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Sustainable Urban Drainage Systems (2014-2023) by Using Bibliometric Analysis Method

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Abstract

Sustainable urban drainage systems (SUDS) are increasingly crucial for stormwater management. This bibliometric review analyses research trends on sustainable urban drainage systems over the past decade (2014-2023) using data from Scopus. The analysis found 705 articles, 192 conference papers, 85 book chapters, and 64 reviews on sustainable urban drainage systems. Publication volume increased by 66% during the study period, indicating rising research interest. The most cited article (294 citations) was a 2019 review by Andrés-Doménech et al. on innovations in sustainable urban drainage systems. Analysis of author keywords revealed 8 clusters of research topics, with "sustainable urban drainage systems" being the dominant term with 889 keywords. Although general sustainable urban drainage system terms prevail, the use of keywords related to network visualization methods like VOS viewer is rapidly increasing. The United Kingdom published the most SUDS research (315 articles), followed by China (149), Spain (135), the United States (126), and Italy (107 articles). Research was concentrated in the environmental science and engineering fields. However, this bibliometric analysis provides insights into SUDS research trends, the most active countries and institutions, and emerging topic areas. The rapid increase in publications and use of network visualization techniques demonstrates SUDS' growing importance in urban stormwater management. The results can help inform future research directions, such as applying advanced data analytics to improve SUDS design and performance. Expanding bibliometric analyses with additional techniques like VOS viewer could further enhance understanding of this critical area of urban environmental research. Developing bibliometric methods and adding feature extraction algorithms when selecting features used to model data can increase the efficiency and accuracy of the data on sustainable urban drainage systems. The development of research data using Vos viewers images with this type of data processing research can also be maximized for research related to the sustainable urban drainage system.

Keywords: Sustainable urban drainage systems; Bibliometric analysis; VosViewer

1. Introduction

The sustainable drainage system is one of the uses of the drainage system in urban areas that manages surface water so that it does not cause problems of inundation, flooding, and drought for the community, as well as being beneficial for environmental sustainability (Acheampong et al., 2016). There has been a change in the paradigm

of a conventional drainage system from a drainage system that drains water to an eco-drain. The principle of eco-drain is to improve the water quality in the drainage system, reduce drainage load, and involve community participation in managing drainage infrastructure. (Alhumaid et al., 2018). The concept of an environmentally friendly or sustainable urban drainage system is to manage floods in which surface water run-off is infiltrated through an integrated artificial facility consisting of side channels, filter layers, and infiltration wells instead of discharging that rough side channel into the water body (Amedu & Nwokolo, 2013).

Thus, a sustainable urban drainage system (SUDS) is designed to create a drainage system model that absorbs runoff water into the soil, which is often referred to as infiltration. This infiltration system continues the runoff water into the drainage channel and is processed with filter-to-filter pollutants or wastewater involved in runoff water (Anton Shkarubaa et al., 2021). The filtration system can use geotextiles or other routes to remove pollutants or garbage (Arahuetes & Cantos, 2019). Drains or Infiltration Trenches Filter Drains can use urban drainage systems on the right and left sides of the road as permeable channels that can run runoff water on the road and carry out temporary water treatment before the water is drained into the ground (Asry et al., 2023). The escalating urbanization has exacerbated the stormwater management difficulties, calling for creative and sustainable solutions (García-Haba et al., 2023). Sustainable urban drainage systems integrate social, environmental, and engineering factors as a comprehensive strategy to solve these flooding issues in the affected areas (Araujo et al., 2021). This review seeks to provide a complete overview of the evolution, current state, and future directions of SUDS research through a bibliometric lens (Attwa & Zamzam, 2020).

This research analysis looks at the geographic distribution of SUDS research and identifies essential nations and organizations making significant contributions. This section aims to draw attention to regional differences in research output and worldwide cooperation (Avila et al., 2019). The most prominent authors, organizations, and journals within the SUDS research topic were (Bakhshipour et al., 2021). This review paper provides insights into the collaborative nature of research and the significance of individual contributions by examining author networks and citation patterns (Berwick, 2016). The review papers discuss the SUDS research community's challenges and propose potential avenues for future research (Byambadorj et al., 2018). This section addresses the review and explores the development of SUDS research by recognizing and analyzing new themes and trending subjects (Casal-Campos et al., March 4, 2018). Identifying the current and potential future study directions entails thoroughly examining keywords, co-occurrence clusters, and citation networks (Chapman & Hall, 2022b). Gaps in the existing literature emphasize the need for interdisciplinary collaboration to advance the field (Charlesworth et al., 2013).

Sustainable Urban Drainage Systems (SUDS) are an integrated network of engineered vegetated areas and open spaces (i.e., green roofs, rain gardens, porous pavements, etc.) used to protect natural ecosystem principles and functions and to offer a wide variety of benefits to people and wildlife (Charlesworth & Warwick, 2020). To reduce the effects of hydrological urbanization and boost urban centers' resistance to high rainfall events, sustainable urban drainage systems (SUDS) are a valuable addition to centralized conventional sewer system architecture (Cothren et al., 2020). These structures are known to provide multiple environmental benefits (Liao et al., 2013), including the reduction of climate change impacts (dos Santos et al., 2022), along with ecological and social benefits and other potentially monetizable benefits in the long run (Elena et al., 2018).

Urban development reduces the soil's ability to absorb rainfall, which sets water resources under high pressure, creates higher volumes of water run-off, and increases the relative risks of pluvial flooding (Araujo et al., 2021). This could make it possible to create urban areas that can challenge climate change and urbanization and complete multifunctional, sustainable, and flood mitigation for regulating water flow, which should be considered an essential aspect when designing a sustainable urban drainage system that can deliver ecosystem services to the urban environment and urban water management system (Galarza-Molina et al., 2017). Protecting and securing the regulation of water-flow capacities of the urban ecosystem must be connected to related policies and choices of urban planning that deal with risk management (García & Santamarta, 8 July 2022). Stormwater design is evolving to create a robust and sustainable urban drainage system that can withstand the effects of urbanization

and climate change (Gonçalves & Nucci, 2017). Designing flexible, multipurpose, and sustainable systems is essential (Guangtao Fu et al., 2016). Long- and short-term co-benefits, as well as flood mitigation, must be considered during the designing and costing phases of the project. In addition, areas already being utilized or being developed to be exploited must be considered when implementing sustainable urban drainage systems (Guangzhou, 27 February 2014). This could create multifunctional, sustainable, flood-mitigated urban regions that address urbanization and climate change (Guo, 2017).

1.1 Research Significance

The significance of conducting a bibliometric analysis using the VosViewer application for a review paper on Sustainable Urban Drainage Systems (SUDS) lies in its potential to provide valuable insights into the current state, trends, and future research directions in this crucial field. Here are several vital aspects that highlight the significance of employing such an approach:

i. Mapping Research Landscape It is vital for bibliometric analysis, which allows for systematically mapping the research landscape related to SUDS. This includes identifying the geographical distribution of research, prominent institutions, and prolific authors and providing a comprehensive overview of the global research network.
ii. Identifying key contributors can be done with the Vos Viewer, which allows one to identify and profile critical contributors to the field of SUDS. This includes recognizing influential authors, institutions, and journals, thereby acknowledging the experts and thought leaders shaping the discourse on sustainable urban drainage.
iii. Understanding research trends will allow the researchers to analyze and identify the research trends, emerging themes, and shifts in focus within the SUDS domain. This information is invaluable for researchers, policymakers, and practitioners to stay updated on the latest developments and align their efforts with the evolving needs of urban water management.
iv. Vos Viewer provides comprehensive knowledge of SUDS research's depth and breadth by enabling quantitative and qualitative literature assessments, such as recognizing topic clusters, citation patterns, and keyword co-occurrence.
v. The study can facilitate interdisciplinary collaboration in the multidisciplinary SUDS field by examining patterns of cooperation between authors and institutions, improving future research initiatives and development.
vi. The review paper identifies research gaps needing further investigation, guides future research efforts and enables comprehensive examination of pertinent sustainable drainage issues.
vii. Insights gained inform evidence-based policies and effective implementation of solutions by policymakers and practitioners at the urban planning level.
viii. The review paper synthesizes and consolidates knowledge on SUDS's historical development and trends through bibliometric analysis, providing a comprehensive resource for researchers and professionals.

