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Research Progress and Trend of Agricultural Non-Point Source Pollution from Non-Irrigated Farming Based on Bibliometrics

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Abstract: The agricultural non-point source (NPS) pollution caused by non-irrigated farming, such as heavy metals, nitrogen and phosphorus, has posed an extreme threat to the security of agricultural product quality and watershed ecology. Thus, it is urgent to sort out the latest research progress and future development trend to effectively guide future scientific research and technological updates in this field. This study integrates the relevant literature of the Web of Science from 1976 to 2021 and analyzes the research hotspots and development trends in the field of agricultural NPS pollution from non-irrigated farming in combination with CiteSpace. The results showed that the proportion of publications from the United States and China accounted for 58.4%. Science of the Total Environment, Water Science and Technology and Journal of the American Water Resources Association were the most published journals. The research topics and hotspots mainly involve agricultural NPS pollution prevention technology, pollution source identification, pollution load and management and landscape pattern evolution. In the future, agricultural NPS pollution research in non-irrigated farming should combine agricultural big data platforms, spectroscopic methods, artificial intelligence technology, etc. and focus on strengthening soil testing formula fertilization management, the efficient use of livestock and poultry breeding manure, climate change and risk early warning.

Keywords: agricultural non-point source; bibliometrics; research hotpots; development trend; non-irrigated farming

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Citation: Liu, D.; Yao, Z.; Yang, X.; Xiong, C.; Nie, Q. Research Progress and Trend of Agricultural Non-Point Source Pollution from Non-Irrigated Farming Based on Bibliometrics. *Water* **2023**, *15*, 1610. https://doi.org/10.3390/w15081610

Academic Editor: Zhenyao Shen

Received: 20 February 2023
Revised: 15 March 2023
Accepted: 22 March 2023
Published: 20 April 2023

1. Introduction

In the world, non-irrigated farming is about five times that of irrigated farming, reaching 1200 million hectares. Non-irrigated farming is agriculture that, under the condition of a serious shortage of water resources, makes full use of natural precipitation without irrigation and continuously improves the effective utilization rate of soil fertility and natural precipitation through dryland agricultural structures and a series of dryland technical measures to achieve stable and balanced agricultural production. It is commonly found in arid, semi-arid, semi-humid and drought-prone areas with annual precipitation of 250–800 mm. According to the limited water supply, non-irrigated dry farming is difficult to replace with irrigated farming.

Non-point source (NPS) pollution refers to the pollution caused by the scouring of rainfall runoff, including soil erosion type non-point source pollution, agricultural non-point source pollution and urban non-point source pollution according to the formation mechanism and occurrence area. Agricultural NPS pollution refers to the process in which various pollutants (salt, nutrients, pesticides, bacteria, etc.) caused by agricultural production activities under the action of precipitation diffuse from the soil sphere to the hydrosphere in a low concentration and wide range through farmland surface runoff, farmland drainage and underground leakage. According to this concept, the pollution of agricultural NPS to water bodies mainly includes two aspects: one is the pollution of external surface water bodies (rivers, lakes, etc.), which is mainly manifested by the aggravation of the eutrophication trend of water bodies. The second is the shallow groundwater pollution from nitrate, pesticides and herbicides, as well as uncommon nutrients such as pathogenic microorganisms, trace elements and dissolved solids (salinization).

Agricultural NPS pollution refers to the pollution of rivers, lakes, reservoirs, the atmosphere and other ecosystems caused by residues of agricultural inputs, waste straw, livestock manure and urine, etc. through the use of chemical fertilizers, pesticides, hormones and other ways of planting and breeding in agricultural production and life [1,2]. The main pollutants of NPS pollution include organic compounds, nitrogen and phosphorus, pathogenic bacteria, harmful heavy metals, etc. [3]. Compared with point source pollution, NPS pollution has a wide temporal and spatial range, strong uncertainty and complex and changeable components and processes [4]. The recent observations showed that most of the eutrophication of rivers and lakes is closely linked to NPS pollution [5], which has become one of the most difficult problems in water pollution control and has attracted extensive attention [6].

