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Review

Contribution of Irrigation Ponds to the Sustainability of Agriculture. A Review of Worldwide Research

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Abstract: The use of irrigation ponds has proved to be an efficient alternative for increasing the availability and quality of water resources for irrigation and contributing to the sustainability of agriculture. This article analyses the dynamics of worldwide research on this topic over the last two decades. To do this, a review including a qualitative systematic analysis and a quantitative bibliometric analysis was carried out on a sample of 951 articles. The results reveal that this line of research is becoming more relevant within agricultural research, particularly in recent years. The research in this topic has focused on the sustainable development of vulnerable regions, the contribution to the agronomic improvement of crops and farms, environmental impact assessment, the joint management of water resources, the restoration of groundwater bodies, and the use of rainfall. Gaps have been found in the literature with respect to the capacity of irrigation ponds to cover the irrigation needs in different agricultural contexts, the perceptions and attitudes of farmers towards the use of irrigation ponds, and the economic–financial feasibility of these systems.

Keywords: irrigation ponds; semi-arid climate; water resources management; rainwater harvesting; groundwater recharge; sustainable agriculture; bibliometric analysis

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1. Introduction

Guaranteeing the supply of food and the conservation and availability of quality and sufficient water resources are two closely related challenges that society must address in the 21st century [1,2]. Agricultural ecosystems play a fundamental role in meeting these two challenges as they are the principal suppliers of food but also the principal consumers of water resources on a global level [3,4]. The consumption of fresh water for agricultural irrigation can vary between 60% and 90%, depending on the level of economic development and the climatic conditions of the region [5,6]. In this respect, the scarcity and the degradation of water resources can constitute an obstacle to economic development, particularly in developing countries and in areas with arid and semi-arid climates, where there is scarce rainfall and a limited availability of surface water [7–9]. Therefore, in order to guarantee the sustainability of agriculture, it is necessary to develop agricultural practices that are safe and do not negatively affect the environment, optimising food production and natural resources, particularly with respect to the management of water resources [10,11].

In this context, recovering certain traditional agricultural management practices can contribute to the sustainability of the activity and of the natural environment as a whole. These practices include the use of irrigation ponds [12,13]. The use of irrigation ponds (IPs) has been a common practice for centuries, both in domestic and agricultural uses [14]. Irrigation ponds are small, shallow bodies of water, varying in size from 1 to 50,000 m^2. They hold water permanently or temporarily and can be man-made or naturally formed [15,16]. There are different types of IP depending on their construction, grouped into two main categories [17,18]: natural substrate ponds, which include embankments in small streams and ponds excavated in natural depressions, and artificial substrate ponds, which include those made from concrete and those lined with polyethylene. On a global level, it is estimated that there are 277,400,000 IPs with an area of less than one hectare and 24,120,000 water bodies with areas of between one and 10 hectares, accounting for more than 90% of the world's standing water bodies [19,20]. Furthermore, the area on which reservoirs are constructed throughout the world has increased from 5% to 50% since the 1960s and, in the case of small ponds for agricultural irrigation, this increase many have been greater [21]. There are no data on a global scale that quantify the area, volume, or irrigation capacity of small ponds [22]. However, some data on a regional level reveal that in India the IP supply crops area varies between 1.5 and 50 hectares [23].

The water of agricultural ponds usually comes from rainfall, runoff, the storage of reused water, or the deviation of water from streams at moments of maximum flow [24]. The IPs allow farmers to capture rainfall, store excess water from irrigation channels, and conserve water from other sources [25,26]. The use of IPs enables the supply of complementary irrigation, which is particularly relevant in areas with scarce water resources, contributing to increasing and stabilising crop yields [27]. Chander et al. [28] showed the efficiency of agricultural IPs for withstanding long periods of drought and intensifying and diversifying production systems. Consequently, in recent years there has been an increase in the construction of agricultural IPs throughout the world [29,30]. In order to function correctly, IPs must be designed according to crop irrigation needs, estimating the possible losses through evaporation and filtration, and they should be located in such a way so as to collect the greatest amount of water possible from the catchment area [14]. Therefore, in order to select the most appropriate location, we must take into account different factors such as the type of soil, the slope of the catchment area, the rate of infiltration, the vegetation, and the amount and distribution of rainfall [31].