1.2 Literature Reviews on Sustainable Urban Drainage Systems Using Bibliometric Analysis.

An overview of Sustainable Urban Drainage Systems (SUDS) through a bibliometric analysis involves examining the literature quantitatively and qualitatively to understand the evolution, current state, and future trends related to sustainable urban drainage research (Haider et al., 2019). Start the overview by concisely defining SUDS (Huertas et al., 2019). Highlight the fundamental principles, emphasizing that SUDS are designed to sustainably manage stormwater runoff in urban areas, addressing flooding, water quality, and environmental concerns (Haider et al., 2019). Articulating the bibliometric analysis goals can explain the study's aim to systematically assess and quantify the scholarly output, impact, and collaboration patterns within the SUDS research domain (Hao et al., 2023). Describe the methodology for data collection. (Andrés-Valeri et al., 2016) Specify that the bibliometric analysis involves gathering relevant publications from reputable databases such as

Scopus (Ibarra, 2012). Explain the criteria for selecting the time frame and types of journals included in the analysis (e.g., articles, reviews and conference papers) (Infante et al., 2020).

The VosViewer application is the chosen tool for bibliometric analysis; it is suitable for this review paper for sustainable urban drainage systems to reduce the problems of flooding worldwide (Lee et al., 2016). Explain its significance in visualizing and interpreting bibliographic data (Li, 15 October 2021). This review paper must mention its ability to generate co-authorship networks, citation maps, and thematic clusters, facilitating a comprehensive understanding of the research landscape (Li et al., 2011). This paper presents the geographical distribution of SUDS research using Vos Viewer to create a world map or similar visualization, highlighting countries with the highest research output. This research study discusses any regional disparities and notes the global collaboration patterns in SUDS research (Wang et al., 11 June 2016). Identify and profile the most influential authors, institutions, and journals in the SUDS domain (Pozo et al., 24 February 2021). Utilize VosViewer to showcase authorship networks, citation indices, and institutional collaborations, providing insights into the key players shaping the field (Quek et al., 2015). Analyze the emerging themes and keywords within the SUDS literature (Ritzema, February 2014). Use VosViewer to generate co-occurrence maps and thematic clusters to highlight the current research focus areas (Rjeily et al., 2017). This review paper discusses how these themes have evolved and their significance in shaping the future of SUDS (Roseboro et al., 2021).

Explore citation patterns to assess the impact of critical publications and researchers (Sagrelius et al., 2023). This paper review discusses highly cited works and their influence on the SUDS research community. Consider factors such as h-index and citation networks to evaluate the overall impact of the literature (Sakuradani et al., 2018). Investigating the interdisciplinary nature of SUDS research, the researchers can use Vos Viewer to visualize collaboration networks between different disciplines, showcasing the interconnectedness of engineering, environmental science, urban planning, and other relevant fields (Sam Cramera et al., 2017, 1–27). In conclusion, by discussing identified research gaps and proposing potential future directions for SUDS research, the potential aims to emphasize how bibliometric analysis contributes to understanding the state of knowledge in the field and how it can guide future research studies in sustainable urban drainage systems worldwide (Sañudo Fontaneda et al., 2016). An overview of Sustainable Urban Drainage Systems through a bibliometric analysis provides a systematic and data-driven exploration of the research landscape, contributing valuable insights for researchers, policymakers, and practitioners involved in sustainable urban water management (Sañudo Fontaneda et al., 2022).

2. Method

This type of research is bibliometric research. Bibliometrics is a quantitative analysis method that uses mathematical and statistical methods to study literature and distribute review papers (Donthu et al., September 2021). This research has three stages: searching, storing, and analyzing data (Schlea et al., 2014). This data is collected from the Scopus database, accessed by Donthu et al. (September 2021), with a time limit for data collection based on research published in the last ten years between 2014 and 2023 to ensure relevance to current conditions in sustainable urban drainage systems research. Metadata was collected using the search keywords "sustainable urban drainage system (Shibuo & Furumai, 2021b).” All obtained articles were extracted into a Microsoft Excel (CSV) file to conduct a linkage analysis between the authors (Zhu et al., 2023).

The obtained Scopus data is then analyzed using the tools analysis website Scopus and extracted to a CSV file type for later analysis using the VOS viewer application (Shibuo & Furumai, 2021a). VOS ("visualization of similarities") is a concept developed less than two decades ago to analyze and visualize patterns in data (Donthu et al., 2021). Several years later, the VOS concept was developed into a program called VOS Viewer for bibliometric analysis, so it has been widely adopted in bibliometric and citation studies to build and visualize bibliometric networks by journals, researchers and individual publications as actors based on- source, bibliographic coupling, or-authorship relations (Donthu et al., 2021).

The previously obtained CSV file is then entered into the VOS viewer software to produce the required statistics. Six objects will be observed from the Scopus database (Shukla et al., 2006). The first is related to the development of sustainable urban drainage systems (Kwon & Kim, 11 December 2021). The second refers to keywords relevant to climate change classification: water quality, floods, runoff, and stormwater. The third relates to the authors' collaboration on sorting for sustainable urban drainage systems (Srishantha & Rathnayake, 2017). The fourth refers to novelty in classifying sustainable urban drainage systems (Suliman et al., 2013). Select a suitable bibliometric analysis tool like Vos Viewer to process and visualize the data (Sun et al., 2022). Import the cleaned dataset into the tool, ensuring it can handle the volume of publications and provide the necessary features for analysis (Tucci, 2016).

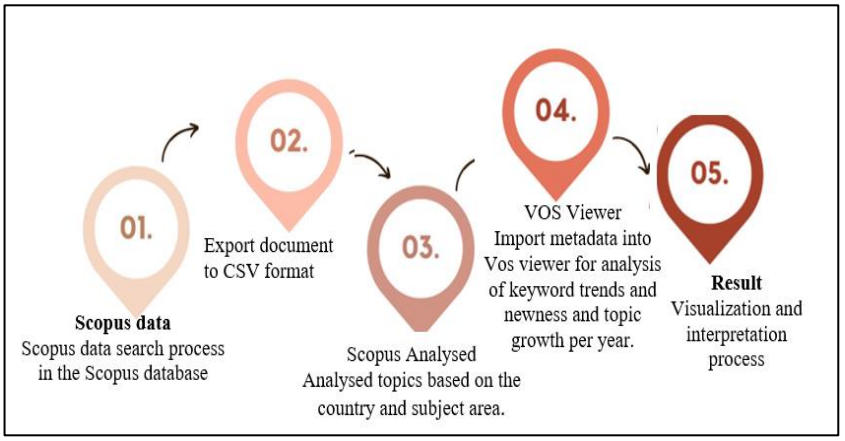

Figure 1. Vos viewer process stages

3. Results and Discussion

Sustainable urban drainage systems have recently gained significant attention as a research area, in which Vos Viewer was used to perform a bibliometric analysis that looked at research trends in SUDS categorization over the previous ten years (2014–2023). The study showed a steady increase in publications on this topic, with 68 articles in 2014 rising to 146 articles in 2022 - an impressive 66% growth over ten years. A total of 1069 documents were published on SUDS classification using Vos Viewer between 2014 and 2023, comprising 705 articles, 192 conference papers, 85 book chapters, and 64 review papers.

Figure 1 shows the number of documents published annually with the most significant studies on sustainable urban drainage systems. There is a clear upward trend, with a notable publication surge from 2018 onwards. The early years saw modest output (below 100 articles a year), but papers doubled from 98 in 2018 to 146 in 2022. This growth suggests increasing research attention on categorizing and analyzing sustainable urban drainage systems using bibliometric techniques and Vos Viewer software (Rjeily et al., 2017; Amedu & Nwokolo, 2013). The field is rapidly developing as urban sustainability gains prominence globally. The bibliometric analysis indicates growing productivity in applying Vos Viewer for sustainable urban drainage systems classification and knowledge mapping. This method will likely advance studies on sustainable urban drainage systems to support evidence-based planning and decision-making on sustainable urban water management.

