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Review

Permeable Pavement Systems for Effective Management of Stormwater Quantity and Quality: A Bibliometric Analysis and Highlights of Recent Advancements

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Abstract: In recent years, there has been growing interest in the field of permeable pavement systems (PPS), especially in the scope of stormwater management as a sustainable urban drainage system (SUDS). In this study, a comprehensive bibliometric analysis followed by a systematic review were conducted to capture the nature and evolution of literature, intellectual structure networks, emerging themes, and knowledge gaps in the field of PPS. Relevant publications over 22 years (2000–2021) were retrieved from the Web of Science database for analysis. Results revealed that slight modifications within the PPS layers or incorporation of innovative filters could result in improved contaminant removal efficiency. Impermeable soils and PPS pore size were the main limiting factors affecting the permeability and infiltration rates. A combination of maintenance procedures was presented and proven effective in mitigating clogging effects, mostly occurring at the upper 1.5–2.5 cm of the PPS. Although partial replacement of the PPS mix design with recycled aggregates improved the overall permeability, the compressive strength was slightly compromised. The present study also discusses several evolving aspects for water quality improvements, innovative investigations that include recycled aggregates, and other lessons learned and future research directions in the area of PPS. Findings from the conducted analysis provide researchers, designers, urban planners, and even municipalities with research gaps and technical deficiencies in implementing and investigating PPS.

Keywords: permeable pavement systems; stormwater management; performance; bibliometric analysis

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1. Introduction

The continuous increase in global temperatures due to the emissions of greenhouse gases, such as carbon dioxide, has led to various climate change impacts and environmental issues [1,2]. This has caused increased frequency and duration of extreme weather events, resulting in increased rainfall and short-duration intensity [3–5]. In addition, the rise in the use of impervious surfaces due to rapid urbanization has also resulted in increased stormwater runoff, peak flows, and a reduced infiltration rate [6]. Stormwater runoff can carry different pollutants, including heavy metals, nutrients, and polyaromatic hydrocarbons (PAHs), resulting in groundwater and soil contamination [7,8]. These pollutants may also result in eutrophication or algal blooms in the receiving water bodies [9]. Furthermore, ineffective management of stormwater runoff may overload the sewerage systems and result in localized flooding events [10]. Therefore, there has been increasing interest in sustainable stormwater management practices.

Different practices have been developed to reduce stormwater runoff and improve its quality. These practices can be classified as sustainable urban drainage systems (SUDS) and include techniques such as permeable surfaces, filter and infiltration trenches, retention basins, wetlands, ponds, and water harvesting [11]. One of the most promising SUDS is permeable pavement systems (PPS). They are considered viable options due to their structural, economic, and road-user benefits. However, the challenges in the practical implementation of SUDS are due to constraints related to construction costs, characteristics of the land, long-term performance, and technical difficulties in installation and maintenance [11].

Some literature reviews have already discussed the different materials used to construct PPS [12–15]. However, this study is different from the previous works of literature, as the main interest of this paper is to conduct a bibliometric analysis of the published research over the past 22 years, highlight trends in this field of research, and discuss the recent advances in improving the performance of PPS. Bibliometric analysis is a quantitative and statistical tool that plays an important role in identifying the productivity of authors, countries, and institutions and provides information about the total publications and citations by thorough network analysis of keywords, articles, and authors [16–18]. These analyses are represented as network maps or graphs to highlight different characteristics, such as identifying collaboration among authors, and countries, identifying main research themes, emerging trends in articles, and understanding the evolution of articles and hence finding the research gaps [19]. In addition, bibliometric analyses can be combined with systematic reviews to provide a more in-depth and comprehensive review of the state-of-the-art while also examining the evolution of certain aspects within the research field with time [20,21]. Previous bibliometric analyses were performed on specific areas of PPS, such as sponge city [16], stormwater management practices [18,22], runoff pollution control technologies [23], and urban heat island effect mitigation [24]. However, a bibliometric analysis that simultaneously studies different aspects of PPS has not yet been conducted.

Accordingly, this study is a bibliometric analysis that provides insights and recent highlights on different aspects of PPS in the field of stormwater management, such as the emergence of unique technologies and structural modifications, improvements in contaminant removal efficiency, characterization mechanisms to reduce clogging and improve infiltration rates along with sustainability considerations. The adaptation of these new technologies could be promising in prolonging the life of PPS, increasing its effectiveness in reducing pollutants from stormwater runoff and results in overall cost savings, which could increase the reliability and feasibility of such systems. Therefore, it is essential to analyze the nature and evolution of literature in the field of PPS to capture conceptual and intellectual structure networks, key concepts, trends, and knowledge gaps in this area of research. Hence, the main objective of this paper is to evaluate the origin, evolution, and research direction for permeable pavement systems with a focus on their performance in managing stormwater quality and quantity. A comprehensive bibliometric analysis of the relevant literature published between 2000 and 2021, followed by an account of recent advancements, was conducted to answer the following research questions:

RQ1: What trends can be detected when analyzing studies investigating the use of PPS for stormwater management?
RQ2: Who are the major contributors to research in the area of PPS for stormwater management?
RQ3: What are the recent advancements and research gaps/future directions?

The structure of this paper includes several sections. Section 2 provides a brief background on investigations concerning the use of PPS for managing stormwater quantity and quality. Section 3 discusses the methodology implemented in this research which includes data extraction, trend analysis, co-citation analysis, and content analysis. Section 4 presents and discusses the results of the bibliometric analysis. Finally, Section 5 provides highlights of recent developments and research opportunities in the field of PPS.

2. Background

There are mainly three types of PPS: pervious concrete, porous asphalt, and permeable interlocking concrete pavers (PICP) [25,26]. Depending on the site and soil conditions, they could be full infiltration, partial infiltration, or no infiltration (full exfiltration), mainly used for low-permeability or clay subgrade soils [27]. These permeable pavements share similar benefits in mitigating stormwater quality impacts. Meanwhile, few studies on PPS have typically focused on evaluating the strength, permeability, design configurations, water quality parameters, stormwater harvesting, groundwater recharge, water reuse, and life cycle assessment (LCA) [15,28–32]. Kia et al. and Mishra et al. have evaluated factors that affect the clogging of PPS, including physical clogging such as the entrapment of fine particles within the pores of the structure, chemical clogging that relates to the formation of scale, and biological clogging due to the accumulation of bacteria and algae or penetration of plant roots [33,34]. These factors were found to reduce the overall functionality of PPS, limit their hydrological performance, and decrease the infiltration capacity. Other factors that were reported to affect clogging in PPS are the size of pollutants present, concrete mix design, the pore structure arrangement, and permeability [35]. In terms of subgrade characteristics, it was found that the presence of clayey soil results in low bearing capacity and low hydraulic conductivity, which affects the exfiltration rate, lag times and the strength of the permeable pavement with time [35].

In addition, some practical field investigations have been conducted by many researchers to simulate the performance and infiltration capacities of different permeable pavements in Australia and the Netherlands. It was reported that although the infiltration capacity of the PPS tended to decrease with time due to the buildup of sediments, poor maintenance, and installation, almost 90% of the 55 pavements (ranging from 1 to 12 years of age) tested had surface infiltration rates that satisfied the infiltration rate standards [24,27]. Another study in Santa Catarina, Brazil, collected stormwater from PPS parking lots and concluded that such systems could save up to 54% in potable water [36]. In Florianopolis, Brazil, stormwater harvesting from permeable pavements was implemented and resulted in potable water savings of up to 19.4, 70.0, and 75.7% in the residential, commercial, and public sectors, respectively [28]. In Melbourne, Australia, there has been a tendency and growing popularity toward rainwater harvesting for domestic purposes ever since the city encountered severe drought for several successive years [30,37].

Few investigations have considered PPS performance in improving stormwater quality. Although several research studies discussed stormwater reuse for potable/non-potable uses for PPS, few articles evaluated their water quality performance [38–41]. In terms of stormwater quality, there has been some literature that has addressed the benefits of PPS in reducing significant contaminants such as turbidity, total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), heavy metals, oils, and hydrocarbons [42–45]. A study in Reze, France, investigated removal efficiency from stormwater pollutants runoff to permeable pavements, which resulted in respective reductions of approximately 59, 84, 77, and 73% for TSS, Pd, Cd, and Zn (heavy metals) when passed through PPS [39]. Another study evaluated the efficiency of PPS with swale to remove yearly pollutant runoff from a 4.65-hectare parking lot in Florida. It was revealed that the system achieved around 75 to 94% removal rates of solids and metal loads [46]. Furthermore, long-term monitoring performed in a section of a road in Auckland resulted in a reduction of around 95% for total zinc loads and 70% for TSS [47].

Therefore, a comprehensive bibliometric analysis is warranted to investigate the evolution and development of different aspects in the field of PPS for stormwater management. In addition, it is important to highlight recent advancements in the field and research opportunities that could be further investigated to improve the performance of PPS.

3. Methods

The results presented in this paper are based on a comprehensive bibliometric analysis of articles published between 2000 and 2021 in the area of PPS for stormwater management. The analysis extracts useful information from the record of published literature to help answer the research questions, discern research trends, identify research gaps, and provide guidance for future research directions. In addition, recent literature, from 2015 to 2022, in the field was screened to highlight developments in the use of PPS, particularly for stormwater contaminant control. The framework for the bibliometric analysis and identifying recent developments is shown in Figure 1, and further explained in the following subsections.