Compared with irrigated farming, non-irrigated farming grows crops through natural rainfall. NPS pollution control in non-irrigated farming usually has three strategies: source control, process resistance and end treatment. Source control aims to reduce the excessive use and leaching of nitrogen, phosphorus, heavy metals and other chemical inputs, such as conservation tillage, fertilization management and water-saving irrigation [7]. Process resistance refers to pollutant elimination, such as ecological ditches, from the field to the runoff process by using the space and time of agricultural production [8,9]. Terminal treatment is the final choice to avoid water pollution when the pollution is higher than the safety value [10]. The above strategies can control agricultural NPS pollution to varying degrees. However, considering the characteristics and complexity of planting and breeding, NPS pollution control is a long-term arduous task. It is challenging to integrate different control schemes from the source to the end.

At present, the research on NPS pollution in non-irrigated farming mainly focuses on the formation mechanism [11], prevention and control measures [12] and the water quality model [13]. Research on agricultural NPS pollution began in the 1960s and was first carried out by some developed countries such as the United States, Britain and Japan. Since the 1970s, agricultural NPS pollution research has been paid more and more attention all over the world. The research on agricultural NPS pollution can be divided into the following three stages. In the 1970s, it mainly focused on the characteristics of NPS pollution, influencing factors, single rainstorms and long-term average pollution load output. Since the 1990s, the study of the influence of microorganisms on the migration and transformation of non-point source pollutants has become a new growth point. Agricultural NPS pollution has become an active field of environmental research in the world. In the early 1980s, the eutrophication investigation of surface water bodies such as lakes and reservoirs and the water quality planning of watersheds started related research in the field of non-point source pollution. The research on NPS pollution mainly focuses on the macroscopic characteristics of agricultural NPS and the preliminary research on the quantitative calculation model of pollution load. At the same time, relevant empirical statistical models developed rapidly and were widely used during this period. These empirical models calculated the agricultural NPS pollution output in the catchment area according to the water quality analysis results of receiving water bodies. In the 1990s, the research on agricultural NPS pollution became more active, and the macro characteristics and influencing factors of pesticide and fertilizer pollution, as well as the relevant black box empirical statistical model, played an important role in the research on agricultural NPS pollution. In recent years, the research on agricultural NPS pollution has mainly focused on the surface water pollution of rivers, lakes, reservoirs and so on, and groundwater pollution research is relatively scarce.

There is still a lack of systematic analysis and an overall grasp of the latest development trends and research hotspots in this field. It is urgent to sort out the literature in this field and conduct a quantitative analysis so as to better grasp the future development trend of agricultural NPS pollution research. Based on mathematical and statistical methods, bibliometrics takes scientific literature as the research object and objectively interprets the knowledge base and evolution characteristics of a research field by analyzing co-citations, keyword co-occurrence relationships, knowledge atlases, etc., which can effectively reflect the overall characteristics, research hotspots and dynamic changes in the research field [14,15]. In recent years, it has gradually been applied to hydrology [16], ecology and environment [17] and other fields. Therefore, with the help of the bibliometric method, and based on the core set of the Web of Science, this study takes agricultural NPS pollution as the research object and selects relevant pieces of literature on agricultural NPS pollution published from 1976 to 2021. CiteSpace software was used to draw the map of scientific knowledge from the perspectives to explore the research progress and hot spots of agricultural NPS pollution so as to provide a scientific reference for correctly understanding the research trend and frontier of agricultural NPS pollution and further explore the internal correlation and development history of agricultural NPS pollution publications. The previous research results and shortcomings of agricultural NPS pollution were summarized comprehensively, and the future development trend of agricultural NPS source pollution was deeply analyzed.

2. Materials and Methods

2.1. Data Collection

The search scope includes the Web of Science (WoS) core collection database from January 1976 to August 2021. The search subject was set as "agricultural NPS pollution OR rural OR agricultural non-point pollution OR diffuse pollution". The literature type is "Article". In order to reduce errors and improve accuracy, all documents are imported into Endnote to be sorted out step by step, including removing duplicates and documents inconsistent with the research topic. The final results are used as the basic data for this study.

2.2. Data Analysis

Using the Web of Science analysis and retrieval function, the annual publication volume, the country and institution and the author of the target literature were statistically classified. CiteSpacer was used to extract important noun phrases from titles, abstracts and keywords for literature co-word, co-occurrence and emergent word analysis in order to explore the international cooperation network, core authors and development trend of the study.