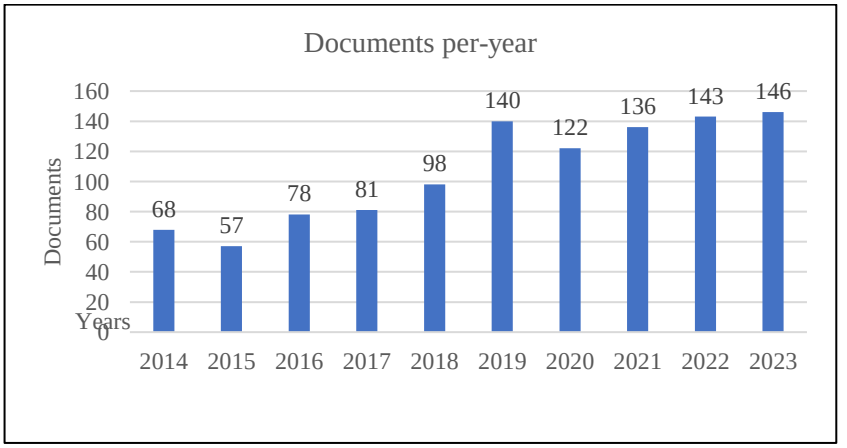

Figure 2. Number of documents published per year

Utilize a bibliometric analysis tool, such as Vos Viewer, to process the cleaned dataset, which shows the generated visualizations and metrics to analyze the growth of publications over time (Wedenig et al., 2023). With a participation percentage of 25% and the highest number of published articles (765) on “water science,” it stands out significantly from other journals. The leading journals are "Engineering" and "Social Science," with 3040 papers (Vilarrasa et al., 2011). Approximately half of the publications on this topic are published in these three journals. To examine this in more detail, the annual distribution of the number of papers published for each publication is shown in Figure 3. The magazine "Environmental Science." has been a top publication recently. In addition, the publication of works on this topic in 2023 has been greatly aided by the three journals "environmental science," "Engineering," and "social science." Therefore, examining research sources will help scholars swiftly identify pertinent research papers from sources and make choosing an appropriate journal for the future publication of their manuscripts easier (Wedenig et al., 2023).

Table 1. Analysed research sources

Journals	Issue Categories	Publisher	No. Publication	Participation Percentages
Water Science and Technology	Environmental Science	Elsevier	765	25%
Hydroelectric Design	Engineering	Elsevier	370	12%
Sustainable Cities and Society	Social Sciences	Elsevier	303	10%
Environmental and Sustainability Indicators	Agricultural and Biological Sciences	Elsevier	159	5%
Remote Sensing and Space Science	Earth and Planetary Sciences	Elsevier	156	5%
Frontiers in Sustainable Cities	Drainage	Elsevier	290	10%
Intelligent Cities: Found., Princ., and Appl.	Sustainable Development	Elsevier	263	9%
Sustainability (Switzerland)	Runoff	Elsevier	249	8%
Revista Brasileira de Geografia Fisica	Urban Drainage	Elsevier	243	8%
Environment and Ecology Research	Water Management	Elsevier	242	8%

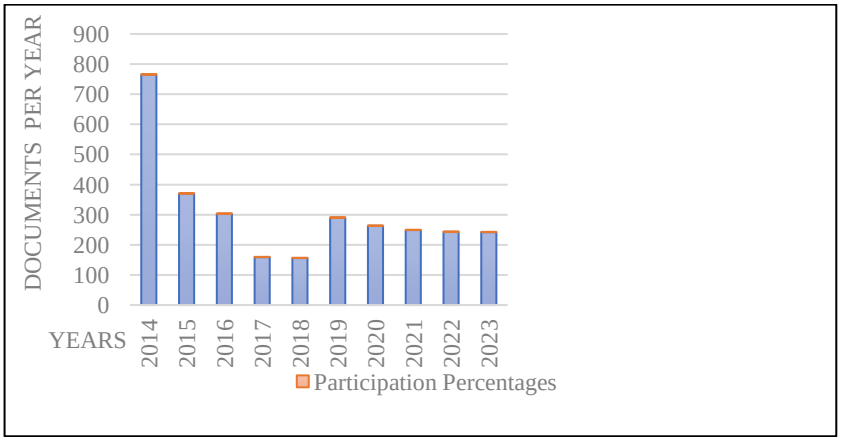

Figure 3. Journals with at least ten published articles

3.1 The Most Important Nations in Publications and Their Cooperation

The study of the countries and organizations that created the sustainable urban drainage system literature found that the United Kingdom was the top producer with 315 published papers, followed by China with 149, Spain with 135, the United States with 126, and Italy with 107. This finding reflects that these countries have invested more in sustainable urban drainage systems research and have investigated climate change, wastewater, water treatment, floods, sewers, runoff, and stormwater (Zhou, 2014). On the other hand, the need for case studies from African and Oceanian nations suggests that further research is needed in these regions (Wen Zhu et al., 2023).

The United Kingdom, as the only developed nation in the top ten, had the highest percentage of co-authors compared to other countries. This underscores the importance of international partnerships in building research capacity and raising the standard of research in poorer nations (Figure 5). China leads sustainable urban drainage system research in Asia, especially for flood mitigation in cities, and it is a famous study on other subject areas such as environmental management and water science (Wolf et al., 2015). Research has also been conducted in Southeast Asia, India, Malaysia, and Indonesia, regions that frequently experience urban flooding (Yamashita et al., 2015). It is important to note that lower publication rates in developing countries do not always indicate a lack of aptitude or motivation for research. These nations face the same urbanization challenges as the rest of the world (Yaghoubzadeh et al., 2022). Furthermore, rapid urbanization and climate change may have a more significant negative impact on high-producing countries, encouraging more funding for research into nature-based solutions. Researchers in these regions might have used their local languages other than English, which could be why they are less likely to publish in their journals indexed in the Scopus database (Zhu et al., 2023). Therefore, when making recommendations to improve research in these areas, research capacity and dissemination limitations in Africa and Asia must be considered (Barreto et al., 2020).

It is essential to acquaint readers with the countries contributing most to the current research on sustainable urban drainage systems. Figure 4 shows the top 10 countries where corresponding authors have studied sustainable urban drainage systems using bibliometric analysis over the past decade. The United Kingdom published the most research articles (22%), with 315. China (10%) published 149, Spain (9%) 135, the United States (9%) 126, Italy (7%) 107, Australia (6%) 89, Brazil (6%) 79, India (4%) 58, and Germany (4%) 57 articles. These ten countries supported nearly half of the studies in this field. Other developed countries contributed significantly, including France, Sweden, Malaysia, the Netherlands, and Denmark. Researchers in Canada, Colombia, Indonesia, South Africa, and Nigeria have also examined bibliometric analysis approaches for advanced sustainable urban drainage systems, moving up the ranks.

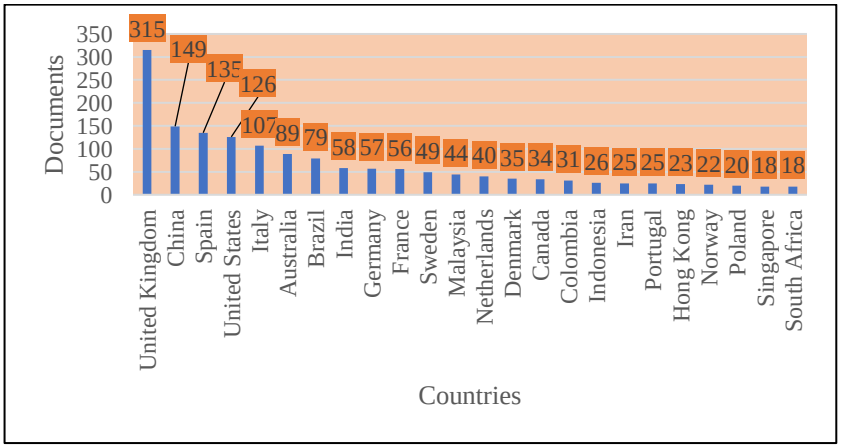

Figure 4. Document published per country for corresponding authors.

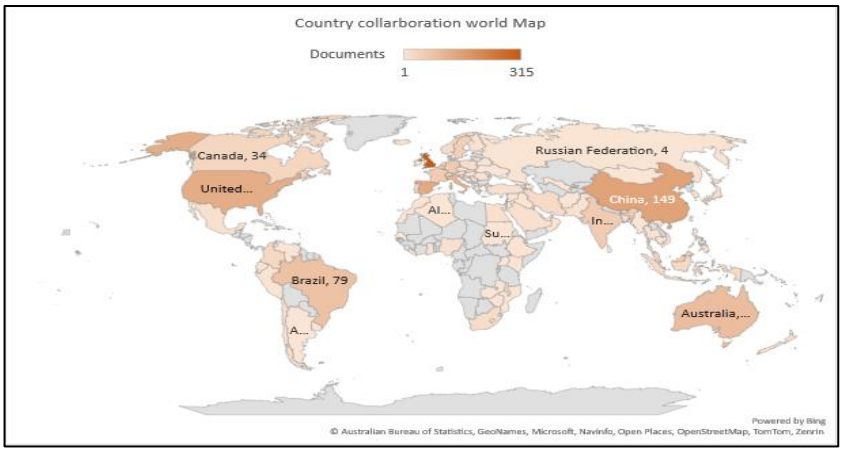

Figure 5. Country's Collaboration World map

International cooperation is crucial for advancing sustainable urban drainage systems (SUDS) (Winter, 2016). An analysis of research publications showed that Europe was the primary location for collaboration on sustainable urban drainage systems. This makes sense since Europe pioneered a focus on the sustainable urban drainage systems concept and is firmly committed to climate change mitigation and adaptation (Roseboro, Torres-Arredondo, Zhu, et al., 2021). However, it is vital to highlight that less developed nations' lack of cooperation may hinder their ability to deal with urbanization and climate change impacts. Developing countries must collaborate with industrialized nations to strengthen their research capabilities and deepen their understanding of sustainable urban drainage systems.