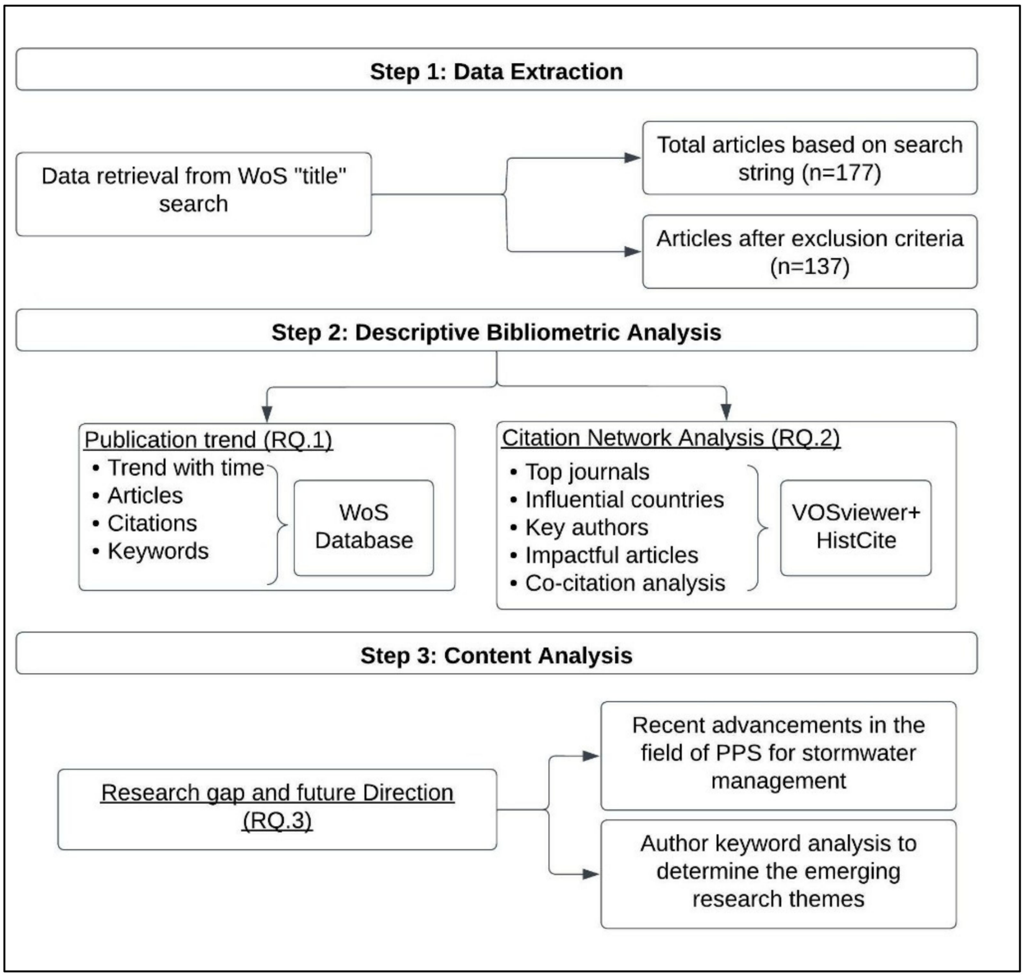

Figure 1. Research methodology flowchart. (n: number of articles, and RQ: Research Question).

3.1. Data Collection and Search Methods

Web of Science (WoS) is considered one of the most popular databases for scientific citation indexing [48]. Some past studies have compared WoS and Scopus databases and reported that both are equally good. However, WoS provides an in-depth citation by source and includes a larger number of scientific papers compared to Scopus, which was only launched in 2004 [49,50]. In addition, the choice of WoS as the source database was made since data from WoS can be easily imported into HistCite software, which will be utilized for the citation network analysis (Figure 1) [51–56]. Hence, to capture all the important past articles that were published in this area of research, WoS was chosen as the database for the present study. The search query targeted published articles from January 2000 until the end of December 2021. This time frame was chosen, as most publications appeared during this period, with only three journal articles published between 1995 and 1999. The data were retrieved on 15 July 2022. The search string performed in WoS was based on "title". The keywords used to conduct the search were selected to screen the articles based on relevance, as follows: ("permeable pavement" OR "pervious concrete" OR "permeable concrete" OR "pervious pavements") AND ("water quality" OR "hydraulic" OR "drainage" OR "runoff" OR "stormwater" OR "infiltration" OR "percolation" OR "hydrolog*")). The asterisk (*) in the search query indicates a continuation of the keyword, such as "hydrological", "hydrology" or "hydrologic".

The initial search string produced 177 articles. To further limit the search query, all articles in the year 2022 were disregarded in the bibliometric analysis, as this may underestimate the number of publications and citations in this year (i.e., 2022) when presenting a research trend. However, papers published in 2022 were included in the analysis of recent advancements. To limit the search to high-quality scientific research, the primary document type among the screened articles was peer-reviewed original research journal articles. Non-relevant articles were excluded, such as articles that focused on the use of harvested stormwater in non-potable use and fire extinguisher systems. Other excluded articles were related to acid mine drainage application in pervious concrete. Moreover, only articles written in English were included in the analysis. A total of 137 articles were obtained after the screening and filtering stage and used for the core bibliometric analysis.

A search query that excluded the hydrological and water quality aspects was also conducted to identify the research themes on PPS that were not water related. The search query included only the first part of the search string as follows: ("permeable pavement" OR "pervious concrete" OR "permeable concrete" OR "pervious pavements"). Interestingly, this returned a total of 631 articles. This means that 494 articles were associated with other research fields that were not relevant to stormwater management or water quality. Apparently, past research focused mainly on either "mechanical performance" or "hydraulic performance" while refraining from investigating any of these two aspects along with the hydrological parameters.

3.2. Data Analysis

WoS database was employed to elucidate articles with the highest number of citations, identify publication trends, and extract the keywords. Data from WoS were imported into VOSviewer (Visualization of Similarities) (version 1.6.18) and HistCite (version 12.3.17) to analyze the articles. VOSviewer was used for visualization, considering it has built-in graphics and algorithms [57–59]. HistCite was used for bibliographic analysis, as it offers extensive citation analysis [56]. Further, VOSviewer and HistCite software analysis tools were collectively employed to visualize and identify the influential countries, leading articles, top journals, and key authors. The ranking of authors, journals, and countries was based on total publications (TP), total citations (TC), and the citations per publication (CPP). TP can represent an author's or country's contribution to the area of research, whereas TC can indicate the relevance and the quality of the papers published. Meanwhile, CPP can be a more reliable indication of the consistency of contribution to knowledge. In addition, for the top authors, the ranking was performed using a normalized citation score, defined as the total number of citations of a particular publication divided by the average number of citations of all the publications in the same year [60].

Co-citation analysis was carried out to facilitate the identification of the collaboration among the authors and countries using the text mining feature of VOSviewer [18]. This analysis helps in identifying the important research studies, interconnections between authors and countries and the fundamental research themes [18]. Top articles were ranked using local and global citation scores. Global citations are the total number of citations across all indexing databases [61]. On the other hand, local citations are those inside the selected 137 articles. A visualization map was plotted to highlight co-authorship between countries and authors to determine which research collaborations are the strongest.

Furthermore, identification and visualization of keywords and their number of occurrences were carried out to determine the timeline for emerging, trending, and missing keywords. In addition, the 'graph maker' tool in HistCite software was applied to create a publication map based on the total number of citations. This tool clusters similar publications into research themes [62]. The clusters were verified by reviewing the abstract, reading the articles' contents, and identifying the major research findings.

4. Results of Bibliometric Analysis

4.1. Data Overview

This section gives a synthesis of the bibliometric analysis results to answer the first research question. To discover research trends on the topic of PPS use in stormwater management, the relevant outcomes included publication trends, citation trends, and emerging versus missing keywords in the literature. From Figure 2, it can be observed that although the search query was initially set to the year 2000, the first two articles appeared in 2003. There was a publication gap between 2004 and 2005, and citations were limited to only three. From 2006 onwards, there has been a steadily increasing trend in citations and the number of publications. The number of citations increased from approximately 10 in 2007 to 740 in 2021. Similarly, as can be inferred from Figure 2, the number of publications has surged since 2013, with an annual average growth rate of approximately 53%. The most productive years with the greatest number of publications were between 2018 and 2020, where the publications varied between 16 to 19, and the peak was reached in 2018. This observation, i.e., the increase in publications after 2014, can be attributed to the fact that articles published prior to 2014 had less emphasis on the performance of PPS in stormwater management, which consequently limited the target audience.