As well as the advantages for agriculture, the use of IPs has a positive impact on groundwater. On the one hand, the availability of surface water reduces the extraction of groundwater, and on the other hand, the use of natural substrate ponds helps to recharge groundwater resources as they allow infiltration to occur [32,33]. Some studies have indicated that IPs can provide many ecosystem services, such as the contribution to biodiversity, the supply and storage of water, the improvement in the quality of the water and air, the regulation of greenhouse gases, and flood control. [34,35]. However, the use of IPs also has drawbacks such as their dependence on rainfall, which is uncertain and limited; the possible losses of water through evaporation and filtration; the reduction in the availability of downstream and surface water resources for production as they are built on arable land; and the possible loss of storage capacity due to sedimentation [36–40].

Over the last few years, there has been an increase in the scientific literature on the use of IPs due to the many contributions of this type of system. However, we are unaware of any study that summarises the vast scientific information on the use, evolution, and trends related to irrigation ponds and their contribution to the sustainability of agricultural activity. Therefore, the objective of this article is to analyse the dynamics of the research on IPs in the agricultural context over the last 20 years, identifying the most relevant lines of research and possible gaps in the literature. The results of this article can be useful for research studies related to the sustainability of agriculture and for policy makers when designing policies and action programmes related to the management of water resources and the agricultural activity in arid and semi-arid environments.

2. Methodology

2.1. Bibliometric Analysis

A bibliometric analysis was used to carry out this study. This method was developed in the 1950s by Garfield with the objective of identifying, organising, and assessing the principal components of a specific field of research [41–43]. Since then, this methodology has been used in different disciplines, such as biology, engineering, medicine, and economics [44]. This analysis uses mapping techniques to represent the available bibliographic information in a database and statistical and mathematical methods to determine the trends in a research field [45,46]. In these types of studies we can find three kinds of indicators [47]: quantity indicators, which measure productivity; relevance indicators, which show the impact of the publications; and structural indicators, which analyse the connections between the different elements of the same research field. On the other hand, there are three approaches that are considered to be traditional for developing bibliometric studies [48]: co-occurrence, co-citation, and bibliographic coupling analysis. This study takes into account the three types of indicators and the traditional approach based on co-occurrence.

First, the journals, countries, and institutions that have most published on the use of IPs as a measure for achieving agricultural sustainability were identified and the impact of the publications was analysed. To do this, the following quality indicators were selected: the counting of citations, the H index, and the impact factor of the SCImago Journal Rank (SJR) journals. The H index shows the number h of a total of N documents that include at least h citations in each of them [49]. Meanwhile, the SJR is an indicator that shows a weighting of the number of the citations received, taking into account the material and the prestige of the journal in which the citation is made [50]. These indicators are highly interesting for researchers, given that they enable them to compare the relevance of the journals in which to publish their articles [44]. Finally, the use of mapping techniques enables us to visualise the network generated between the agents who participate in a research field and to determine its trends [4].

2.2. Data Processing

The Scopus database was used to obtain the sample of studies to analyse based on different criteria. Scopus is the largest abstract and citation database of peer-reviewed literature [51]. Furthermore, this database is the most widely used in bibliometric studies on similar topics such as irrigation, agriculture, and water resources [52,53]. The selection of the sample of articles to analyse in this study was carried out in February 2020 based on the following parameters: TITLE-ABS-KEY (pond OR reservoir OR "irrigation raft" OR "farm dam") AND TITLE-ABS-KEY (irrigation OR agricultur* OR crop* OR farm* OR "greenhouse cultivation" OR horticulture) AND TITLE-ABS-KEY (sustainability OR sustainable). The search was limited to the period 2000-2019. Only documents up to 2019 were included so that complete annual periods can be compared [54]. It is worth pointing out that different search queries can give rise to different results.

In order to avoid duplications, only original articles and reviews were included in the sample [55]. The initial sample was made up of 1343 documents. Then, a review of the documents was carried out based on titles and abstracts in order to eliminate from the sample all documents whose principal theme was not the analysis of the use of IPs in agriculture. The final sample was made up of 951 documents. After the information was downloaded, the data were refined to eliminate duplications, omissions and errors and to search for incomplete information [49]. Furthermore, a search for articles on agriculture with the same restrictions was carried out to analyse the relative importance of the use of IPs for sustainable agriculture within this general theme. The variables analysed were the number of articles, their year of publication, the subject area, the name of the journals, and the trends in the main keywords. The tools used were Excel (version 2016, Microsoft, Redmond, DC, USA), SciMaT (v1.1.04, Soft Computing and Intelligent Information Systems research group, University of Granada, Granada, Spain), and VOSviewer (version 1.6.5., Leiden University, Leiden, The Netherlands). Figure 1 shows the methodology applied in this study.