The CiteSpace (5.7. R5W 64 bit) document visualization analysis tool was used to conduct co-citation analysis, keyword co-occurrence analysis, keyword emergence analysis and map output [18,19]. Time slicing was selected from 1976 to 2021. Keywords and co-citations are selected as node types. Path-finding networks, pruning slicing networks and pruning merging networks were selected as clipping methods [20]. Other settings were default. Keywords are highly generalized literature research topics, which can accurately express the paper. It is helpful for researchers to understand the hot spot and development trend in this field. In the keyword clustering view, circles and labels form an element, and the size of the element depends on the degree of nodes, the strength of lines, the number of citations, etc. The color of the element represents the cluster to which it belongs, and different clusters are represented by different colors. In the co-occurrence view, the sizes of nodes and lines respectively represent the number of documents and the cooperative relationship between them. The purple outer ring indicates that the document has a high intermediate centrality, different colors of the lines represent different years and the thickness of the lines represents different connection strengths.

2.3. Calculations

Intermediary centrality is a key parameter for characterizing influence. The larger the value, the greater the influence and the stronger the fulcrum role in promoting research cooperation in this field. The calculation formula is as follows:

$$BC_i = \sum\nolimits_{a \neq b \neq c} \frac{n_{ac}^b}{g_{ac}} \quad (1)$$

where BC_i is intermediate centrality; g_{ac} is the number of shortest paths from node a to node c; $n^b{}_{ac}$ indicates the number of shortest paths through node b in the g_{ac} shortest paths from node a to node c.

Connection strength is an important parameter indicating the degree of cooperation, and the larger the value, the closer the cooperation. The calculation formula is as follows:

$$\mathrm{Cos}\ \left(x_{ij}, s_i, s_j\right) = \frac{X_{ij}}{\sqrt{S_i S_j}} \quad (2)$$

where Cos (x_{ij},s_i,s_j) is the strength of the connection; X_{ij} is the co-occurrence frequency of i and j; S_i is the occurrence frequency of i; S_j is the frequency of occurrence of j.

3. Results

3.1. Publications

From January 1976 to August 2021, a total of 3700 papers were issued. The trend of papers issued has increased rapidly since 1990 (Figure 1). The number of papers issued by China, the United States and the United Kingdom ranked in the top three (Table 1). Among them, the United States was the highest, 1.3 times higher than China. The number of papers issued by China and the United States accounted for 58.4% (Table 1). In 1979, the United States first proposed the concept of "agricultural non-point source pollution". In the United States, England and other countries, relevant studies started earlier, mainly focusing on the causes and countermeasures of agricultural NPS pollution. The research in China started late and, on the basis of inheriting foreign research, focused on the causes of agricultural NPS pollution in China and its impact on the social economy. In recent years, Chinese scholars have begun to summarize the experience of foreign countries in controlling agricultural NPS pollution and explore ways to control agricultural NPS pollution based on a comprehensive comparison of the experience of developed countries and regions in controlling agricultural NPS pollution. Science of the Total Environment, Water Science and Technology and the Journal of the American Water Resources Association have the largest number of papers, with a total of 481 papers, accounting for 13.0% (Table 2).

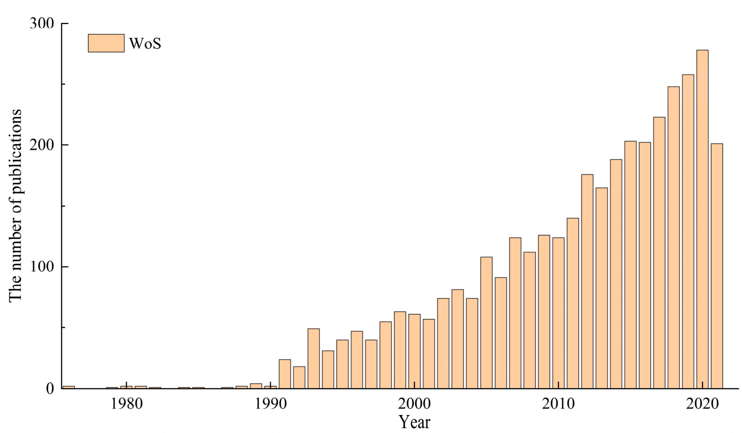

Figure 1. The number of publications.