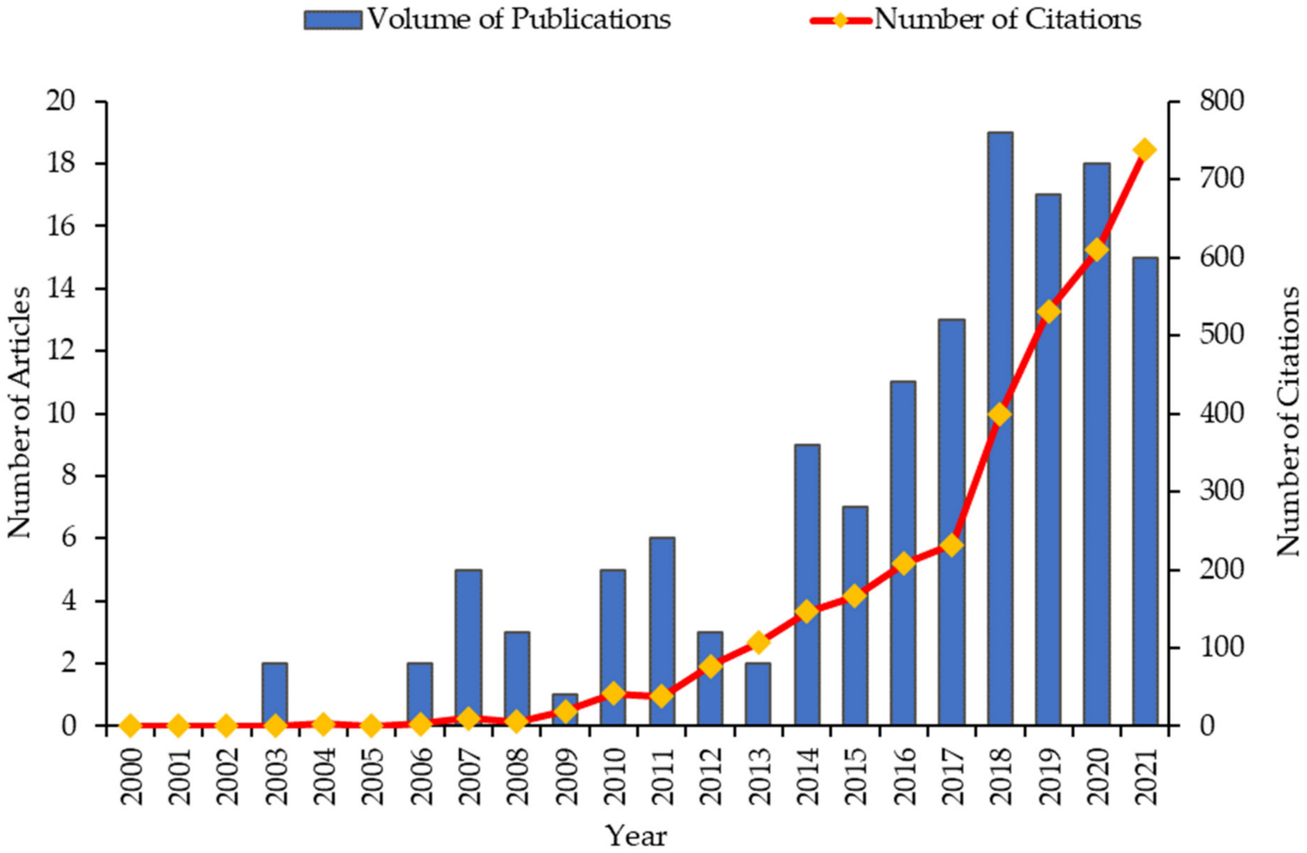

Figure 2. Number of articles and number of citations for articles published on the topic of PPS for stormwater management.

4.2. Keyword Analysis and Recent Research Trends

VOSviewer was used to generate a conceptual keyword map of the research area. A threshold value of five minimum occurrences was set to include keywords that are frequently used [18]. It was observed that out of the 578 keywords obtained, only 47 met the threshold criterion. Figure 3 represents the authors' keywords and the clustered publication themes. It can be noted that three clusters were formed, and for each cluster, a primary keyword represents a specific field. For example, the words "pervious concrete" and "performance" are the main clusters that are illustrated by green color. This cluster includes several significant keywords, such as permeability, hydraulic conductivity, and compressive strength. Similarly, there are other keywords represented by smaller circles, such as "no-fines concrete", "drainage" and "rainfall-runoff". Similarly, "infiltration" and "clogging" are the main themes in the blue cluster. The articles in this cluster link "infiltration" and "clogging" with different themes, such as "stormwater management", "urban drainage", "best management practice", "maintenance", and "SUDS". Lastly, the prominent keyword in the red cluster is "runoff", and the related words are "water quality"," removal", "bioretention", "reduction", and "adsorption". Therefore, it is inferred that the green cluster is primarily associated with the structural and hydrological performance of permeable pavements, the blue cluster is related to various stormwater management practices, and the red cluster focuses on different water quality aspects. In addition, all three clusters have the words permeable, porous, and pervious pavement/concrete in common.

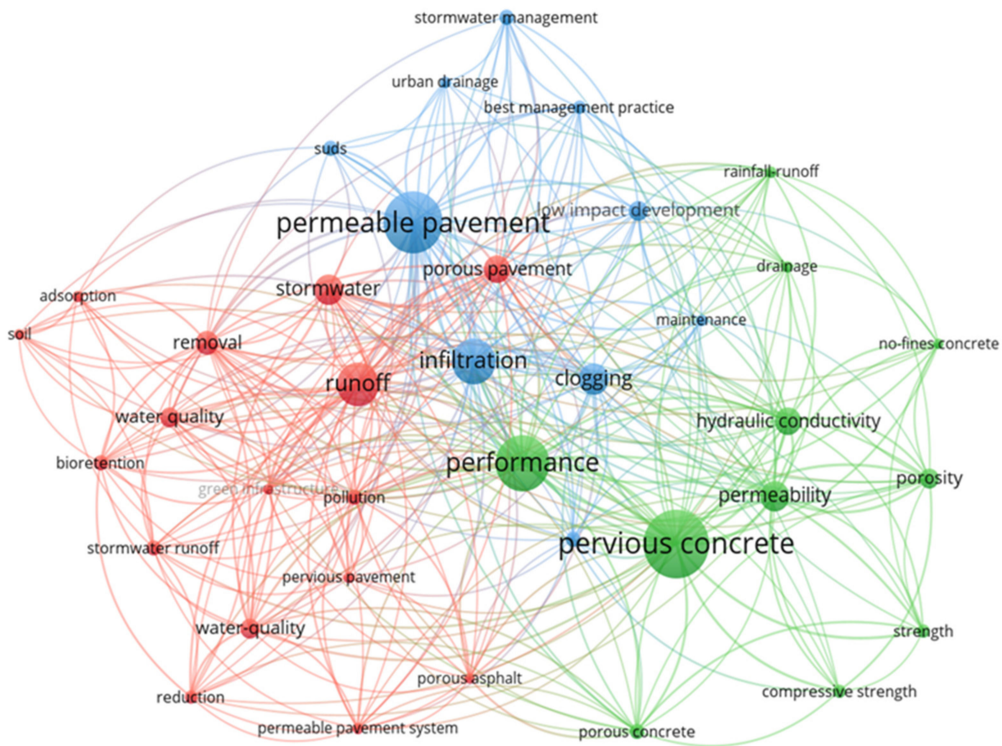

Figure 3. Network map for the top keywords subdivided into three different clusters based on the main research theme. The green cluster represents aspects of structural and hydrological performance, the blue cluster includes stormwater management practices, and the red cluster focuses on water quality aspects. (The size of the bubble represents the frequency of occurrence, and the curved lines show the co-appearance between the keywords).

Furthermore, analyzing the sequence of keywords year-wise provides information on the frequency of the published papers containing that keyword. Figure 4 represents the trends in the top ten (10) keywords based on the WoS search query and HistCite analysis. It can be depicted that the word "infiltration" has been steadily increasing from 2013 until 2021. This indicates that the frequency of the word "infiltration" has been investigated in several studies throughout this period. Although the word "performance" first appeared in 2003, there was a large gap until the year 2009, evident by the horizontal line during that period, which indicates that the articles gained less attraction during this period. However, there has been an increase since 2009, and it spiked in 2018. One possible explanation is that the authors are interested in the long-term performance of PPS. Similarly, for "stormwater", there has been a large gap from 2007 until 2013, and ever since, there has been a large interest in the topic. This could be associated with the increased impervious surfaces that resulted in increased stormwater, hence being given more attention. The word "removal" had been prominent in the early years but had a large gap from 2010 to 2015 and has been increasing since 2020. This gap could be associated with more emphasis on other PPS topics, such as "hydrological/hydrologic", which steadily increased from 2005 until 2021. The word "hydraulic conductivity" had a series of gaps from 2006 to 2010 and 2012 to 2015, and there has been a slight increase from 2015 to 2021. This trend is evident and parallel to those of other keywords. For instance, when the word "stormwater" had a steady increase, there was a corresponding increase for other words, such as “water quality”, “permeability”, “hydraulic conductivity” and “clogging”. In addition, a combination of two or more keywords could be mentioned in the same article. Therefore, it is evident that since 2013 there has been a surge and constant increase in the major keywords in the field of PPS in stormwater management. This provides a strong indication that the core keywords are gaining momentum, and the number of articles is increasing accordingly.