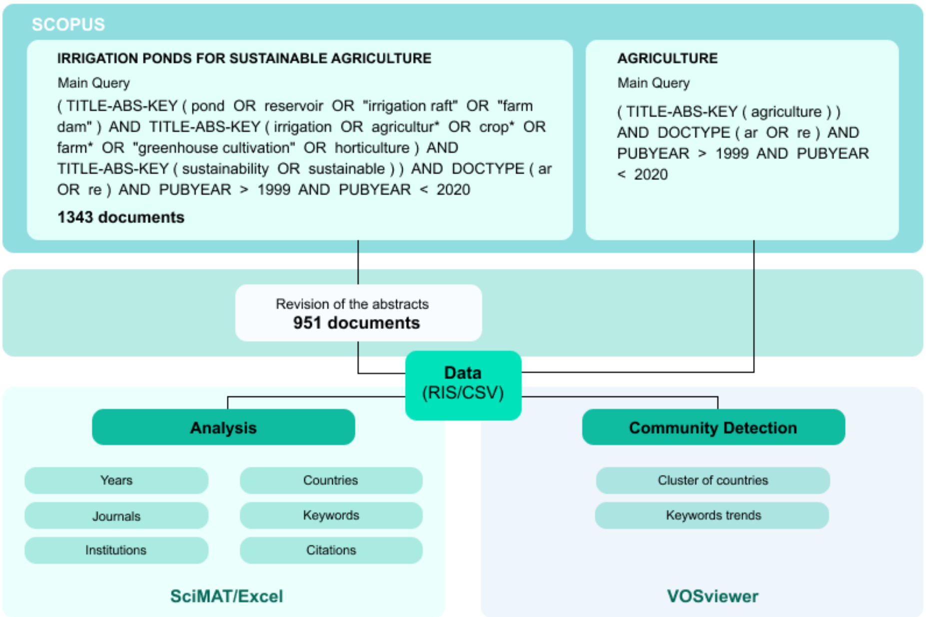

Figure 1. Summary of the methodology.

3. Results

3.1. Evolution of the General Characteristics of Research on Irrigation Ponds for Sustainable Agriculture (IPSA)

Table 1 shows the evolution of the principal variables related to the research on the use of irrigation ponds for sustainable agriculture (IPSA) in the period 2000–2019. The number of articles increased from 10 in 2000 to 111 in 2019. It is important to point out that this line of research has been experiencing strong growth in recent years, given that more than 50% of the articles of the sample have been published in the last five years. In order to determine whether the growth in the number of articles is due to the general trend in the research as a whole on agriculture, the annual variation in the number of articles published in both lines of research was calculated, taking the first year of the period analysed as a base (Figure 2). The average annual growth of the articles on agriculture was 9.97%, while that of articles on IPSA was 13.51%. These data allow us to confirm that IPSA is an increasingly relevant line within research on agriculture.

During the whole period analysed, a total of 3317 authors participated in the 951 articles that make up the sample. This is the variable that has experienced the most growth, increasing from 25 authors in 2000 to 492 in 2019. The average number of authors per article doubled from two to four. It is worth pointing out that the number of studies carried out by each of the authors is very low. Almost 95% of the researchers participated in only one article. Only 0.5% of the authors participated in four or more articles, and no authors participated in more than six. In the year 2000, the 10 articles analysed were published in 10 different journals, while in 2019 the 111 articles of the sample were published in 88 different journals. The average number of articles per journal has remained practically constant, increasing from one to two at the end of the period analysed. With respect to the countries that participated in carrying out the articles, during the whole period analysed there were a total of 106. The number of countries increased from 8 in 2000 to 52 in 2019. With respect to the citations, all of the documents in the sample accumulated a total of 16629 during the whole period. This figure increased from 8 in 2001 to 2938 in 2019. The average number of citations obtained per article grew from 0.3 in 2001 to 17.5 in 2019.

