |
| Conservation      | 8.48           | 2009          | 2021     |
| Equity            | 7.46           | 1999          | 2021     |
| Energy            | 6.44           | 2011          | 2021     |
| Choice            | 6.43           | 1990          | 2021     |
| Water quality     | 6.38           | 1999          | 2021     |
| California        | 6.37           | 1995          | 2021     |
| Management        | 6.28           | 2009          | 2021     |
| Diffuse pollution | 6.28           | 2010          | 2021     |

8 Q Value: Modularity, which means the value of clustering module. It is generally believed that Q > 0.3 means that the cluster structure is significant; S Value: Silhouette, which means the average contour value of the cluster. It is generally believed that a cluster of S > 0.5 is reasonable, and S > 0.7 means that the clustering is reliable.
On the one hand, human social activities will bring land pollution problems, on the other hand, these can also carry out reasonable and scientific control and protection of the natural environment. The promulgation of a series of policies related to environmental pollution prevention and control and ecological protection, and the development of innovation-driven green technologies reflect the agency of mankind in the face of natural problems. For example, Jahiel (1998) pointed out that China’s Ninth National People’s Congress not only made reforms in the field of government management system, but also clearly stated that environmental issues are serious issues that the central government needs to pay more attention to in the future. Khanna (2001) argues that the approach to environmental protection has evolved from a regulatory-driven adversarial ‘government-led’ approach to a more proactive approach, including voluntary and ‘enterprise-led’ and ‘social-led’ initiatives to self-regulate the environmental performance of society and the market. At the same time, the government has provided more and more environmental information on enterprises and products to attract market forces and communities, and by showing their preference for environmentally friendly companies to create demand for corporate environmental self-regulation. Jaffe et al (2002) pointed out that in the past ten years, the relationship between technological change and environmental policy has attracted more and more attention from scholars and policy makers, not only because the environmental impact of social activities is significantly affected by technological changes, but also environmental policy intervention will produce new constraints and incentives that affect the technological development process. Annicchiarico & Di (2015) studied the dynamic behavior of the economy under different environmental policy systems based on the new Keynesian model, and found that the emission cap policy may suppress macroeconomic fluctuations; staggered price adjustments have significantly changed the environmental policy systems that have been implemented performance; the response of the best environmental policy is strongly influenced by the degree of price adjustment and the response of monetary policy. Yoeli et al (2017) believes that in order to increase consumer protection of energy and other resources, government agencies, public utilities, and energy-related companies can supplement regulatory and market-based policy. Carlsson et al (2021) discussed the use of green nudge (behavioral intervention aimed at

| ID | First-level cluster name | Second-level cluster name (select 10) |
|----|-------------------------|-------------------------------------|
| 1  | Air pollution           | Nitrogen dioxide; pm2.5; traffic-related air pollution; ambient air pollution; air pollution exposure; epidemiology; perfluoroalkyl substance; aircraft emissions; adult asthma prevalence; particulate pollution |
| 2  | Water quality           | Groundwater; drainage; diffuse source pollution; aquatic invertebrates; surface runoff; transparency; water eutrophication; catchment environment; nutrient loss; aquifer vulnerability |
| 3  | Soil conservation       | Organic agriculture; agri-environmental schemes; catchment planning; voluntary farmer behaviour; soil management; volatile organic compounds; land division scheme; intermittent land allocation; discharge permit; nitrate vulnerable zones |
| 4  | Built environment       | Environmental protection; land use transition; urban spatial structure; wind energy potential; decision support system; innovation-driven development; spatial construction sequence; metropolitan statistical areas; urban ventilation performance; soil conservation program |
| 5  | Land cover              | Deforestation; environmental management; environmental absorption efficiency; social-ecological hybridity; carbon stock; future cities; comprehensive pollution index biomass; interval linear programming; tree grooming; species diversity |
| 6  | Air quality             | Carrying capacity; exposure-response curve; ozone; chemical standard; greenhouse gas; biomass burning and atmospheric emissions; airshed model; non-renewable resources; indicators of sustainable development; co-benefit |
| 7  | Urbanization            | Market; urban form; integrated-participatory planning; partial monitoring; industry location; ecosystem service bundles; infrastructure; urban land use efficiency; irrigation-development projects; efficient resource allocation |
| 8  | Redundancy analysis     | Best management practices; fuzzy comprehensive assessment; theory of planned behavior; pearson’s correlation analysis; landscape composition and habitat fragmentation; poisson lognormal; a multi-scale model; yield loss; disposal practice; international and institutional collaborations |
| 9  | Virtual water trade     | Water footprint; water scarcity; energy demand; dynamic simulation modeling; energy diversification; virtual trade; spatial panel econometrics methods; industrial structure; energy water nexus; feedback mechanism |
| 10 | Urban heat island       | Sensitivity analysis; urban green infrastructure; vegetation indices; surface albedo; total suspended particles; daily temperature oscillation; remote sensing images; heat-related mortality; socio-environmental conflict; threat to biodiversity |
| 11 | Heavy metal pollution   | Industrial area; spatial distribution; potentially toxic elements; ecological risk assessment; lichen biomonitoring; strategic environmental assessment; eco-toxicology study; remediation during fallow; trace elements; pesticide use |
| 12 | Stormwater              | Breeding bird; population; woodland; grassland; environmental justice; remote sensing; nonpoint source pollution; urban form; risk mobile monitoring; agricultural ecosystems |
reducing negative externalities) as an environmental policy tool. Therefore, they proposed a new framework. Empirical research shows that whether it is pure or ethical, green nudge will have a significant impact on behavior and the environment, but its impact is highly dependent on the environment. To sum up, we can clearly see from the clustering results that the research topics and directions related to LP basically cover all issues related to the natural environment and ecology, and also show a close relationship with human social activities.