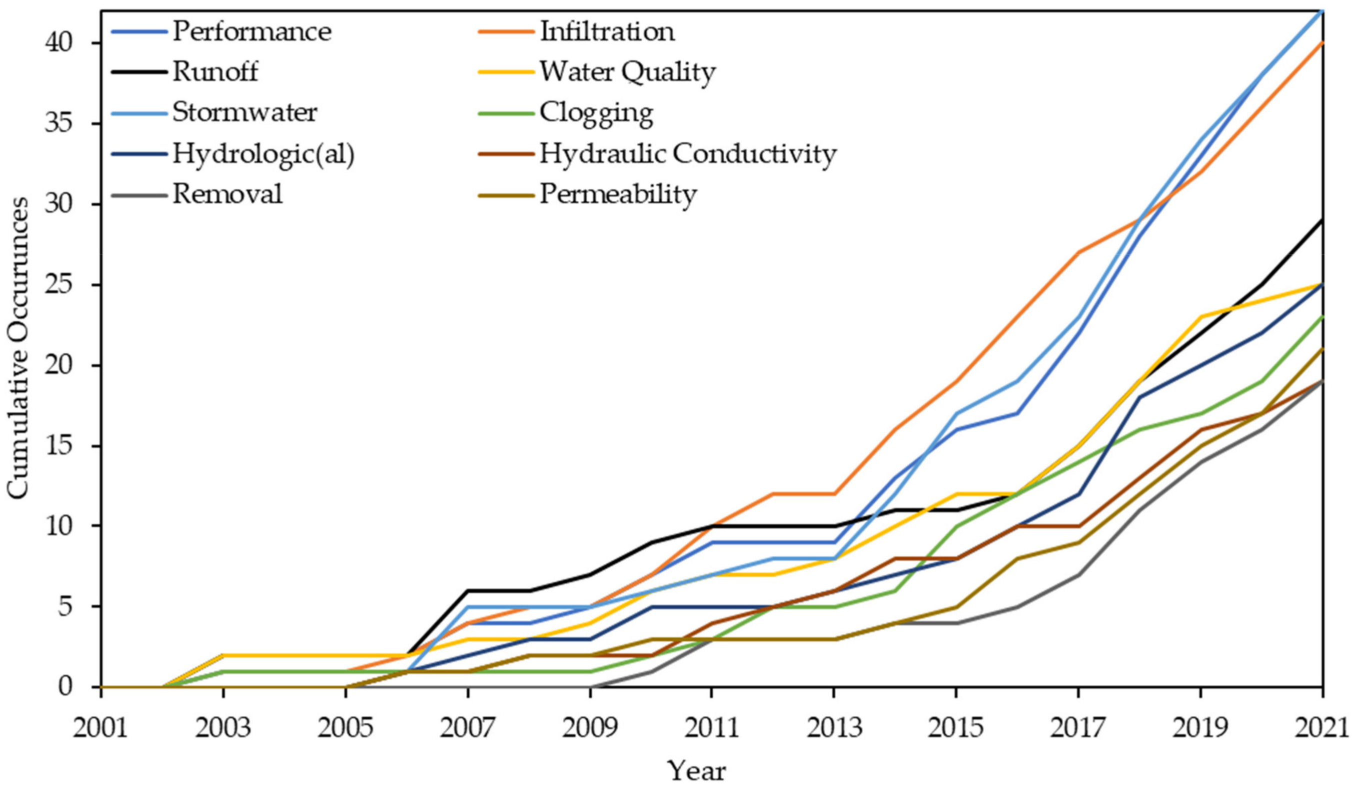

Figure 4. Year-wise analysis of major keywords in the field of PPS and stormwater management.

In addition to the top ten (10) keywords mentioned above, several keywords started to emerge, and other continued to disappear within the studied timeframe (2000–2021), as shown in Figure 5. From 2015 onwards, specific keywords, such as “bioretention”, “recycled” and “adsorption” had lower occurrences; however, there has been an increase lately in the recent research trends. The word “biodegradation” appeared from 2010 until 2013 and ever since has not been mentioned in any articles related to PPS. Furthermore, another significant missing keyword, “Kozeny carman”, which is mostly implemented for correlating the porosity of PC and hydraulic conductivity, was not mentioned from 2016 onwards. This could be due to the emergence of different modeling software tools and/or empirical models that are easier to adapt. Moreover, some of the emerging keywords, such as “X-ray tomography” appeared from 2008 until 2011, and there was a ten-year gap until 2021, when they started to reappear. In research related to the improvement of stormwater quality by PPS, the first appearance of the word “adsorption” in 2017 was investigated by Holmes et al. [63]. This work examined the use of cementitious fly ash material to enhance the removal of heavy metals in pervious concrete due to their effectiveness as an adsorption material in industrial wastewater containing cadmium and zinc. It was found that the high sulfur and carbon contents provided improved removal capacity for heavy metals in PPS, especially at lower concentrations due to the presence of adsorption sites [63].

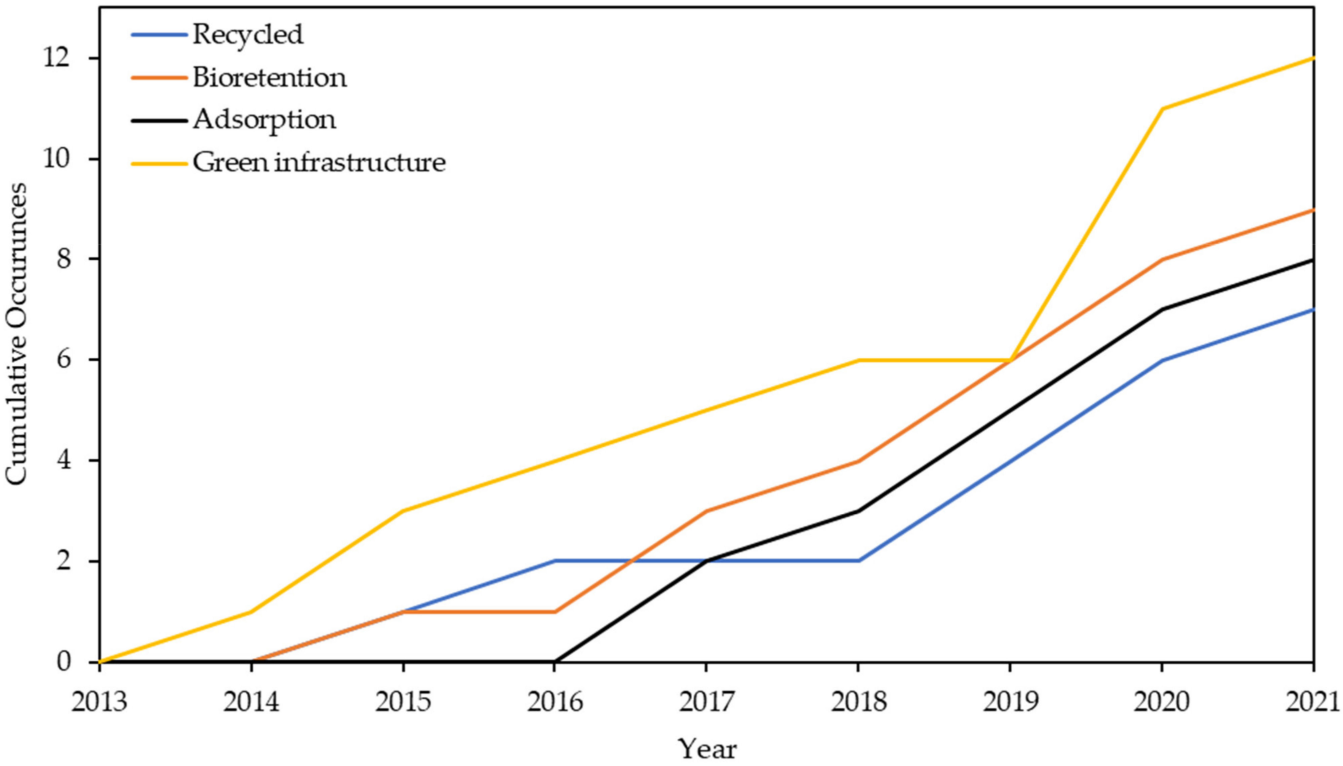

Figure 5. Emerging keywords in the field of PPS and stormwater management.

Similarly, in 2020, a lab experiment was performed on the use of multifunctional green pervious concrete (MGPC) to adsorb organic materials such as PAHs [64]. Results showed that it has great potential for long-term use and effective stormwater quality control [64]. Furthermore, the word "bioretention" first appeared in 2017, when Hwang et al. [46] reported that bioretention basins played a very important role in reducing the non-point source pollutants and certain nutrients, thereby improving the overall stormwater quality and reducing the runoff volume [47]. The number of publications on this topic surged from one to four articles during the one-year period from 2017 to 2018. Most recent articles in 2020 by Winston et al. [36] found that a treatment train that incorporates permeable pavements, along with internal water storage (IWS) zone, significantly reduced the peak flow rate and runoff volume and had a promising nutrient removal percentage similar to bioretention cells [40,65]. Lastly, the word "no-fines concrete" vanished in 2011 and started reappearing in 2018 and 2019 with more than two articles.