Interestingly, the United Kingdom published the most works on sustainable urban drainage systems and ranked highly for published works on the subject (see Table 2). Forty-six countries had authors who published on sustainable urban drainage systems, evidencing broad international interest. While Europe, the United States, and Australia dominated, developing nations like Iran, Colombia, India, and South Africa also contributed. Expanding cooperation globally will be vital for implementing SUDS comprehensively. This analysis of publications and collaborations reveals Europe's central role and opportunities to broaden sustainable urban drainage systems research and adoption worldwide through greater international cooperation.

Table 2. Countries in Vos views

Country	Documents	Citations	Total Link Strength
United Kingdom	313	8366	164
United States	127	34154	90
Australia	89	3418	79
China	149	2964	73
Spain	135	1782	62
Germany	57	2080	56
France	56	2313	51
Sweden	49	2554	50
Canada	34	1726	39
Italy	107	1843	38
Netherland	40	982	37
Brazil	79	930	33
Hong Kong	23	789	26
Portugal	25	304	24
Singapore	18	912	23
Iran	25	347	22
Colombia	31	217	21
Demark	35	1788	21
India	58	855	21
Norway	22	275	21
Austria	16	554	20
Saudi Arabia	12	166	20
Switzerland	14	472	17
New Zealand	7	1164	16
South Africa	18	314	16
Malaysia	44	250	15
Japan	14	309	14
Greece	11	238	13
South Korea	12	163	13
Viet Nam	12	207	13
Belgium	10	230	12
Egypt	14	284	12
Thailand	6	76	12
Chile	12	76	11
Finland	6	237	11
Lebanon	10	219	11
Pakistan	7	168	9
Poland	20	127	8
Mexico	10	69	7
Indonesia	26	45	5
Taiwan	6	287	5
Bangladesh	9	35	4
Nigeria	12	16	4
Ghana	5	21	3
Slovakia	10	60	1
Turkey	10	228	1

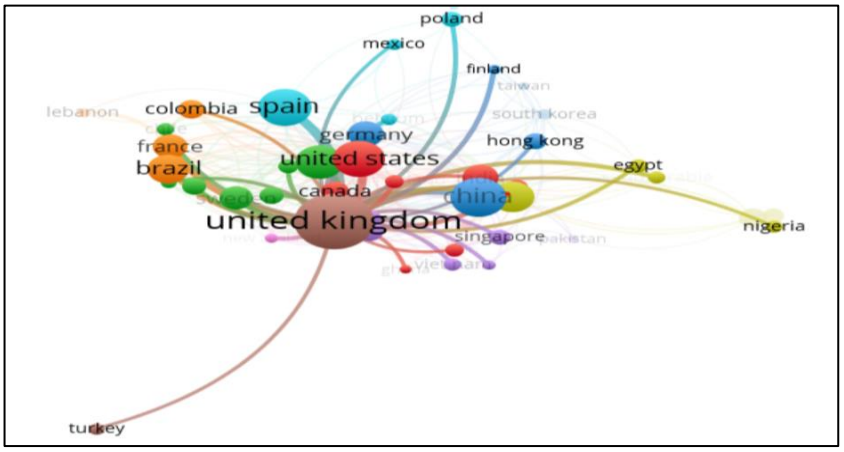

Figure 6. The network visualization of countries from the Vos view

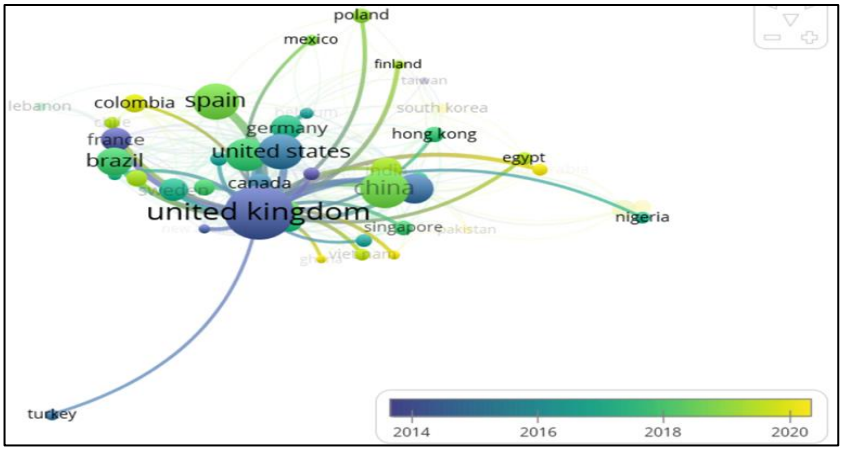

Figure 7. The network visualization of countries years for many publications in Vos view

Figure 8. The density visualization for countries with many documents in the Vos view

3.2. Most Relevant Affiliations, Authors, and Sources

3.2.1 Affiliations

The top affiliations researching sustainable urban drainage systems offer insights into impactful organizations and potential partners. As seen in Figure 9a, the leading universities are in developed nations. With 32 papers each, Coventry University (UK) and Universitat Politècnica de València (Spain) in Europe rank highest. This aligns with the long history and ongoing efforts towards research in industrialized countries. Other top European institutions include the Universidad de Cantabria and Politecnico di Milano. Next, with 17 publications each, are the University of Exeter (UK), Ecole des Ponts ParisTech (France), Lunds Universitet (Sweden), and others across Europe, Asia, and South America. The concentration of high-ranking institutions in Europe reflects the region's prominence in sustainable urban drainage systems research. One notable European affiliate is Universidad de Oviedo in Spain, ranking 13th globally. This highlights Europe's sustained commitment to advancing these systems. While this research study on sustainable urban drainage systems is concerning, it also presents an opportunity to spur collaboration with researchers in less developed nations to build capabilities. Interestingly, despite Europe's strength in nature-based solutions research, sustainable urban drainage systems publications are more distributed across institutions than concentrated in one university. This suggests healthy networks and cooperation between European researchers and international affiliates. Fostering partnerships beyond Europe seems vital for a comprehensive understanding of research progress. In this research study, the leading affiliations provide insights into impactful organizations and potential collaborators, with a notable concentration in Europe indicating the region's prominence. Distributing research across institutions by encouraging global cooperation, especially with developing nations, can strengthen worldwide capabilities and knowledge sharing.

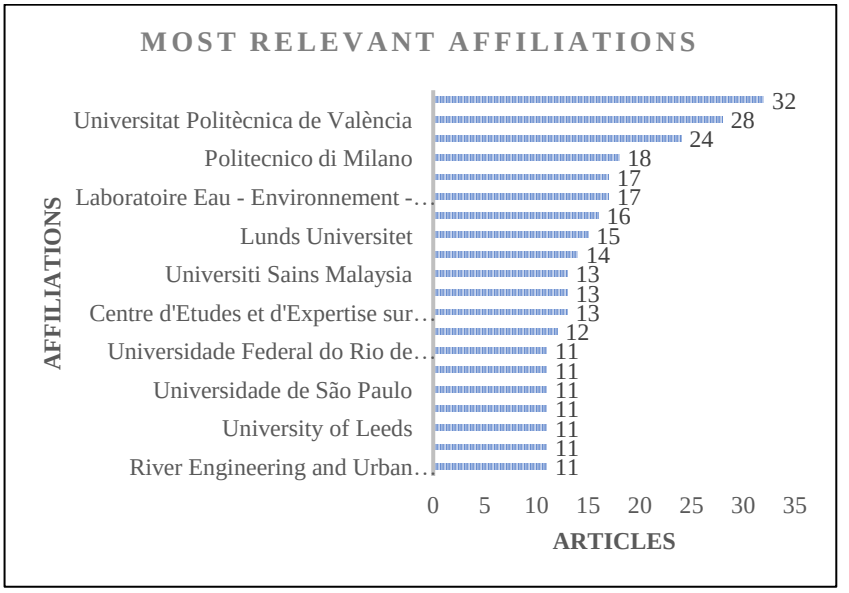

Figure 9. Most of the relevant affiliations.