Table 1. Top 10 countries.

No.	Countries/Regions	Number of Publications
1	USA	1225
2	China	936
3	England	279
4	Canada	171
5	Germany	167
6	France	136
7	Italy	126
8	Spain	104
9	Australia	103
10	South Korea	96

Table 2. Top 10 journals.

No.	Journals	Publisher	Number of Publications
1	*Science of the Total Environment*	Elsevier	182
2	*Water Science and Technology*	IWA	156
3	*Journal of the American Water Resources Association*	Wiley–Blackwell	141
4	*Environmental Science and Pollution Research*	Springer	95
5	*Journal of Hydrology*	Elsevier	92
6	*Journal of Environmental Quality*	ASA/CSSA/SSSA	89
7	*Water*	MDPI	82
8	*Journal of Soil and Water Conservation*	SCSA	81
9	*Journal of Environmental Management*	Academic Press	75
10	*Environmental Monitoring and Assessment*	Springer	73

3.2. Co-Citation Analysis

Co-citation analysis was put forward by Henry Small in 1973. More and more researchers now use co-citation analysis to explore the background, development profile and research frontier of a certain discipline. The top three highly cited papers were Gassman et al. [21], Moriasi et al. [22] and Ongley et al. [23] (Figure 2a). The clustering of best management measures, pollution prevention techniques, pollution models, agricultural land, phosphorus loss, sensitive zones, GIS indexes, rural catchment areas and eastern coastal plains are important topics for agricultural NPS pollution research (Figure 2b).

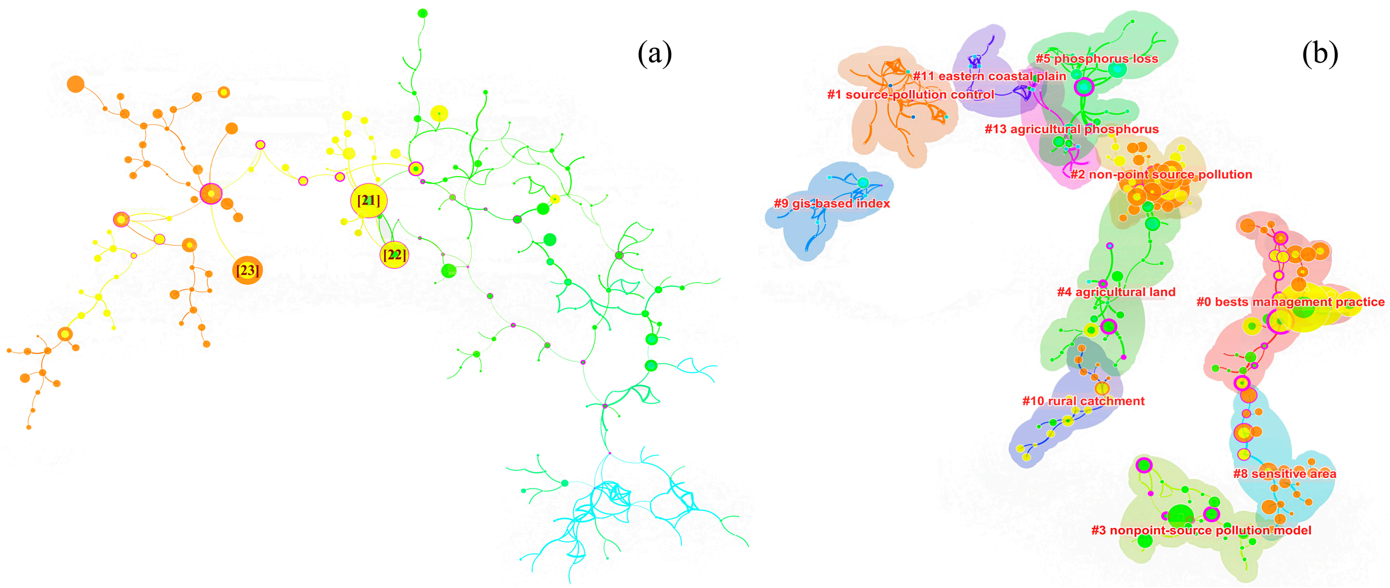

Figure 2. Co-citation network (**a**) and cluster analysis of papers [21–23] (**b**) from WoS. Note: The node represents the citation, and the size of the node is in direct proportion to the frequency of the citation. The appearance of purple in the outer circle of the node indicates that the citation has a high centrality. The color of different cluster groups is random, and the lines are the same color.