According to the clustering results, we can further obtain the time-line graph of keyword, as shown in figure 9.

3.2.4. Literature co-citation
Literature co-citation is essentially the same as the principle of author co-citation and journal co-citation. It reflects the citation phenomenon between two specific articles. This relationship is caused by citing them at the same time by a specific other article. At the same time, the relationship between the two cited articles is dynamic. By analyzing the betweenness centrality of key nodes, the basic authoritative literature in the field of LP studies can be identified. The result is shown in figure 10.

Still exporting it according to the indicator of betweenness centrality, the detailed information we get is shown in table 9.

Table 9 shows the basic and representative literature on LP research, involving several fields: (1) climate change air pollution and air quality issues, such as Lubowski et al (2006) discussed the impact of land use change on carbon emissions and climate change. They believe that if the US chooses to implement the greenhouse gas emission reduction plan, it is necessary to decide whether to include carbon sequestration policies as part of the domestic portfolio of compliance activities. Han et al (2014) discussed the relationship between urbanization level and air pollution. They pointed out that there is a causal relationship between land pollution and air pollution. (2) land use and soil pollution issues, such as Beelen et al (2013) used land use regression (LUR) to explain and predict the spatial comparison of air pollution concentration, and explained the environmental pollution caused by land use. Brook et al (2010) discussed the relationship between land use change and air pollution and its impact on cardiovascular disease. (3) agricultural issues and the decline of biodiversity, such as Polasky et al (2008) developed a landscape-level model to analyze the biological and economic consequences of alternative land use patterns. They found that land pollution caused by land use reduced biodiversity. Fezzi et al (2010) described a statistical method to derive the impact of policy options aimed at reducing nitrate diffusion pollution on the farm economy. Butchart et al (2010) and Kalcic et al (2012) discussed the relationship between global biodiversity reduction and land pollution. (4) global water supply and cost accounting, such as Hoekstra (2011) discussed the challenge of land pollution to global water supply. He believes that land pollution will greatly increase the treatment cost of water supply. (5) worldwide disease problems, such as Lim et al (2012) found that land pollution leads to the re-pollution of livestock, vegetables, and fruits, forming a serious dietary risk of exceeding the content of harmful substances.