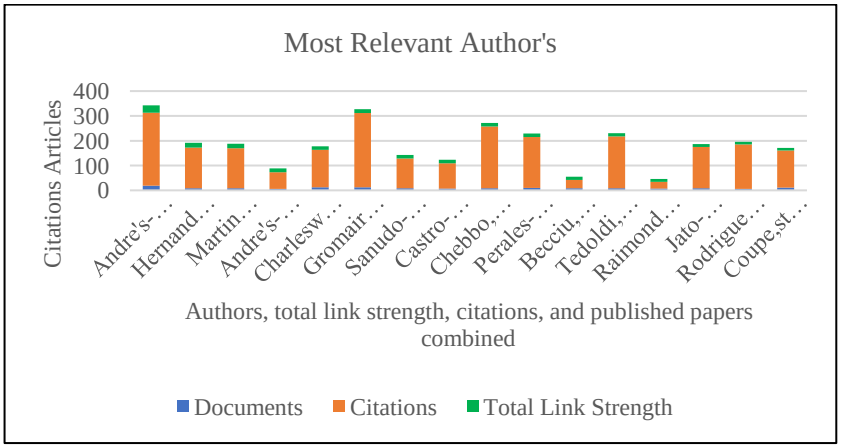

Figure 10. Most of the relevant authors

Table 3. Corresponding authors'

Author	Documents	Citations	Total Link Strength
Andre's-Domenech, ignacio	19	294	29
Hernandez-crespo, carmen	9	163	19
Martin Miguel	8	162	18
Andre's-Valeri, Valerio c	6	67	15
Charlesworth, susanne m	13	150	15
Gromaire, maire-christine	13	299	15
Sanudo-fontaneda,luis a.	8	120	15
Castro-Fresno, daniel	7	102	14
Chebbo,ghassan	8	249	14
Perales-momparler,Sara	10	205	14
Becciu, gianfranco	9	33	13
Tedoldi, damen	8	209	13
Raimondi, anita	7	27	12
Jato-espino, daniel	8	167	11
Rodriguez-hernandez, jorge	6	179	11
Coupe, Stephen J.	11	150	10

3.2.2 Authors

The research on sustainable urban drainage systems, stormwater, wastewater treatment, runoff, and climate change has evolved. Andre's-Domenech, Ignacio was one of the first researchers to focus on sustainable urban drainage systems in this field starting in 2014, as seen in the annual evolution of published research (Figure 11). However, interest and studies on sustainable urban drainage systems and climate change have declined after 2020, indicating a growing trend toward implementing these systems in urban areas.

Floods, stormwater, and sustainable urban drainage systems are analyzed using Vos views, a revolutionary bibliometric review method that accurately represents an author's contribution (Table 4). Authors with participation percentages above 25% are shown. Andre's-Domenech, Ignacio has the highest percentage (25%) out of the total 134% for the most productive authors, followed by Hernandez-Crespo, Carmen (12%), and Martin Miguel (10%). This demonstrates their significant influence in this research area. Readers looking to select relevant academic publications for further research may find this helpful information. Influential authors in sustainable urban drainage systems, stormwater, wastewater treatment, runoff, and climate change are examined to highlight the potential for more research and increased collaborative and capacity-building programs.

Table 4. Authors with the most often cited documents.

Author	Document	Citation	Total Link Strength	Participation Percentages
Andre's-Domenech, Ignacio	19	294	29	25%
Hernandez-crespo, carmen	9	163	19	12%
Martin Miguel	8	162	18	10%
Andre's-Valeri, Valerio c	6	67	15	5%
Charlesworth, susanne m	13	150	15	5%
Gromaire, maire-christine	13	299	15	10%
Sanudo-fontaneda,luis a.	8	120	15	9%
Castro-Fresno, daniel	7	102	14	8%
Chebbo,ghassan	8	249	14	8%
Perales-momparler,Sara	10	205	14	8%
Becciu, gianfranco	9	33	13	7%
Tedoldi, damen	8	209	13	7%
Raimondi, anita	7	27	12	6%
Jato-espino, daniel	8	167	11	5%
Rodriguez-hernandez, jorge	6	179	11	5%
Coupe, Stephen J.	11	150	10	4%

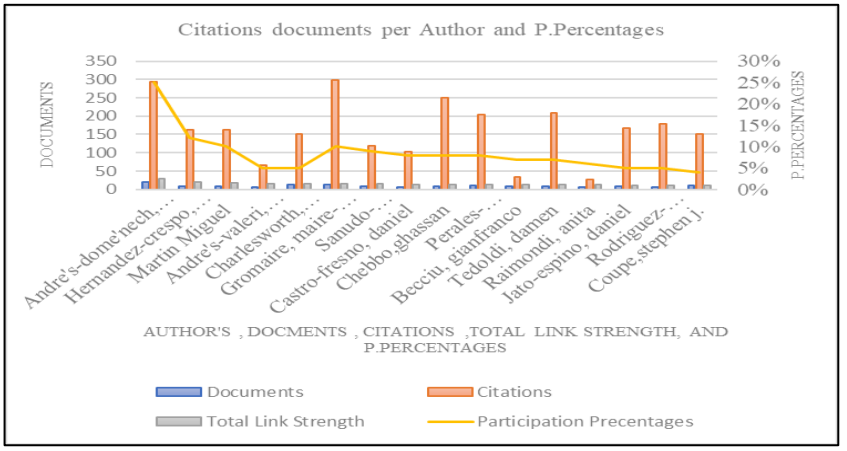

Figure 11. Citations per author and participation percentages

3.2.3 Sources

The analysis of original research publications is crucial in bibliometric studies. The authors utilized the Scopus database to determine the top 10 journals in sustainable urban drainage systems and green technology by the number of documents published (Figure 12). The Journal of Water Switzerland ranked first with 79 articles, demonstrating its prominence in this sector. Sustainability Switzerland published the second most with 52 articles, and the Journal of Environmental Management ranked third with 36 articles, highlighting its importance. Other notable journals included the IOP Conference Series: Earth and Environmental Science, Science of the Total Environment, and Urban Water Journal. Half of the top journals are from European countries, supporting Europe's focus on sustainable urban drainage systems research. The research also identified the most highly cited journals (Figure 12). Water Switzerland received the most citations with 79 articles, further evidencing its significance in water science and technology. High citation counts for the Journal of Cleaner Production, Urban Water Journal, Journal of Hydrology, and Green Energy and Technology also demonstrate their influence. This citation analysis provides insight into critical channels for disseminating sustainable urban drainage systems research. Researchers can use this data to identify trends, potential collaborators, and high-impact publication venues. The number of annual documents published illustrates the growth of sustainable urban drainage systems

research over time (Figure 12). Publications increased steadily from 2014 to 2023, with the highest output in 2022, with 14 documents in Water Switzerland. Sustainability Switzerland and IOP Conference Series: Earth and Environmental Science also had upticks in 2019 and 2021, respectively. The continuous increase in publications across major journals emphasizes the expanding prominence of this research field. In this research study, bibliometric analysis of sources, citations, and publication volumes quantitatively examines the progression of sustainable urban drainage systems research. Researchers can utilize these findings to better understand impactful journals and publication trends to inform their work. The results highlight the growth of this critical area of study within the water science, environmental management, and sustainability domains.

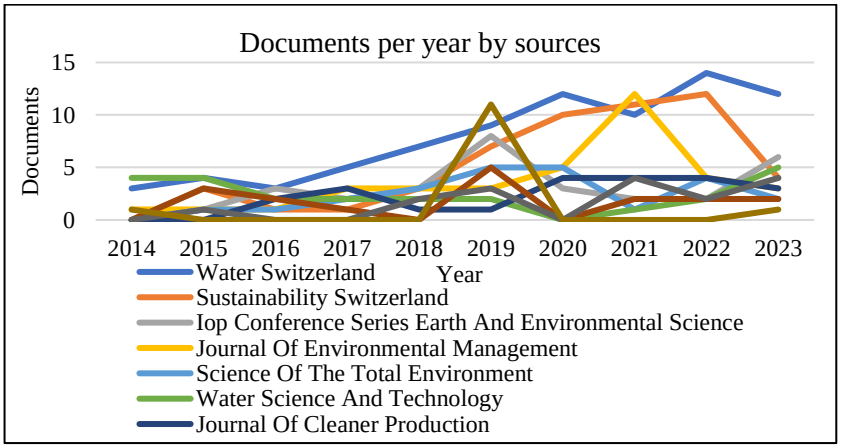

Figure 12. Documents per year by sources

Table 5. Documents per year by source

Years	Document Source Codes									
	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
2014	3	0	0	1	0	4	0	0	0	1
2015	4	3	1	1	1	4	0	3	1	0
2016	3	1	3	1	1	2	2	2	0	0
2017	5	1	2	3	2	2	3	1	0	0
2018	7	3	3	3	3	2	1	0	2	0
2019	9	7	8	3	5	2	1	5	3	11
2020	12	10	3	5	5	0	4	0	0	0
2021	10	11	2	12	1	1	4	2	4	0
2022	14	12	2	4	4	2	4	2	2	0
2023	12	4	6	3	2	5	3	2	4	1
Total	79	52	30	36	24	24	22	17	16	13

01- Water Switzerland
02- Sustainability Switzerland
03- IOP Conference Series Earth and Environmental Science
04- Journal Of Environmental Management
05- Science Of the Total Environment
06- Water Science and Technology
07- Journal Of Cleaner Production
08- Urban Water Journal
09- Journal Of Hydrology
10- Green Energy and Technology

A three-field plot linking nations, authors, and keywords is shown in Figure 7. The association between 46 countries, 50 authors, and 889 keywords was depicted in a chart produced by setting the maximum number for each field at 889 items. "Sustainable urban drainage systems, flooding, drainage, runoff, sustainable development" and "articles" were the most frequently occurring keywords. Furthermore, European nations, mainly the UK and Spain, showed several connections.