Furthermore, it is worth mentioning that some new keywords emerged within the past decade (2012–2021), as shown in Figure 5. The term "adsorption" was used in articles that mainly examined the use of novel materials for water treatment and quality assessment, including photocatalysts and nano materials. Meanwhile, the keyword "recycled" was highlighted in various articles that examined the replacement of aggregates and/or cement with recycled waste materials. In some articles the inclusion of bioretention basins was proposed to contribute to the degradation of pollutants by physical and biological processes and to reduce stormwater runoff. Green infrastructure is another keyword that is a synonym for sustainable urban drainage systems "SUDS" and low-impact development or "LID"; the three terms focus on technologies that maximize the beneficial reuse of stormwater with minimal impact on the environment and lower costs. Indeed, from their first use, the keywords "adsorption", "recycled", "bioretention", and "green infrastructure" had respective annual growth rates of 55, 52, 61, and 63%, signifying their importance in the field of PPS as more investigations focus on their hydrological and water quality performance.

4.3. Major Contributors to Research in the Area of PPS for Stormwater Management

The analysis revealed that the top journals, based on total publications (TP), are *Construction and Building Materials* (*Constr. Build. Mater.*), *Journal of Hydrologic Engineering* (*J. Hydrol. Eng.*), *Journal of Irrigation and Drainage Engineering* (*J. Irrig. Drain. Eng.*), *Journal of Environmental Management* (*J. Environ. Manage*), and *Journal of Environment Engineering* (*J. Environ. Eng.*) with TPs of 13, 9, 9, 8, and 6, respectively. Similarly, in terms of total citations (TC) and citations per publication (CPP), these journals have the highest rankings and appear in the top 10 for all the classifications, as shown in Table 1. Although *Water Research* (*Water Res.*) appears to have around 410 TC, it had relatively lower TP and CPP compared to other journals. The most cited article from the journal *Constr. Build. Mater.* is an experimental study performed on different pervious concrete (PC) mixtures. Different relationships were established between the size of aggregates, cement content, water-to-cement ratio and permeability, porosity, and tensile strength to assess concrete mechanical and hydrological properties [66]. Similarly, *J. Hydrol. Eng.* had the highest number of citations during the years 2008 and 2010, with a total number of citations of around 369 out of the 541 total citations. Articles published in *J. Hydrol. Eng.* discussed important hydrological aspects, such as peak flow rate, surface runoff volume, and total outflow volume from permeable pavement systems. Other articles discussed the effects of PPS installation over impermeable soils and compared similar hydrological parameters. Lastly, *J. Irrig. Drain. Eng.* had most of their cited articles discussing the infiltration rates of different PPS; however, the last published article was in 2015 [32,67]. Water Res. journal has the highest TC and CPP, and this is linked to one of the earliest articles published in 2003 [44].

Table 1. Top Journals ranked by total citations, total publications, and citation per publication.

Ranked by TP *			Ranked by TC *			Ranked by CPP *		
Rank	**Journal Name**	**TP**	**Rank**	**Journal Name**	**TC**	**Rank**	**Journal Name**	**CPP**
1	*Constr. Build. Mater.*	13	1	*J. Hydrol. Eng.*	541	1	*Water Res.*	103
2	*J. Hydrol. Eng.*	9	2	*J. Irrig. Drain. Eng.*	508	2	*J. Hydrol. Eng.*	60
3	*J. Irrig. Drain. Eng.*	9	3	*Constr. Build. Mater.*	426	3	*J. Irrig. Drain. Eng.*	56
4	*J. Environ. Manag.*	8	4	*Water Res.*	410	4	*J. Hydrol.*	45
5	*J. Environ. Eng.*	6	5	*J. Environ. Manag.*	290	5	*J. Environ. Manag.*	36
6	*Water Sci. Technol.*	6	6	*J. Hydrol.*	178	6	*Constr. Build. Mater.*	33
7	*Water*	6	7	*Environ. Eng.*	75	7	*JOEE*	13
8	*J. Sustain. Water Built Environ.*	5	8	*Water Sci. Technol.*	59	8	*Water Sci. Technol.*	10
9	*J. Test. Eval*	5	9	*Water*	53	9	*Water*	9
10	*Water Res.*	4	10	*J. Sustain. Water Built Environ.*	38	10	*J. Sustain. Water Built Environ.*	8

* TP: Total Publications, TC: Total Citations, CPP: Citation per publication, *Constr. Build. Mater.: Construction and Building Materials, J. Hydrol. Eng.: Journal of Hydrologic Engineering, J. Irrig. Drain. Eng.: Journal of Irrigation and Drainage Engineering, J. Environ. Manag.: Journal of Environmental Management, J. Environ. Eng.: Journal of Environment Engineering, Water Sci. Technol.: Water Science & Technology, Water: Water (Switzerland), J. Sustain. Water Built Environ.: Journal of Sustainable Water in the Built Environment, J. Test. Eval.: Journal of Testing and Evaluation, J. Hydrol.: Journal of Hydrology.*

An overview of the most influential countries is presented in Table 2, with a minimum number of five publications. The USA is ranked first for the total number of publications and citations but ranked third in the citation per publication. In addition, the USA was the first country to introduce stormwater quantity and quality aspects in the field of PPS and assess long-term performance in 2003. Although China is ranked second for TP, it is ranked fourth and seventh in TC and CPP, respectively. China initially started publishing in 2011 about various water quality aspects, including stormwater harvesting, storage, and reuse in the previous pavement, but there was a five-year gap until publishing again in 2016. However, from 2016 until 2021, there have been continuous publications, with a peak of five publications in 2021 on different aspects of stormwater quantity and quality. It is evident from Table 2 that Canada has the highest number of CPP, which is due to the article published in 2010 that investigated the hydrologic performance over clayey soils and included long-term quality monitoring and practical investigations [68]. However, Canada is ranked seventh in total publications, with only six in the country. Lastly, Italy is ranked second for the total number of publications and citations. Recent articles focus on different aspects of the numerical modeling and characterization of hydraulic strength of pervious concrete for deep-drain trenches. It is also worth mentioning that the total number of publications in Table 2 adds up to more than 137 because the counting method in WoS is based on the total number of countries affiliated with a published paper. For example, if a published article had authors affiliated with different countries, i.e., two or more countries are in the same published paper, then the paper is counted once for each of those countries, hence overestimating the number of publications [69]. Most of the investigated publications are in geographic locations that experience frequent rainfall from medium to high intensities. Many countries with arid to semi-arid climate conditions have very few publications. Furthermore, most investigations are based on laboratory work rather than practical field investigations.

Table 2. Influential countries ranked by total publications, total citations, and citations per publication.

Ranked by TP			Ranked by TC			Ranked by CPP		
Rank	**Country**	**TP**	**Rank**	**Country**	**TC**	**Rank**	**Country**	**CPP**
1	USA	61	1	USA	2315	1	Canada	49
2	China	20	2	Italy	395	2	Italy	40
3	England	10	3	Canada	293	3	USA	38
4	Brazil	10	4	China	231	4	Australia	27
5	Italy	10	5	Australia	187	5	Scotland	20
6	Spain	8	6	England	143	6	England	14
7	Australia	7	7	Scotland	98	7	China	12
8	Canada	6	8	Spain	79	8	Germany	11
9	Scotland	5	9	Germany	57	9	Spain	10
10	Germany	5	10	Brazil	50	10	Brazil	5

In addition, the analysis of the top authors provides a better understanding of their expertise in certain topics of PPS. VOSviewer was used to determine the top authors from the 137-node network analyzed. The minimum number of publications per author was set to 3, and hence 18 authors out of the 446 met that threshold. Furthermore, many authors had three publications, so the top 10 were filtered based on the normalized citations presented in Table 3. From the normalized citation score, the top authors are William Hunt, Ryan Winston, Xuheng Kuang, Vittorio Ranieri, and John Sansalone, with normalized citation scores of 13, 9, 5, 5, and 5, respectively. Therefore, these five authors are considered to be the most productive in this field. They are from the USA, China, and Italy and have discussed various mechanical, hydraulic, hydrologic, and water quality aspects of PPS.

The last part of this section discusses the leading articles in stormwater management. Table 4 depicts the top 10 articles in terms of global and local citations that were obtained from HistCite software. For the global citations, Brattebo and Booth were ranked first with 318 citations, followed by Fassman and Blackbourn, Collins et al., and Bean et al. with 169, 167, and 165 citations, respectively. From the perspective of local citations relating to the citations within the 137 node-network, it is evident that these four articles are still the most impactful articles. For instance, Brattebo and Booth [44] evaluated different commercial paving systems (grass pave, gravel pave, turf stone, and eco-stone) and assessed their durability, infiltration rate, and water quality parameters, such as motor oil, copper, zinc, and lead. They revealed that all the incoming precipitation was infiltrated, even during intense rainfall events [44]. Furthermore, copper, zinc, and motor oil had very low concentration levels compared to traditional asphalt pavements [44]. Fassman and Blackbourn evaluated permeable pavements over impermeable soils with an underdrain and compared them with traditional asphalt pavements [68]. A large reduction in the surface runoff volume and peak rate was reported alongside a delay in the peak flow rate [68]. A similar investigation was carried out by Collins et al., who assessed four different types of permeable pavements over poorly drained soils. The results were identical in that the PPS systems reduced the runoff volumes, thus, decreasing and delating the peak flow rate [70]. Therefore, it is clear from previous literature and their global citations that more attention was given to the hydrologic parameters, such as runoff reduction, comparison between asphalt and permeable pavement, and construction of such PPS systems over low-permeability soils. In addition, many of these articles had practical field investigations compared to other articles that evaluated PPS in laboratory scale studies.