Figure 9. Keyword evolution time-line graph.
4. Discussion: challenges and prospects

The above analysis shows that LP research still has some shortcomings and needs to be further improved. From the perspective of research objects, the current research on LP mainly presents two types of characteristics: one part of the literature takes LP as an independent variable to explore the impact of LP on social and economic development and ecosystem services, and the other part of the literature takes LP as the dependent variable to explore the impact of spatial environmental factors on LP. We found that most of this literature suffers from quantitative bias and relies mainly on new methods, especially cluster analysis. Many studies have used GIS to quantify the impact of LP on social and economic development and ecosystem services, or geospatial methods to determine the impact of environmental factors on LP in a region. However, our study shows that integrated studies emphasizing the natural and human dimensions of land contamination are clearly lacking. A complex systems approach can help scholars to study the causal relationships between LP and the corresponding policy design, socioeconomics, and environment. Therefore, it is necessary to bring land use change as a factor into this process and its consequences. Secondly, among the studies related to land pollution and environmental remediation, different remediation methods correspond to the factors leading to land pollution and the scale of land pollution, but these methods are often single remediation strategies and do not do cost-benefit or socio-economic perspectives, we believe that the research needs to combine experimental results with socio-economic analysis to propose joint pollution remediation methods. Finally, local, or regional forces undoubtedly have a great influence on the LP process, and the driving forces from globalization cannot be ignored. Cross-border (transnational) LP has become an important reality of current LP problems, and land pollution from large flows of runoff, ocean currents, air currents, goods, people and capital play an important role in the open land system, especially global climate change has become an important topic in land pollution research. Research needs to link local LP and global-scale factors, but LP is currently under-researched at the broadest scales.

4.1. Bringing land use change as a factor into LP studies

Although many current studies have brought land use as a factor into LP studies, current LP studies are to some extent fragmented. On the one hand, current studies focus more on land use types related to human use such as...
Table 9. Literatures listed by betweenness centrality indicators (Top 10).

| Centrality | Titles                                                                 | First author | Journals                          | Years |
|------------|-----------------------------------------------------------------------|--------------|-----------------------------------|-------|
| 0.1        | Impact of urbanization level on urban air quality: A case of fine particles (PM2.5) in Chinese cities | Han LJ       | Environmental pollution           | 2014  |
| 0.09       | Global biodiversity: indicators of recent declines                    | Butchart SHM | Science                           | 2010  |
| 0.08       | Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association | Brook RD     | Circulation                       | 2010  |
| 0.08       | The global dimension of water governance: Why the river basin approach is no longer sufficient and why cooperative action at global level is needed | Hoekstra AY  | Water                             | 2011  |
| 0.08       | A geospatial approach to targeting constructed wetlands for nitrate removal in agricultural watersheds | Kalcic M     | Applied engineering in agriculture | 2012  |
| 0.07       | A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010 | Lim SS       | Lancet                            | 2012  |
| 0.07       | Integrated assessment of water framework directive nitrate reduction measures | Fezzi C      | Agricultural economics            | 2010  |
| 0.06       | Land-use change and carbon sinks: econometric estimation of the carbon sequestration supply function | Lubowski RN  | Journal of environmental economics and management | 2006  |
| 0.06       | Where to put things? Spatial land management to sustain biodiversity and economic returns | Polasky S    | Biological conservation           | 2008  |
| 0.05       | Development of NO2 and NOx land use regression models for estimating air pollution exposure in 36 study areas in Europe—the ESCAPE project | Beelen R     | Atmospheric environment           | 2013  |
agricultural land, industrial land, urbanization, etc.; on the other hand, current studies seldom take the time of land use change as a variable and do not examine the land use transition. On the other hand, the current studies seldom consider land use change over time as a variable and do not examine the mechanisms and effects of land use transition on land pollution. The process of land use change is coupled between humans and nature and needs to be studied from an integrated perspective (Aspinall and Staiano 2017, Verburg et al 2013). Therefore, presenting trend changes in land use patterns in a land systems science approach (including land scale, land spatial pattern, pollution, and degradation patterns, etc.) is beneficial to improve the explanatory power of existing studies on land pollution formation (Robinson 2006, Verburg et al 2013). Our study shows that integrated studies emphasizing the natural and human dimensions of land pollution are clearly inadequate. In particular, after bringing land use change as a factor into LP studies, the study of causal relationships between LP and corresponding policy design, socioeconomics and environment (integrated study of natural and human dimensions) will also be more widely emphasized.