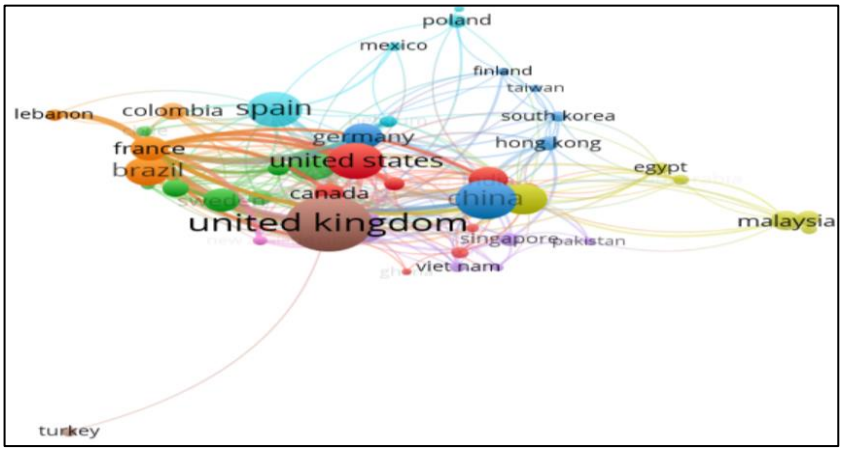

Figure 13. Countries with many documents

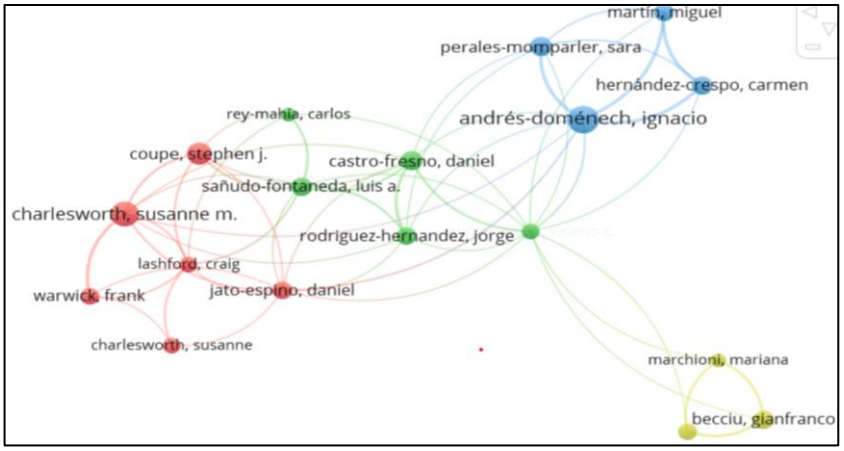

Figure 14. Authors from different countries

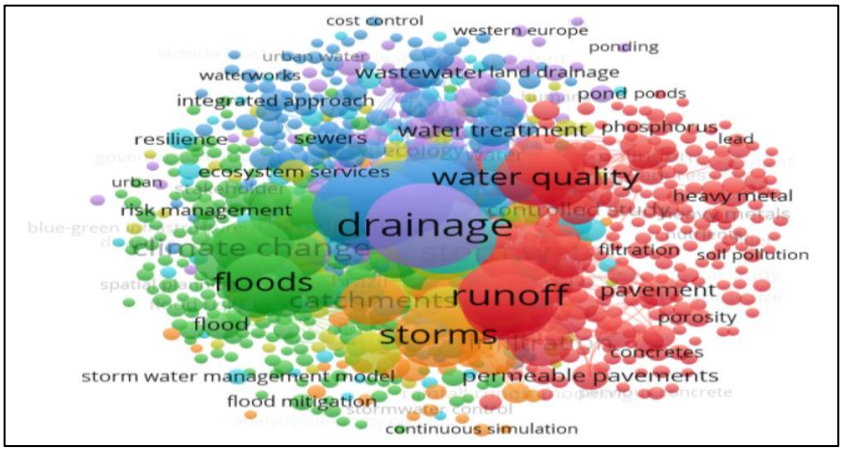

Figure 15. Number of the document's keywords

Table 6. The primary characteristics of the top terms in the co-occurrence network, arranged according to total link strength.

Keyword	Occurrences	Total Link Strength
Drainage	452	7407
Water management	352	6562
Sustainable development	410	6540
Runoff	337	6517
Urban drainage	333	6034
Urban area	280	5943
Storms	253	4925
Article	167	4736
Sustainability	256	4550
Stormwater	241	4606
Sustainability of urban drainage` systems	258	4128
Water quality	200	4101
Rain	193	4081
Floods	227	3962
Water supply	177	3944
Climate change	198	3182
Stormwater	100	2925
Urban planning	186	2887
Catchments	143	2804
Flooding	138	2766

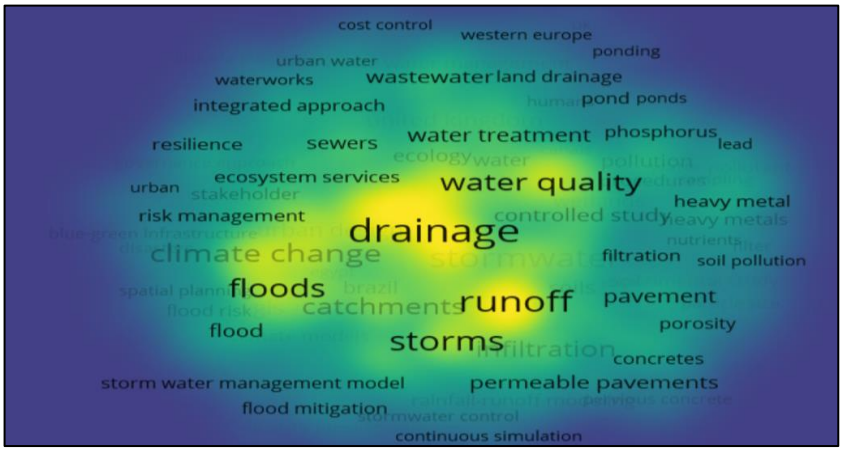

Figure 16. Density visualization of co-occurrences

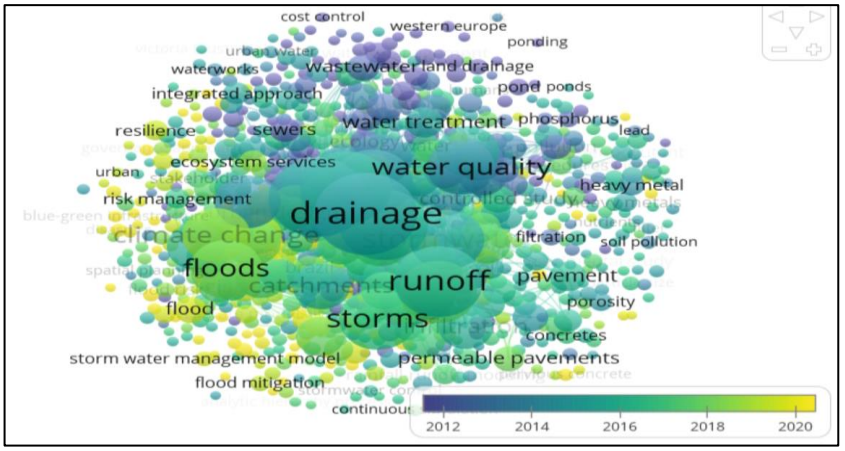

Figure 17. Number of co-occurrence keyword cluster maps, density visualization of co-occurrences, and the overlay timeline map