3.3. Keyword Co-Occurrence Analysis

Co-occurrence analysis is an analysis method that quantifies the co-occurrence information in various information carriers, which can reveal the content association of information and the co-occurrence relationship implied by feature items. According to the co-occurrence analysis, the high-frequency keywords mainly include water quality, nitrogen, phosphorus, management, runoff, polling, soil, land use, quality, model, etc. (Figure 3).

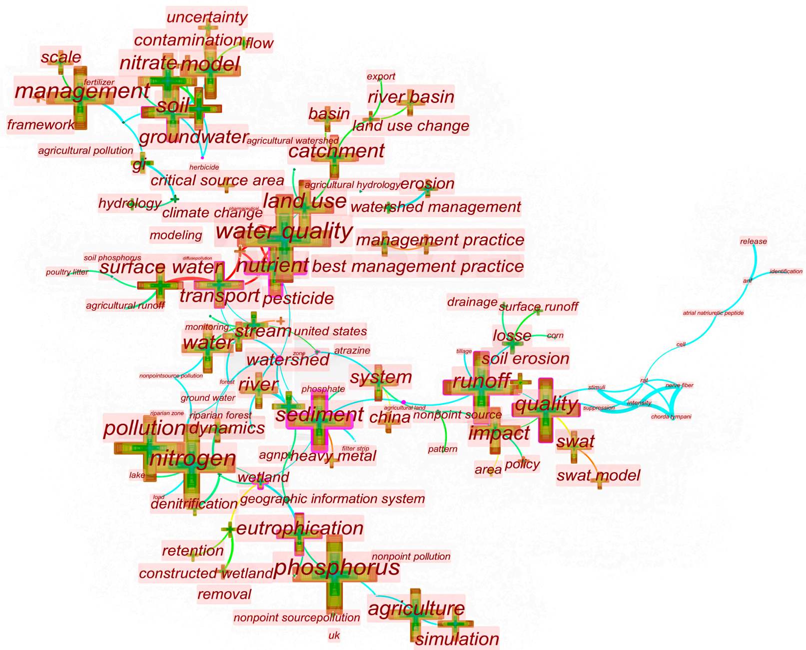

Figure 3. Co-occurring networks of keywords. Note: Nodes represent keywords. The size of nodes is proportional to the frequency of occurrence. The lines between nodes represent the co-occurrence relationship. The thicker the lines, the stronger the co-occurrence relationship.

4. Discussion

4.1. Prevention and Control Technology

Recent research has been conducted on the prevention and control technology of agricultural NPS pollution. In terms of pollution prevention and control in the planting industry, many technologies have been developed, including the efficient utilization of water and fertilizers, soil testing formulas and nutrition diagnosis, nutrient balance and new fertilizer technology, planting optimization and ecological interception. Among them, measures such as artificial wetland ecosystems, vegetation buffer zones and earthworm ecological filters have been developed and applied to a certain extent through integrated innovation [24–26]. The breeding industry mainly involves ecological fermentation beds, feces collection and composting, the efficient conversion of biogas and other treatment technologies and recognizing that livestock manure is a resource and good biomass material [27–29]. In addition, the biological effectiveness of biochar in improving fertilizer utilization, reducing pesticide residues and reducing heavy metals has been fully verified, but it has not been widely applied and popularized in the field [30,31]. Conservation tillage can improve the soil structure, field biological habitat and system stability, thus effectively reducing agricultural NPS pollution [32,33]. In summary, the concept of "source control first, process resistance control combined with end treatment" is fully recognized [34,35]. However, the existing technology still has shortcomings such as a single effect, being constrained by climate and environmental conditions, being greatly affected by water quality and quantity and high construction and manual maintenance costs. In the future, we should focus on integrating multiple technologies, such as ecological treatment technology [36] in combination with the systematic strategy (4R, reduce–retain–rescue–restore) [37], according to local conditions, strengthen the research on the passivation and recovery of pollutants and explore small automatic equipment for achieving the win–win of economic benefits and treatment effects.