4.2. Socio-economic analysis of LP remediation methods

Environmental remediation is an important research topic among LP studies, and these studies mainly focus on technical strategies for environmental remediation, such as physical remediation, solidification/stabilization techniques, leaching methods, application of chelating agents, microbial remediation, phytoremediation, vermicomposting, etc. (Elzieta and Krystyna 2015, Dhaliwal et al 2020). Among the current studies related to land contamination and environmental remediation, different remediation methods correspond to different scales of land contamination according to the factors that lead to land contamination and the scale of land contamination, but these methods are often single remediation strategies, and the treatment efficiency of a single remediation technique may be reduced due to the complexity of certain contaminants. And without cost-benefit or socio-economic perspectives, we believe that the research needs to combine LP experimental results with socio-economic analysis to propose joint pollution remediation methods. In addition, land remediation projects also show obvious regional characteristics, for example, for land contaminated by industrial pollution sources, combined physical-chemical remediation techniques are mostly used, such as the application of combined soil replacement-solidification/stabilization remediation techniques, combined solidification/stabilization-leaching remediation techniques, and combined chelating agent-leaching remediation techniques. Land contaminated by agricultural pollution sources generally uses physical-chemical or chemical-biological remediation techniques. By taking advantage of rapid physical or chemical remediation, the characteristics of nondestructive bioremediation techniques can be combined. For land contaminated by domestic pollution sources, combined phytoremediation-microbial remediation and combined microbial-Earthworm remediation-phytoremediation remediation techniques are generally used (Wu et al 2022). Therefore, appropriate remediation techniques should be selected based on socioeconomic factors, pollutant types, pollutant sources, and predictions of remediation costs/effectiveness.

4.3. Linking regional LP to globalization

The betweenness centrality indicator (table 9) indicates that the impact of globalization on LP has become the focus of current research. However, in the literature review, we still see that LP studies have a tradition of region-based studies, focusing on the causes of land pollution and its impacts in a particular region. With globalization, there are indications that LP has a large impact on global environmental change, global health, and global biodiversity; while global warming, global natural factors (runoff, ocean currents, air currents, etc.) and global movement of people/capital have a negative impact on land pollution. However, the distant drivers of LP have received little attention. In order to understand the impact of global forces on regional land pollution, it is necessary to capture visible or invisible information related to LP using information geography and statistical methods or approaches, which include information geography methods such as remote sensing, GIS, and also methods such as qualitative comparative analysis (QCA). These methods help to discover that LP-related causality is not limited to local factors, but also includes the effects of globalization, such as market economies, technology diffusion, international political forces, and ethnic conflicts/wars (Tang 2015).

5. Conclusion

The paper locates 'land pollution' in the core collection of the Web of Science database, uses CiteSpace software to process all relevant research articles, and presents the research dynamics on LP completely and clearly. We draw the following conclusions:

First, through the indicator of betweenness centrality, basic and authoritative authors in this field include Braden Brennan, Cervero Robert, Brunekreef Bert, Hock Gerard, etc.; basic and authoritative journals include.
AM BIO, Science, Atmospheric Environment, etc. From the perspective of institutions and affiliated nations that publish papers, the United States is an important place for research on LP.

Second, keywords such as ‘land use’, ‘soil pollution’, ‘air pollution’, ‘impact’, and ‘management’ are all high-frequency words. The result of keyword clustering and the co-citation information of documents indicate the historical dynamics of LP research, which mainly include natural dimensions such as air, land, and water, as well as social dimensions such as urbanization and environmental policies. In addition, through careful inspection, it can be found that these two dimensions are intertwined. The change or deterioration of the natural environment poses challenges to human survival, social production, social life, and related governance, and we can exert our agency and take corresponding scientific measures to deal with these major challenges.

Third, in academic research, there is more cooperation among countries, which can be clearly seen from the connection between countries in figure 5. The question is, how to convert academic achievements into practical performance, that is, to generate actual returns for the control of LP, which requires more practical consultation and concerted actions among various countries, and truly regard the problem of LP as a global problem. Therefore, we believe that social organizations may become a third force alongside the market and government to deal with LP. And this may be a focus for future academic research and action.

Finally, current LP research remains challenges and prospects: (1) future research needs to incorporate land use change as a factor in the LP formation process and its consequences; (2) research needs to combine experimental results with socioeconomic analysis to propose joint pollution remediation methods; (3) local, or regional forces may have a strong influence on the LP process, and the driving forces from globalization cannot be ignored.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/ Web of Science database (https://clarivate.com/webofsciencegroup/solutions/web-of-science-core-collection/).