Eight unique clusters are seen in Figure 16 and 17, each representing a different theme focus within the research field. Keywords like "Runoff," "pavement," "permeable pavement," "environmental monitoring," "pollution," "water pollutant, "sustainable urban drainage systems in the center," and "stormwater" are included in Cluster 1 (red). This cluster highlights the importance of considering the controlled study and how water quality contributes to good infiltration, soil pollution, and stormwater (Ramírez et al., 2016). The clusters in the (blue) terms "sustainable development," "water management" and "urban area" suggest that the institutional and regulatory components of establishing and overseeing sustainable urban drainage systems are highly valued. Keywords like "water supply," "water conservation," "sewage," "wastewater management system," "recycling," "wastewater reclamation," and "sanitation" are all included in Cluster 2. This cluster focuses on high-impact development plans and how well they are sustainable for development and water management, particularly the technical aspects of sustainable urban drainage systems. Additionally, it implies that academics are interested in creating models to evaluate and maximize the use of these solutions and comprehending their advantages, functionality, and design elements (Lashford et al., 2022). Keywords in purple, like "drainage," "surface waters," and "human," are included in Cluster 3. The increasing understanding of the importance of sustainable urban drainage systems in reducing the effects of climate change and assisting cities in adapting to them is shown in this cluster. The phrase "drainage" appears in the sentence, indicating that academics are trying to create thorough and cohesive methods for evaluating and applying sustainable urban drainage systems in the context of surface waters and

humans (Ssempeera, 2023). Keywords in green like "climate change," "flood control," "urban development, urban planning, urban drainage systems, flooding, risk assessment, decision-making urbanizations," and "urban growth" are included in Cluster 4. This cluster emphasizes sustainable urban drainage systems' co-benefits in maintaining and promoting urban biodiversity and primarily focuses on decision-making and flood risk reduction (Rendana et al., 2023). The co-occurrence of these buzzwords highlights sustainable urban drainage systems' multifunctionality and capacity to solve several urban concerns concurrently.

The primary keywords in orange are associated with sustainable urban drainage systems, "storms, rainfall, stormwater, performance assessment," "catchments," and "hydrological modeling," which are strongly correlated with the term "runoff." These three terms, used for the literature review but not explicitly covered by our search, may be regarded as study subjects (Chapman & Hall, 2022a) in cluster (5).

One of its main advantages is the ability of sustainable urban drainage systems to increase stormwater management and support the flow, runoff, and storm. A conceptual framework is important for people's health because it lets us think critically about the long-term viability of cities, flood prevention, and the water cycle. For example, it helps with urban drainage, modeling rainfall-runoff, and designing cities that are sensitive to water (Madrazo-Uribeetxebarria et al., 2019). Additionally, the keywords in light orange for cluster (6), like" low impact development, engineering geology, sustainable stormwater management, and their capacity to adjust to changing circumstances in sustainable urban drainage systems, depend on green infrastructure for urban drainage design (Štrbac et al., 2023). Among the many advantages that sustainable urban drainage systems may offer are the best management practices, the preservation and improvement of species' habitats, and the encouragement of the sustainable use of natural resources (Xenia et al., 2019). For instance, green infrastructure, like urban green spaces, can offer a variety of other advantages to people, such as leisure, relaxation, and better air quality, as well as serving as habitats for birds and insects. It is crucial to remember that biodiversity is not only one of sustainable urban drainage systems' co-benefits but also a vital component of the idea.

The keywords in the light blue cluster (7), like "urban drainage," hydrology, water flow, sewer, water management, numerical model, urban drainage system, and computer simulation, defined sustainable urban drainage systems as "actions that protect, sustainably manage, and restore natural or modified ecosystems that effectively and adaptively address societal challenges, simultaneously providing benefits to biodiversity and human well-being" (Vijayaraghavan et al., 2021). As a result, any society that does not view biodiversity as a fundamental component runs the danger of being finished and performing better than intended. The keywords in cluster (8), like "ecosystem service, blue-green infrastructure, disaster management, and greenspace, are vital for environmental management (van der Werf et al., 2023).

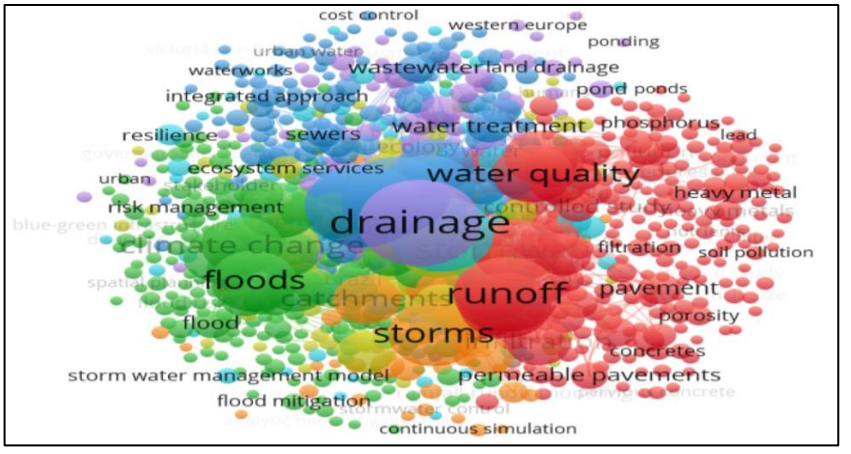

Figure 18. Different color cluster explanations

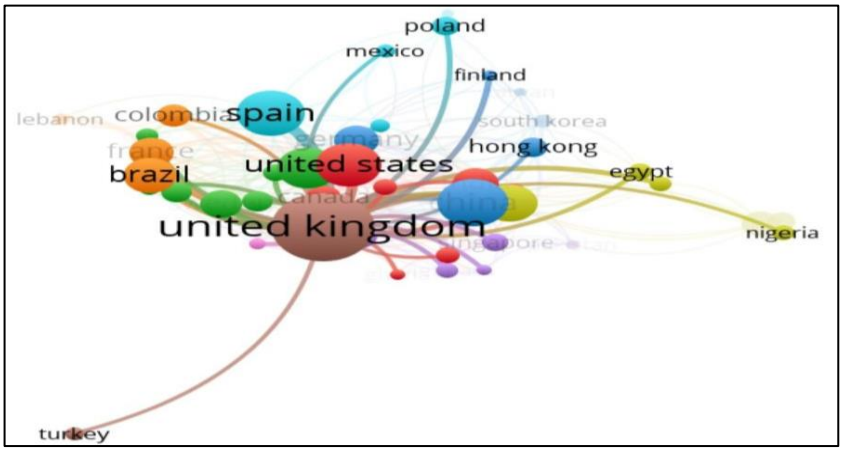

Figure 19. Artificial neural network of the United Kingdom as the first dominant for SUDS

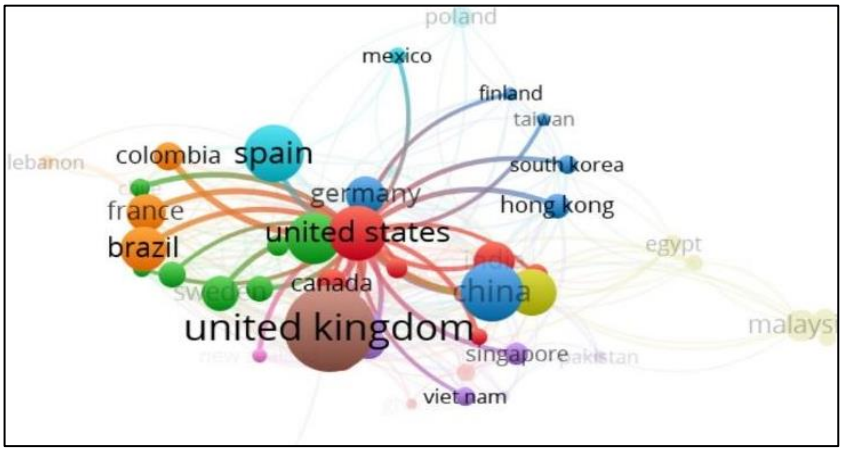

Figure 20. The artificial neural network of the United States is the second dominant SUDS.