Table 3. Top authors ranked by normalized citations.

		Ranked by Normalized Citation Score (NCS)		
Rank	**Author**	**Affiliation**	**Country**	**NCS**
1	William Hunt	North Carolina State University	USA	13
2	Ryan Winston	Ohio State University	USA	9
3	Xuheng Kuang	Tsinghua University	China	5
4	Vittorio Ranieri	Politecnico di Bari University	Italy	5
5	John Sansalone	University of Florida	USA	5
6	Jay Dorsey	Ohio State University	USA	4
7	Krishna Biligiri	Indian Institute of Technology (IIT)—Tirupati	India	4
8	Luis Sanudo-Fontaneda	University of Oviedo	Spain	3
9	Haiyan Li	China University of Mining & Technology	China	3
10	Xiaoran Zhang	Beijing Adv Innovat Ctr Future Urban Design	China	3
11	Ziyang Zhang	Beijing University of Civil Engineering & Architecture	China	3

Table 4. Top ten articles based on global and local citations.

Ranked by Global Citations			Ranked by Local Citations		
Rank	**Article**	**Global Citations**	**Rank**	**Article**	**Local Citations**
1	Brattebo and Booth (2003) [44]	318	1	Brattebo and Booth (2003) [44]	44
2	Fassman and Blackbourn (2010) [68]	169	2	Bean et al. (2007a) [67]	29
3	Collins et al. (2008) [70]	167	3	Collins et al. (2008) [70]	28
4	Bean et al. (2007a) [67]	165	4	Bean et al. (2007b) [32]	25
5	Ibrahim et al. (2014) [66]	134	5	Fassman and Blackbourn (2010) [68]	19
6	Bean et al. (2007b) [32]	126	6	Montes and Haselbach (2006) [71]	18
7	Sansalone et al. (2008) [72]	115	7	Drake et al. (2014) [73]	12
8	Rahman et al. (2015) [74]	84	8	Sansalone et al. (2008) [72]	11
9	Montes and Haselbach (2006) [71]	83	9	Chopra et al. (2010) [75]	11
10	Drake et al. (2014) [73]	79	10	Kwiatkowski et al. (2007) [76]	11

4.4. Nature of Collaboration in the Field of PPS

Country authorship analysis was conducted with a minimum of two publications per country. Out of the 33 identified countries, 16 met the criterion. However, three countries did not have any link with the other 13 countries and hence were excluded from the country–coauthor map, as presented in Figure 6. The circled nodes depict the total number of publications for each country. As the node size increases, it indicates a larger number of publications. Furthermore, the curved lines that connect one country to another signify the co-authorship among these countries. In the same context, the thickness of the lines illustrates the term recurrence between the countries [18]. Accordingly, the USA had the largest number of publications (61), followed by China, England, Brazil, and Italy, with 20, 10, 10, and 10 publications, respectively. The most prominent collaboration is between the USA and Italy, with a total link strength of 6, followed by Spain and England, with a link strength of 5. This means that a total number of 6 and 5 publications were co-authored between each of these two countries, respectively. Similarly, the link strength between the USA and China is 3. The rest of the countries exhibit low co-authorship, with 2 links or less. Most of the collaborative articles between these countries include various fields in stormwater management ranging from hydrological properties such as infiltration rate, stormwater runoff, and different water quality testing. As such, more collaborations are needed between different countries to study the effect of variability in materials and climate conditions on the performance of the PPS.

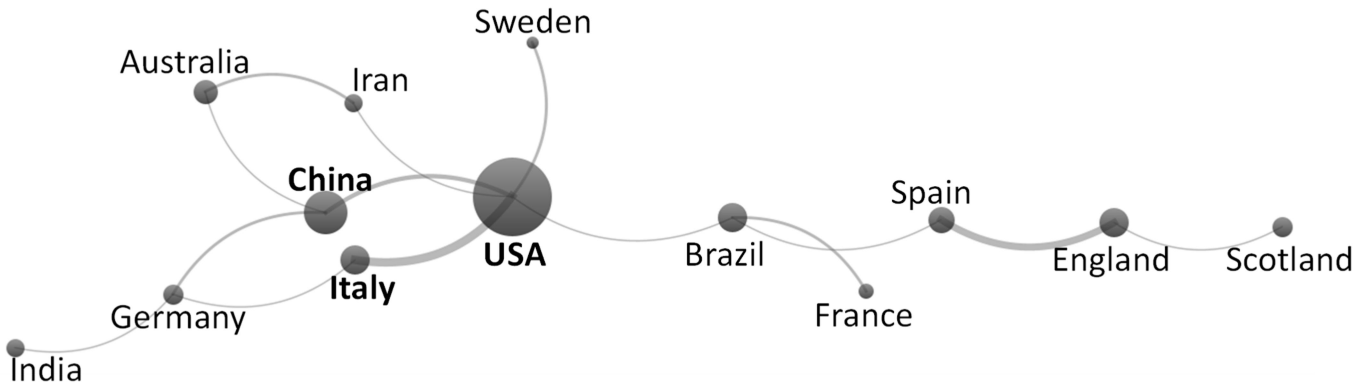

Figure 6. Co-authorship and countries (size of the bubble represents the volume of publications, and line thickness illustrates the term recurrence between the countries).

Similarly, a co-authorship map was created between the authors, with the minimum number of documents being 2. This resulted in 51 authors meeting this criterion out of a total of 443. However, 44 authors were excluded from the analysis as no links/cooperations were found among them, as shown in Figure 7. The greatest collaboration was between William Hunt (North Carolina State University) and Ryan Winston (Ohio State University), with a total link strength of 6, followed by William Hunt/Ryan Winston and Jay Dorsey (Ohio State University), with a total link strength of 3. It is worth noting that these authors are ranked among the top 6 in terms of normalized citation score. The rest of the authors have a link strength of 1 or 2, indicating a maximum number of one or two articles published together among the authors. Furthermore, it is very evident that although 44 authors were independent and did not collaborate, many of these authors focused on the same research field, but international collaborations were very low. Therefore, it is worth mentioning that there is a lack of cooperation among many authors who are experts in the same field of stormwater management.

4.5. Co-Citation Analysis and Clustering

There are different processes and techniques that can be utilized in bibliometric citation analysis, including co-authorship, bibliometric coupling-citation, co-word, and co-occurrence analysis [77]. Co-citation analysis describes the frequency of two or more articles cited by other articles [78]. It is considered to be one of the significant analyses, as it presents different research themes and assists in analyzing the source and direction for future research in the field of PPS. From the co-citation analysis performed in Figure 7, the co-cited articles were determined. These articles were grouped into several sub-streams, i.e., clusters, according to the context similarity, which corresponds to specific research themes [79]. It is worth mentioning that some articles belonged to two clusters, i.e., the topic under investigation fit two research themes, highlighting the presence of interrelations between the different clusters [51].

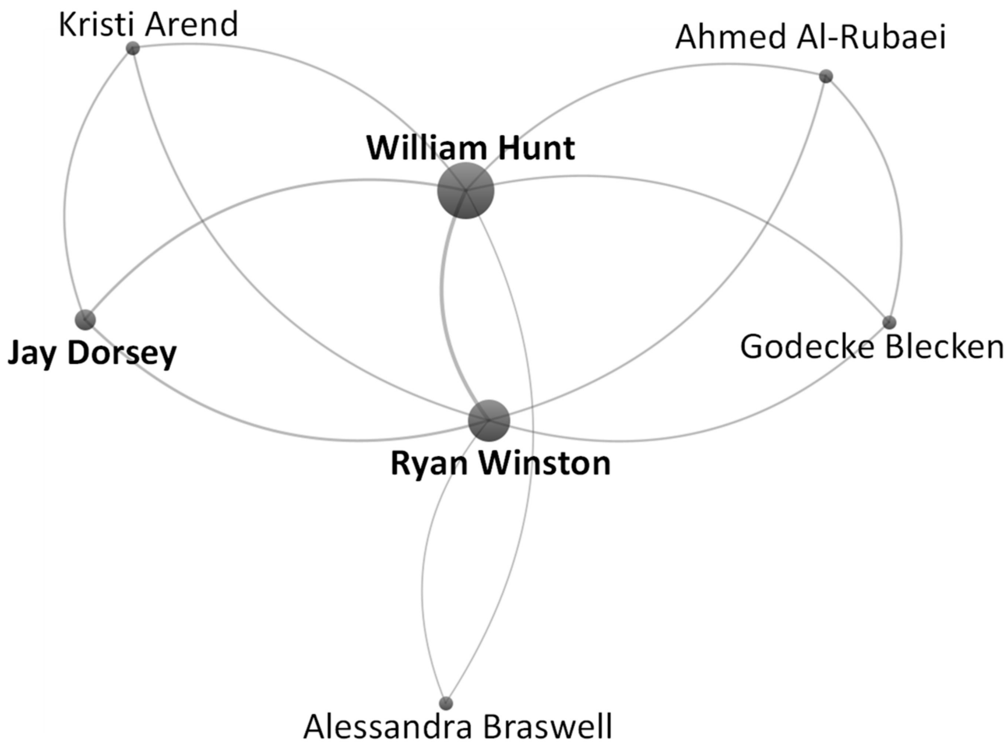

Figure 7. Network mapping associated with the greatest co-operation between authors (the size of the bubble depicts the number of publications, and the thickness of the curved lines represents the number of shared articles between the authors).