4.2. Pollution Source Identification

Pollution source identification mainly includes quantitative, semi-quantitative and empirical identification methods. The quantitative method mainly uses modeling to analyze the temporal and spatial distribution of pollution on the basin scale and identify the key source areas of NPS pollution, mainly including the output coefficient method and pollution index method [38]. The semi-quantitative and empirical methods mainly use the synchronous monitoring data of hydrology and water quality to calculate the spatial distribution of the pollution load in the basin, establish the risk classification of pollutant loss in the basin scale and explore the source of pollutants in small basins through GIS technology [39]. The current research mainly focuses on the optimization of crop growth, farmland nitrogen and the phosphorus cycle and other models, as well as multi-angle identification, the integration of identification methods and integration with new technologies [40,41]. However, the existing identification methods have shortcomings such as a slow emergency response and multiple-data integration. In the future, research on the rapid diagnosis of pollution identification, real-time prediction and early warning systems should be carried out in combination with artificial intelligence (AI) technology, spectroscopy methods, etc., which is an important trend in agricultural NPS pollution simulation research.

4.3. Assessment of NPS Pollution Load

The NPS pollution load assessment is mainly based on the data of hydrometeorology, land use and pollution surveys and the application of the output coefficient, SWAT, DPeRS, JOHNES and other models to research the distribution and load intensity of pollutants such as total nitrogen, total phosphorus, nitrate nitrogen, ammonia nitrogen and organic phosphorus [42,43]. Among them, SWAT and best management practices (BMPs) tools can simulate the mathematical expression of the water cultural heritage process of pollutant migration and transformation in the basin under complex and changeable conditions such as soil type, land use and management measures, based on hydrological processes such as rainfall, evaporation, infiltration, runoff generation and confluence, with water as the carrier, and simulate the migration and transformation of total nitrogen, total phosphorus, nitrate and other pollutants and their internal relations [44,45].

This article focuses on the Soil and Water Assessment Tool (SWAT) model, which is a continuation of nearly 30 years of modeling efforts conducted by the USDA Agricultural Research Service (ARS). The model has been adopted as part of the U.S. Environmental Protection Agency (USEPA)—Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) software package and is being used by many U.S. federal and state agencies, including the USDA within the Conservation Effects Assessment Project (CEAP). At present, over 250 peer-reviewed published articles have been identified that report SWAT applications, reviews of SWAT components or other research that includes SWAT. Many of these peer-reviewed articles are summarized here according to relevant application categories such as streamflow calibration and related hydrologic analyses, climate change impacts on hydrology, pollutant load assessments, comparisons with other models and sensitivity analyses and calibration techniques. The strengths and weaknesses of the model are presented, and recommended research needs for SWAT are also provided [21]. Watershed models are powerful tools for simulating the effect of watershed processes and management on soil and water resources. The objectives of this research were to: determine recommended model evaluation techniques (statistical and graphical), review reported ranges of values and corresponding performance ratings for the recommended statistics and establish guidelines for model evaluation based on the review results and project-specific considerations; all of these objectives focus on the simulation of streamflow and the transport of sediment and nutrients [22]. This article compares the primary methods used for NPS estimation in China with their use in America. Two observations are especially notable: empirical research is limited and does not provide an adequate basis for calibrating models nor for deriving export coefficients; the Chinese agricultural situation is so different from that of the United States that empirical data produced in America, as a basis for applying estimation techniques to rural NPS in China, often do not apply. We propose a set of national research and policy initiatives for future NPS research in China [23].