Author contributions

Conceptualization, L L and L G, methodology, B Z and M Z, software, T H, validation, L L, L G and B Z, formal analysis, T H All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the Ministry of Education China, grant number 21YJC790033.

Institutional review board statement

Not applicable.

Informed consent statement

Not applicable.

Conflicts of interest

The authors declare no conflict of interest.

ORCID iDs

Li Li https://orcid.org/0000-0002-6011-2843
Baoqing Zhu https://orcid.org/0000-0002-7163-3740
References

Annicchiarico B and Di D F 2015 Environmental policy and macroeconomic dynamics in a new Keynesian model J. Environ Econ Manage 69 1–21

Aspinall R and Staino M 2017 A conceptual model for land system dynamics as a coupled human–environment system Land 6 81

Beelen R et al 2013 Development of NO2 and NOx land use regression models for estimating air pollution exposure in 36 study areas in Europe—the ESCAPE project Atmos. Environ. 72 10–23

Blanco H and Lal R 2008 Principles of Soil Conservation and Management. (Berlin: Springer)

Boyd C E 2019 Water Quality: an Introduction (Boca Raton: CRC Press)

Brook R D et al 2010 Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association Circulation 121 2331–78

Brunekreef B and Holgate S T 2002 Air pollution and health Lancet 360 1233–42

Butchart S H M et al 2010 Global biodiversity: indicators of recent declines Science 328 1164–8

Carlsson F et al 2022 The use of green nudges as an environmental policy instrument Rev. Environ. Econ. Policy 15 216–37

Chen H et al 2017 Exposure to ambient air pollution and the incidence of dementia: a population-based cohort study Environ Intern 108 271–7

Dhaliwal I, Singh P K and Taneja A 2020 Mandal Remediation techniques for removal of heavy metals from the soil contaminated through different sources: a review Environ. Sci. Pollut. Res 17 1319–33

Elzbieta H and Krystyna M 2015 Wetting properties of biosurfactant (rhamnolipid) with synthetic surfactants mixtures in the context of soil remediation Annules UMCs, Chemia 70 29–39

Fezzi C et al 2010 Integrated assessment of water framework directive nitrate reduction measures Agri Econ 41 123–34

Foley J A, DeFries R, Asner G P and Barford C 2005 Global consequences of land use Science 309 570–4

Gao B, Ning L and Sui H 2020 Analysis on spatial pattern changes of land resources utilization and soil pollution sources in the new period IOP Conf. Ser.: Earth Environ. Sci. 514 032012

Han L et al 2014 Impact of urbanization on air quality of China: A case of fine particles (PM2.5) in chinese cities Environ Pollu 194 163–70

Heidi N, Geisz R M, Dickhut M A, Cochran W R, Fraser and Hugh W 2008 Melting glaciers: a probable source of DDT to the antarctic marine ecosystem Environ Sci Tech 42 3958–62

Hellin J 2019 Better land husbandry: from soil conservation to holistic land management. (CRC Press)

Hoekstra A Y 2011 The global dimension of water governance: why the river basin approach is no longer sufficient and why cooperative action at global level is needed Water 3 21–46

Higuera C et al 2016a Prenatal exposure to NO2 and ultrasound measures of fetal growth in the Spanish INMA cohort Environ Health Persp 124 235–42

Jacob D J and Winner D A 2009 Effect of climate change on air quality Atmos. Environ. 43 51–63

Jaffe A B, Newell R G and Stavins R N 2002 Environmental policy and technological change Environ Res Econ 22 41–70

Jahiel A R 1998 The organization of environmental protection in china The China Quarterly 156 757–87

Jerrett M et al 2009 A cohort study of traffic-related air pollution and mortality in toronto, ontario, canada Environ Health Persp 117 772–7

Jin S, Blueingland B and Mol A P J 2018 Mitigating land pollution through pesticide packages—the case of a collection scheme in rural china Sci. Total Environ. 622–623 302–9

Jones A P 1999 Indoor air quality and health Atmos. Environ. 33 4535–64

Kalcić M et al 2012 A geospatial approach to targeting constructed wetlands for nitrate removal in agricultural watersheds App. Eng. Agri. 28 347–57