The clustering of the articles was performed using HistCite. Only articles within the top 30 based on global citations score were considered based on previous bibliometric analyses performed [80,81]. Figure 8 depicts the historiographic citation mapping of the top 30 most cited papers on the basis of global citations score. The circles (or nodes) represent the articles, while the number inside each circle represents the unique node number assigned for each article. The larger the circle, the larger the global citations and the more influential this article is compared to others [81]. The citation links among the articles are shown by a set of lines and arrows, where the head of the arrow represents the article being cited. For instance, the article of node #5 was cited by articles in nodes #27, #55, #68, #12, and #52. It is worth mentioning that some articles appeared not to be cited. This is due to the limiting of the number of articles to the top thirty (30) most cited articles only.

The column on the left of Figure 8 represents the year in which the node (article) was published, with the total number of publications in that year shown in parentheses (i.e., the number of circles horizontally across the year). However, as the number of articles shown in Figure 8 was limited to the top 30 most cited articles, a limited number of articles is shown on the same row as that number. Furthermore, the closer the nodes are to each other, the more often these articles are likely to have been co-cited together [82,83]. Yet, it should be noted that some articles either did not focus on any of the topics associated with the five major clusters or were not linked to any other articles. Hence, they were not assigned to a specific cluster and were subsequently excluded from the clustering process. For instance, node #30 discussed the effect of evaporation on the hydrological aspects of pervious concrete [84]. Similarly, node #33 investigated twenty-four PC mixes by varying the aggregate sizes and assessed their effect on hydrological properties, such as porosity, permeability, and compressive strength [66]. Node #3 assessed the performance of PPS in a motorway service station parking [85]. In addition, certain independent nodes, such as node #20 and node #93, were part of the red and yellow clusters, respectively [86,87]. Still, they did not have any co-citations with other articles and were therefore excluded. From this point, the citing and cited articles and their clusters can be identified. For example, article #37 ([73]), published in 2014, was cited by article #89 [41], published in 2018.

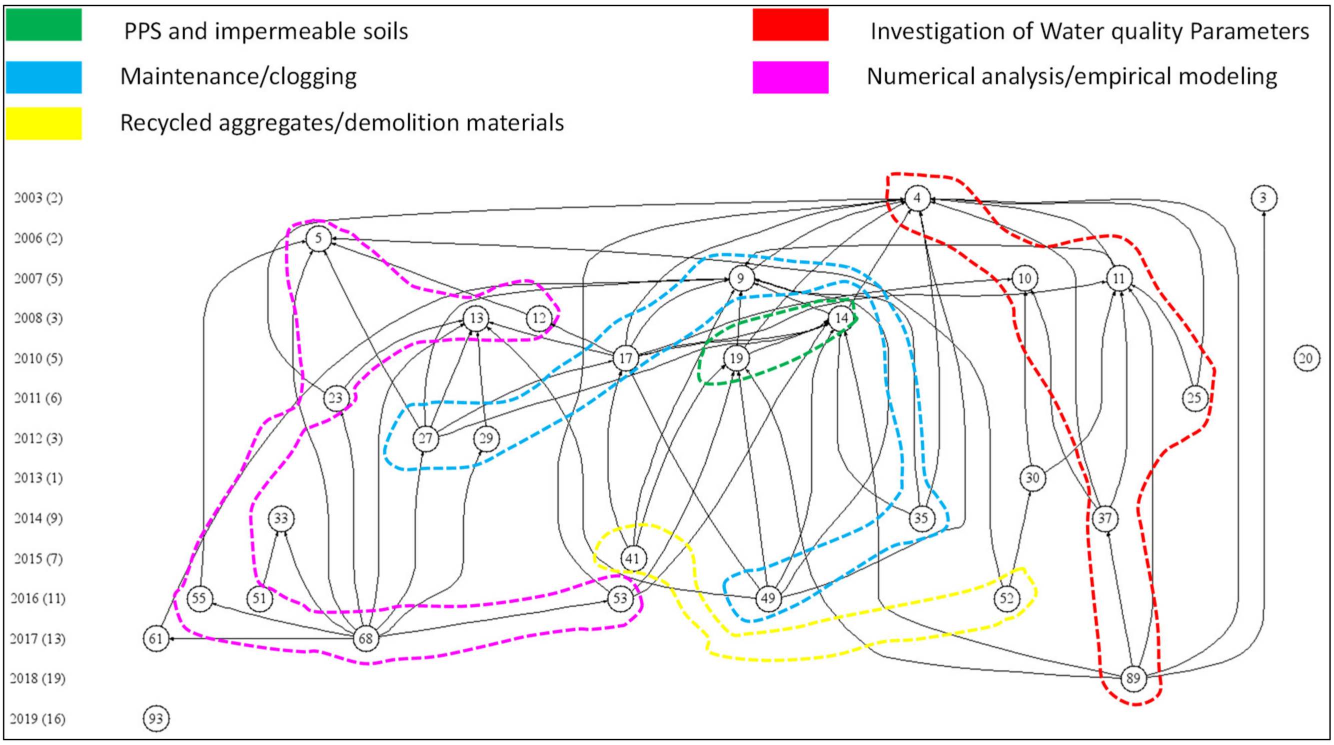

Figure 8. Citation mapping of the top thirty cited papers along with the clusters and years of publication.

From the clusters formed in Figure 8, one can infer that the red cluster primarily illustrates the removal efficiency of different water contaminants such as total suspended solids (TSS), heavy metals, nutrients (total phosphorus and total nitrogen), turbidity, and chemical oxygen demand (COD) [32,43,44,76]. Articles associated with the red cluster had either lab or field investigations, with study durations ranging from 10 to 26 months. Meanwhile, articles belonging to the magenta cluster utilized regression analysis equations, such as Kozeny–Carman models, to establish relationships among various hydraulic parameters for PPS [71,88,89]. In addition, this cluster incorporated articles that employed modeling software, such as Hydrus 1-D and Hydrus 2-D, to analyze the hydraulic behavior and properties of PPS [90,91]. On the other hand, the blue cluster focuses on exploring the effects of different sediment materials, characterizing layers prone to clogging, and the effects of soil type on clogging and maintenance techniques required to prolong the life of the PPS [67,75,92–96]. Furthermore, the green cluster discusses the reduction in hydrological properties, such as outflow volumes, peak flow rates, and surface runoff, with respect to PPS systems built over poorly drained soils [65,68,97,98]. These studies involved long-term monitoring, typically in the range of 10–24 months. Lastly, the yellow cluster illustrates the inclusion of different recycled materials in the mix design of PPS to assess its mechanical and hydraulic properties [74,87,99].

Moreover, it is interesting to note that articles belonging to a certain cluster cited articles from the same or different clusters. For instance, article #4, belonging to the red cluster, has been cited by articles in the red, blue, magenta, and green clusters, highlighting its importance as a resource across different research themes [44]. Similarly, it is evident from Figure 8 that there are frequent co-citations between the magenta and blue clusters. This is because articles employing regression or numerical analysis need to analyze porosity, hydraulic conductivity, and clogging potential. Similarly, the red and green clusters are closely related in terms of co-citations, owing to the fact that certain articles examined water quality parameters over PPS built on impermeable soils. Additionally, the green and blue clusters were closely linked to one another. This is because articles associated with PPS over impermeable soils also examined the effect of clogging and/or maintenance.

5. Discussion of Recent Developments

From the bibliometric analysis presented in this paper, it can be deduced that the main distinctive themes in the research topic of PPS for stormwater management are as follows: (1) improving and predicting the removal of contaminants, (2) characterizing and minimizing the effects of clogging, (3) improvements for infiltration rate (IR) assessment and characterization, and lastly, (4) sustainability considerations. Therefore, it is pertinent to highlight recent advancements to overcome challenges in each of the identified research themes. This would, in turn, allow for identifying knowledge gaps and future research opportunities. Table 5 depicts some of the major recent advancements along with the research opportunities that researchers could address in their future investigations.

Table 5. Recent advancements and research opportunities.