BMPs proposed by the US Environmental Protection Agency and the US Department of Agriculture are the most successful in the control of agricultural NPS pollution. BMPs refer to the use of engineering methods or non-engineering management measures to reduce water pollution, the core of which is to prevent or reduce the load of agricultural NPS pollution, maintain and promote the maximization of benefits and minimize losses of nutrients in agricultural production so as to protect soil resources and improve water quality. The pollution prevention techniques of agricultural NPS pollution that have been studied and put into use include the control technology of nitrogen and phosphorus pollution of domestic sewage in villages and towns and irrigation water in farmland, storm runoff, harmless treatment technology of rural solid waste, rapid repair technology, ecological interception technology of surface runoff and seepage such as biological hedge, etc. There are many watershed models at regional, national and global levels, which can be summarized into many spaces: the empirical lumped model and mechanism distributed model, according to whether the simulation parameters take into account factors of the physical mechanism process and spatiotemporal variability. The empirical lumped model homogenizes all factors that affect the pollution process and obtains a parameter that synthesizes all factors so as to implement the average simulation of regional spatial characteristics. The distributed mechanism model subdivides the basin into several continuous small cells, and the basin factors in different cells are different. However, the basin factors in the same unit are similar, and the model series the simulation results of each unit in the basin to expand the output results of the whole basin, which can simulate the natural process of the basin more accurately and with higher accuracy.

The effectiveness evaluation of best management practices was mainly explored in semi-arid areas, basins, plain farming areas, urban small watersheds, lakes and other regions [46], which provided effective solutions for the scientific decision making of NPS pollution management. However, the applicability of existing evaluation models to complex environments still needs to be strengthened considering one-sided and standardized data [47]. Therefore, research on timely data sharing and algorithm optimization should be strengthened to improve the accuracy, comprehensiveness and timeliness of large-scale NPS pollution load assessment.

4.4. NPS and Landscape Pattern

With the continuous intensification of NPS pollution, guided by the principle of landscape ecology, effective planning and management should be carried out on the quantity, proportion and spatial and temporal allocation of landscape elements so as to make the combination of landscape resources close to or achieve optimization in structure and function, improve the stability of the landscape and effectively control the non-point source pollution. The effects of landscape pattern change on the occurrence, migration and transformation of NPS pollutants such as nutrients are mainly reflected in the changes in the flow process of ecosystem matter and energy caused by land use and land cover change. The relationship between the landscape pattern and NPS pollution load, the impact of land use and land cover change on biodiversity and the transformation of the "source-sink" relationship of pollutants were mainly focused on in recent studies [48]. The internal relationship between the landscape pattern evolution (patch size and edge density, etc.) of forests, urban land, cultivated land, orchards and grasslands with the change in the water quality of the basin were also discussed [49]. The relationship between the output characteristics of NPS pollution from different land uses and vegetation coverage, the amount of pesticide and chemical fertilizer applied, and the landscape area was explored [50]. The reduction effect of NPS pollution from shelter forest protection and the conversion of farmland to forests was evaluated [51]. However, the research on the impact of the regional landscape pattern evolution on ecological value transformation, the carbon storage and carbon budget and regional climate change is still insufficient, which should be paid attention to in the future. It is worth noting that the microplastic pollution caused by the use of a large number of agricultural films should be included in NPS pollution and will be focused on in the future research work.

5. Conclusions

Non-point source pollution is one of the most important environmental pollution problems that the world cannot escape because of its wide range of influence and it being difficult to control. For a long time, researchers and managers have paid more and more attention to it. The trend of issued papers in the non-point source pollution research of non-irrigated farming increased rapidly from 1976 to 2021, which is closely related to the demand for rapid economic development and green transformation. With the extension and depth of the research content, the research hotspots mainly involve source identification, load management, control technology, landscape pattern evolution, etc. In the future, research should focus on land security control, fertilizer and pesticide reduction, regional landscape optimization, waste recycling and utilization, farmland restoration and land productivity improvement, climate change and risk warning. It is necessary to combine agricultural big data platforms, spectroscopy methods, artificial intelligence and other new technologies for future non-point source pollution control research and practice.

Author Contributions: Q.N. and D.L. designed the experiment; C.X. and D.L. performed the experiments; X.Y. and Z.Y. analyzed the data and wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Program of Chongqing Science and Technology Commission (cstc2020jcyj-msxmX0095); the Science and Technology Research Program of Chongqing Municipal Education Commission (KJZD-K202001203, KJZD-K202003501); and the Innovative Research Group of Universities in Chongqing (CXQT P19037).

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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