Khanna M 2001 Non-mandatory approaches to environmental protection J. Econ. Surveys. 15 291–324

Lambin E F et al 2001 The causes of land-use and land-cover change: moving beyond the myths Global Environ. Change 11 261–9

Lambin Eric F, Geist Helmut J and Lepers E 2003 Dynamics of land-use and land-cover change in tropical regions Annual Review of Environment and Resources 28 203–241

Lee M, Stock C, Shevliakova E, Malyshew S and Milly P C D 2021 Globally prevalent land nitrogen memory amplification Environ Sci. Technol. 55 2224–34

Liu Q et al 2008 The ESCAPE project Atmos. Environ. 42 1082–92

Lubowski R N, Plantinga A J and Stavins R N 2006 Land-use change and carbon sinks: econometric estimation of the carbon sequestration supply function J. Environ Econ Manage 51 135–52

Ma L, Xiao T, Ning Z, Liu Y, Chen H and Peng J 2020 Pollution and health risk assessment of toxic metal(loids) in soils under different land use in sulphide mineralized areas Sci. Total Environ. 724 138176

Mayer H 1999 Air pollution in cities Atmos. Environ. 33 4029–37

Mone M S, Gillman M W, Miller E H and Lipshultz S E 2004 Effects of environmental exposures on the cardiovascular system: prenatal period through adolescence Pediatrics 113 1058–69

Meyer H 1999 Air pollution in cities Atmos. Environ. 33 4029–37

McConnell K E 1983 An economic model of soil conservation American Journal of Agricultural Economics 65 83–89

McNewnuijen M J et al 2014a Air pollution and human fertility rates Environ Intern 70 9–14

McNewnuijen M J et al 2014b Positive health effects of the natural outdoor environment in typical populations in different regions in Europe (PHENOTYPE): a study programme protocol BMJ Open 4 e004951

Olmstead S M 2010 The economics of water quality Rev. Environ. Econ. Policy 4 44–62

Olasky S et al 2008 Where to put things? spatial land management to sustain biodiversity and economic returns Bio Conservation 141 1505–24

Porta D et al 2016b Air pollution and cognitive development at age 7 in a prospective Italian birth cohort Epidemiology 27 228–36

Robinson T 2006 Adaptation of a resilience program in NSW: the rural RAP Acta Neuropsychiatr. 18 306–7

Shekarrizfard M, Faghih-Imani A and Hatzopoulou M 2016 An examination of population exposure to traffic related air pollution: Comparing spatially and temporally resolved estimates against long-term average exposures at the home location Environ. Res. 147 435–44

Su J et al 2009 Predicting traffic-related air pollution in Los Angeles using a distance decay regression selection strategy Environ. Res. 109 657–70

Swetts B and Lambin E F 2021 Institutional changes drive land use transitions on rangelands: the case of grazing on public lands in the American West Glob. Environ. Chang. 66 102220

Tang S 2015 The onset of ethnic war: a general theory Sociological Theory 333 256–79
Tyagi S et al 2013 Water quality assessment in terms of water quality index Am. J. Water Res. 1 34–8
Verburg P H, Erb K H, Mertz O and Espindola G 2013 Land system science: between global challenges and local realities Curr. Opin. Environ. Sustain. 5 433–7
Wang M et al 2014 Long-term exposure to elemental constituents of particulate matter and cardiovascular mortality in 19 European cohorts: results from the ESCAPE and TRANSPHORM projects Environ Intern 66 97–106
Weichenthal S et al 2016 Characterizing the spatial distribution of ambient ultrafine particles in Toronto (Canada: A land use regression model) Environ. Pollut. 208, 241–8
Wolkoff P 2018 Indoor air humidity, air quality, and health—An overview Intern. J. Hygiene. Environ Health 221 376–90
Wu Y, Li X, Yu L, Wang T, Wang J and Liu T 2022 Review of soil heavy metal pollution in China: spatial distribution, primary sources, and remediation alternatives Resour. Conserv. Recycl. 181 106261
Wulder M A et al 2018 Land cover 2.0. Intern. J. Remote. Sens. 39 4254–84
Yoeli E et al 2017 Behavioral science tools to strengthen energy & environmental policy Behavi Sci Policy 3 68–79