Research Theme	Recent Advancement	Research Opportunity
Improving and predicting the removal of contaminants	• Mixing sorbent materials such as pozzolanic materials [100], photocatalytic nanomaterials, and iron oxides [101–103], replacing sand and gravel layer with coal gangue [104], biofilms for removal of mercury [105], bentonite [106], diatomite and zeolite powder [107] • Structural modifications, such as: increasing the number of layers and their thicknesses [108], a combination of different layers with varying properties [109], the inclusion of an internal water storage zone [40,41,110], multifunctional green-pervious concrete (MGPC) to remove PAHs contaminants [64]. • Predicting contaminant removal: modeling contaminant removal rates by regression analysis [111].	• Assessing the long-term performance of PPS for: ○ Water quality enhancement ○ Leaching of adsorbed contaminants ○ Possibility of simplifying the PPS system to be implemented by another research. ○ Limiting the number of contaminants investigated and detailed focus on the effect of certain contaminants on clogging. ○ Focus on the effectiveness of PPS in removing emerging contaminants
Characterizing and minimizing the effects of clogging	• Relating clogging to maintenance effectiveness: clogging usually affects the top 1.5–2.5 cm of the PPS system [70,93–95] and hence vacuum sweeping and/or pressure washing are the most common and [112] effective methods for increasing IR [95,112,113]. In addition, maintenance is not required when IR is greater than 250 mm/min [114]. • Accurate characterization of clogging such as X-ray CT for analyzing pore network, computational fluid dynamic (CFD) to predict hydraulic conductivity [115,116], utilizing 2D and 3D microtomography techniques to visualize clogging [117,118], water content reflectometers (WCR) and time domain reflectometers (TDRs) [119], regression analysis and artificial neural networks (ANN) to predict clogging by means of lab experiments [120,121]. • Modeling of clogging dynamics such as: determining and predicting hydraulic conductivity and pore-clogging using regression analysis, discrete element modeling, and the Kozeny–Carman model [89,122–124].	• Develop a standardized clogging test that researchers can adopt and implement to compare their results. • In addition to sediments, exposing the PPS systems to a wide variety of pollutants and clogging materials to assess the clogging effect. • Investigate different chemical or biological techniques that could be more effective in removing soluble contaminants. • Emphasize the use of numerical modeling along with experiments to verify clogging effects and predict optimal porosities and pore size. • Investigating deep layers of PPS using advanced imaging techniques to attribute the observed effects on IR and hydraulic conductivity.

Table 5. *Cont.*

Research Theme	Recent Advancement	Research Opportunity
Improvements for IR assessment and characterization	• Enhancements for PPS field tests: large infiltration rings (>200 mm) are recommended for accurate assessment of field infiltration tests [125,126]. PC slab specimens are more representative of field conditions than cylindrical specimens [33,127]. • Modifying PPS structure, such as coarse aggregates with copper slag or inclusion of a high-permeability media mixture (HPMM) increases porosity, permeability rate, and infiltration rate [87,110,128], reducing fine aggregates from 0% to 100% from concrete mix design increases IR significantly [129].	• Comparing results from previous literature to assess the feasibility and conduct LCA for the long-term monitoring of such modifications. • Investigate the effect of different rainfall intensities on the IR and the impact it may cause with varying dry and wet weather conditions.
Sustainability Considerations	• Focus on cement replacement such as a combination of PA mix (PAC) and permeable cement mix (PCC) with varying layers and structural thicknesses [108], recycled asphalt pavement (RAP) aggregate [130], incorporation of sugar cane bagasse ash (SCBA) pozzolanic materials [100,131], recycled fine aggregates [132], GGBS [133], and construction and demolition (C&D) materials [74]. • Life cycle analysis (LCA): energy and cost assessment based on the transport and operational energy of the PPS and LC cost assessment based on the main and subcomponents for the construction of PPS [10,134].	• Including life cycle assessment and relying on advanced inventories such as (SimaPro and Ecoinvent) in terms of construction costs, acquisition of materials, feasibility studies, cost savings, and overall environmental impact. • Importance of incorporating stormwater harvesting and continuous monitoring of such systems to determine any degradation in the water quantity or quality, especially for areas prone to drought.

In addition to Table 5, it is important to emphasize certain elements that were previously discussed in the bibliometric analysis. For instance, most of the clogging tests were performed by either evaluating the infiltration rates or permeability. The most common IR tests are ASTM C1701 and ASTM C1781 for PC and PICP, respectively [35,94,119,135,136]. In addition, falling head and constant head permeability tests were used to assess the clogging effect of different materials by measuring their permeability over a simulated time period [117,137]. Although some infiltration and permeability tests follow Darcy's laminar flow regime, this may not be valid for some PPS applications, and hence modifications of such equations have been addressed by some authors [127,138,139]. Furthermore, in the articles that conducted clogging experiments, the sediment loadings were not specified, with some either evaluating sand and/or clay with different proportions. Therefore, it is essential to have a benchmark and consistent sediment loadings for other researchers to follow and compare the findings. Furthermore, it is worth mentioning that the conclusions relevant to clogging effects in PPS varied and conflicted across different articles. Some authors reported that sand sediments did not substantially reduce the permeability, whereas others concluded that sand particles were a major contributor to clogging [33]. Such anomalies need to be addressed and discussed in detail when performing future investigations.

Moreover, some articles explained that the removal efficiency of selected contaminants in PPS was enhanced with an increase in the pH values (> 8.0) [101,137,140]. However, there could be a set of drawbacks when such effluents are to be discharged into natural or ground water bodies and may have a negative effect on the environment. Therefore, modifications to the concrete mix design, stabilization of the pH, or additional secondary treatments could be employed in the future.

Other interesting findings observed that the reductions in runoff volumes were greatly reduced from 70 to 90% when transitioning from a relatively wet climate to a relatively drier one [141]. Yet, such a conclusion was limited to one article. Therefore, future investigations could incorporate additional parameters when evaluating PPS, including weather and climatic data conditions, such that researchers could adopt an optimal design depending on the site location and weather conditions.

Although infiltration rates tended to increase with increased rainfall intensities, such pavements deteriorated over time and required frequent service and maintenance [119,142]. Experimental investigations regarding the variations in cross slope, longitudinal slope, and rainfall intensity with respect to infiltration rate are of great importance, especially for terrain areas [142]. Therefore, continuous research on such aspects is essential for effective planning and designing in large-scale construction.

6. Conclusions and Way Forward

The bibliometric analysis revealed important findings regarding research in the field of PPS for stormwater management. The results revealed that the number of citations increased from approximately 19 in 2009 to approximately 740 in 2020. Similarly, the number of publications had an annual growth rate of 53% from 2013 to 2020 in the field of PPS and stormwater management. It was also concluded that some of the most impactful journals in terms of publications included *Constr. Build. Mater.*, *J. Hydrol. Eng.*, *J. Environ. Manag.*, and *J. Environ. Eng.* Furthermore, three major clusters were identified as the dominant themes in PPS research, namely hydrological performance, stormwater management practices, and water quality aspects. Furthermore, the use of keywords "infiltration", "performance", "stormwater", "runoff" and "hydrological" have been increasing exponentially. This was associated with the growing interest in investigating various fields in PPS. Furthermore, the analysis highlighted key emerging trends in the field of PPS, the most compelling of which included "bioretention", "adsorption" and "no-fines concrete". It was also revealed that the USA, China, England, Brazil, and Italy are the leading countries in PPS investigations. The greatest collaboration was between the USA and Italy and both countries investigated different aspects of PPS, with recent articles focusing on the use of modeling software such as Hydrus 1-D and clogging characterization using X-ray chromatography. However, only six articles were co-authored between the two countries, indicating a need for more collaboration.

Similarly, there was a lack of collaboration among authors, and the maximum number of collaborative articles between William Hunt and Ryan Winston was 6 out of 137 articles. Other key conclusions from the bibliometric analysis and recent development are as follows:

- For water quality improvements, different structural modifications, the addition of different sorbent materials, and modeling to predict the removal of contaminants could be promising in increasing the percentage removal of certain contaminants.
- Recent advancements in water quality improvements were investigated by the addition of adsorbents such as pozzolanic materials, nanomaterials, or cementitious materials. This was proven by the use of the keyword "adsorption" in recent years.
- Clogging characterization gained momentum in recent findings, especially using imaging techniques. The keywords associated with this topic included "clogging", "hydraulic conductivity" and "permeability".
- Improving the infiltration rate characterization and assessment of PPS has taken two routes: (1) concrete mix design modifications and (2) enhancing lab experiments to better represent field investigations.
- Innovative investigations and design considerations that included recycled aggregates within the PPS systems provided adequate mechanical and hydrologic properties while, importantly, being more sustainable in the long run.

Furthermore, the identified recent developments and research gaps pave the way for future researchers and decision makers to develop a better understanding of the behavior and performance of PPS. The following are the key recommendations that can be adopted for future studies on PPS:

- Leaching from PPS is an important aspect to investigate to safeguard the quality of the groundwater.
- A holistic approach is needed to incorporate the hydrological, mechanical, hydraulic, and water quality investigations to understand the overall functionality of the PPS.
- Developing a dataset of benchmark performance of PPS is essential for standardizing the PPS investigations.
- More on-site investigations need to be conducted to simulate the actual performance of PPS exposed to different wet and dry conditions, unlike lab-scale experimental investigations.
- There is a lack of models to predict the long-term performance of PPS. Hence, it would be important to incorporate both model and experimental simulations in future studies to simulate field experiments.
- Unifying testing parameters across conducted investigations is essential for assessing the viability of PPS.
- More investigations on the potential water savings from PPS harvesting schemes.
- There needs to be more collaboration between authors from different countries to assess the impact of different materials and climatic conditions on the performance of PPS.

The analysis conducted in this study might be affected by some limitations. The study only included publications after the year 2000, which was justified by the focus on recent advancements in the field. However, this may have resulted in the exclusion of earlier contributions to the field of PPS from the analysis. Furthermore, as the search focused on the occurrence of the keywords in the "title" rather than "all fields", this could have resulted in missing some relevant articles from the analysis. Limiting the document type to only journal articles and not including conference papers or book chapters could have eliminated some relevant research from the analysis; however novel ideas are usually present in journal articles.

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