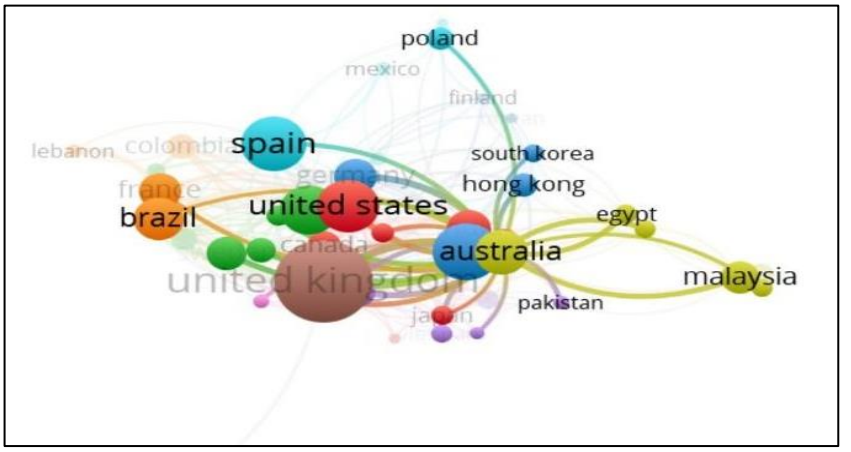

Figure 21. Artificial neural network of Spain as the fifth most dominant country with SUDS

3.3 Distribution of Articles Based on Subject Area

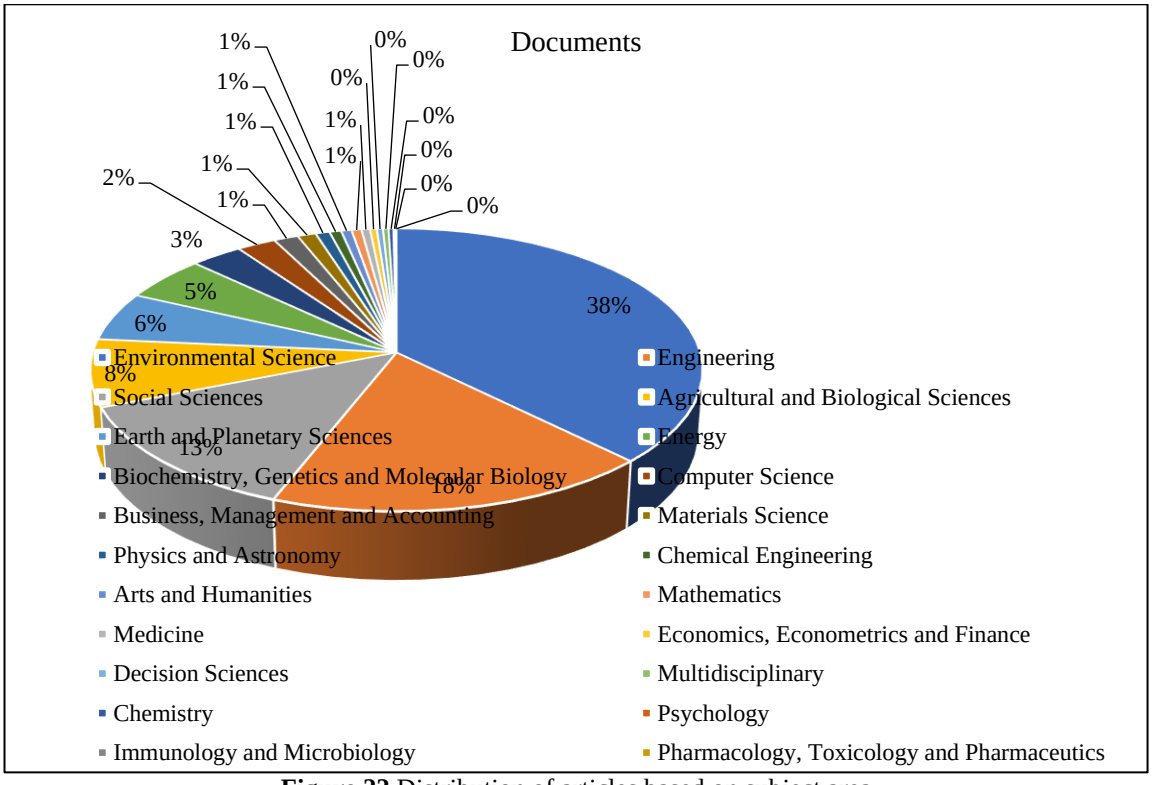

Figure 22 Distribution of articles based on subject area

Figure 20 shows the distribution of articles based on subject areas dominated by Environmental Science (38%), Engineering (18%), Social Science (13%), Agricultural and Biological Science (8%), Earth and Planetary (6%) and Energy (5%) because machine learning mainly discusses science subjects as the research object area. To fully comprehend the potential and usefulness of sustainable urban drainage systems, interdisciplinary and

collaborative study is necessary, as it is a multifaceted and intricate concept (Abellán García et al., 2021). More cooperation between many disciplines, such as Biochemistry, Genetics and Molecular Biology, Computer Science, Business, Management and Accounting, environmental science, Materials Science, Physics and Astronomy, Chemical Engineering, social sciences, Arts and Humanities, Mathematics, Medicine, economics, Econometrics, Decision Sciences, and chemistry, Psychology, Immunology and Microbiology and Pharmacology, Toxicology and Pharmaceutics, is required, according to the literature study. Numerous scholarly investigations have emphasized the necessity of conducting a multidisciplinary and transdisciplinary study to bolster the advancement and execution of sustainable urban drainage systems within urban settings (Zubelzu et al., 2019).

4. Limitations and Prospective Paths

Even though sustainable urban drainage systems have demonstrated much promise in solving social and environmental challenges, they still must be considered and scaled up in various settings and stages. According to a literature review, most studies have been on local or small-scale interventions (Pusalkar et al., 2020). Therefore, further research is required to fully understand the potential of sustainability in various contexts and in more excellent dimensions. Several research studies have emphasized the necessity of flood control and expanding sustainability to promote resilient and sustainable urban development (Yudianto et al., 2018). A thorough and coordinated strategy involving all sectors and stakeholders is needed to scale up and monitor sustainable urban drainage systems (Ward et al., 2022). To facilitate the implementation of sustainable urban drainage systems at various scales, policies, rules, and funding sources must also be developed (Boogaard et al., 2016). Future studies should concentrate on determining the opportunities and obstacles to sustainable urban drainage systems and creating plans and solutions to overcome these obstacles. Policymakers, practitioners, researchers, and the public are just a few groups and sectors that must be included in this collaborative, interdisciplinary approach.

Developing a comprehensive and integrated approach to sustainable urban drainage systems research and practice and encouraging multidisciplinary and collaborative research for monitoring sustainable urban drainage systems in many settings and at various sizes should be the key goals of sustainable urban drainage systems' future research viewpoint. This will assist in the creation of creative and practical responses to environmental and social problems in various contexts and advance the science and practice of sustainable drainage systems.

5. Conclusion

Regarding the idea, possibilities, and difficulties of nature-based solutions for sustainable urban drainage systems in urban sustainability, risk assessment, and flood risk control, the literature review that is the subject of this discussion offers essential insights. The literature analysis identified several important conclusions and avenues for further research. First, sustainable urban drainage systems comprise many nature-based interventions, including blue-green infrastructure, urban development, water management, and runoff. Sustainable urban drainage systems can address various social and environmental issues that urban areas encounter. Several variables affect sustainable urban drainage systems' effectiveness, including the intervention's scope and character, the local environment, and stakeholder participation.

Moreover, executing sustainable urban drainage systems demands a comprehensive and integrated strategy that includes several sectors and stakeholders, such as practitioners, policymakers, researchers, and the public. Encouraging the implementation and expansion of sustainability in urban areas, water quality, and climate change requires policies, laws, and funding sources. Even so, several obstacles impede the execution of sustainable urban drainage systems, such as inadequate financial resources, restricted understanding, consciousness, and competing agendas and concerns. Interdisciplinary and collaborative research is essential to fully comprehending the potential and effectiveness of sustainable urban drainage systems. Research on sustainable urban drainage systems must incorporate other fields of study, including social sciences, hydrology, and water flow. Integrating

varied viewpoints and expertise to address complex environmental and social concerns in sustainable stormwater management is made more accessible by interdisciplinary and collaborative research.

Furthermore, future studies should encourage the urban planning and expansion of sustainable urban drainage systems in various contexts and scales. This entails determining the opportunities and obstacles to sustainable urban drainage systems, creating plans and approaches to deal with these issues, and researching the possibilities of sustainable urban drainage systems on a larger scale. In addition to improving sustainable urban drainage systems and practices, scaling up and monitoring sustainable urban drainage systems will support the creation of creative and practical responses to environmental and social problems in various settings.

Sustainable urban drainage systems are viable for attaining resilient and sustainable urban development. The successful implementation of sustainable urban drainage systems necessitates a comprehensive, coordinated strategy involving numerous sectors and stakeholders. Subsequent investigations should focus on advancing interdisciplinary and cooperative research, expanding and implementing sustainable urban drainage systems, and investigating innovative methods for including diverse fields and stakeholders in the research procedure. Through these initiatives, the science and practice of sustainable urban drainage systems will progress, and creative and practical solutions to environmental and social problems in various urban environments will be supported.

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Declaration of Conflicting Interests

The authors declare no conflicts of interest.

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