Table 1. Main characteristics of the irrigation ponds for sustainable agriculture (IPSA) research.

Year	Articles	Authors	Journals	Countries	Citations	Average Citations [1]
2000	10	25	10	8	0	0.0
2001	16	41	16	10	8	0.3
2002	12	23	12	8	4	0.3
2003	22	65	22	15	13	0.4
2004	20	59	18	14	44	0.9
2005	27	87	22	17	75	1.3
2006	34	107	30	21	142	2.0
2007	30	82	26	17	196	2.8
2008	48	152	40	29	252	3.4
2009	52	168	42	32	368	4.1
2010	28	104	25	21	496	5.3
2011	54	191	50	34	672	6.4
2012	49	216	42	41	812	7.7
2013	73	272	60	34	1183	9.0
2014	63	245	48	30	1416	10.6
2015	58	275	52	39	1545	12.1
2016	77	330	61	38	1845	13.5
2017	73	318	58	37	2186	15.1
2018	94	460	69	57	2434	16.3
2019	111	492	88	52	2938	17.5

[1] Total number of citations accumulated to date divided by the total number of articles published to date.

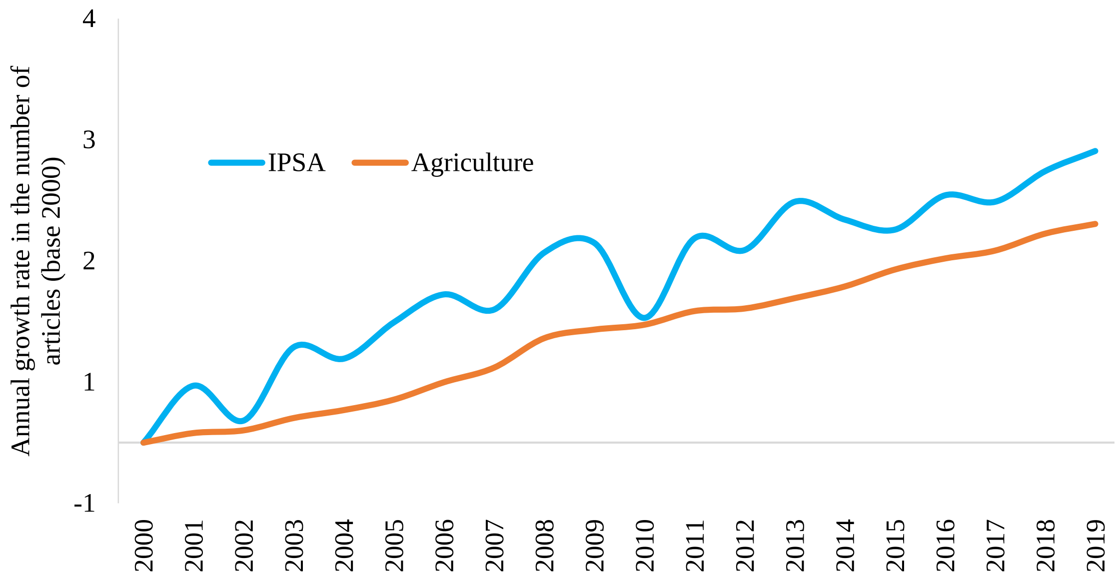

Figure 2. Comparative trends in irrigation ponds for sustainable agriculture (IPSA) and agriculture research.

3.2. Evolution of Research in IPSA by Subject Area

Figure 3 shows the evolution of the articles published that have been classified based on the thematic categories established by Scopus. It should be taken into account that the same study may be classified in more than one category simultaneously. The category that accumulates the highest number of studies is Environmental Sciences with 64.35% of the total sample. This is followed by Agricultural and Biological Sciences with 34.38%, Earth and Planetary Sciences with 17.46%, Social Sciences with 16.41%, and Engineering with 13.76%. This concept of sustainability covers three fundamental dimensions: the environmental, economic, and social aspects [56]. The categories classified as being economic (Economics, Econometrics, and Finance and Business, Management, and Accounting) account for barely 5% of studies in the sample. Other representative categories such as Multidisciplinarity or Decision

Science represent less than 2% and 1% of the total studies in the sample, respectively. These data highlight that there is a predominance of studies that analyse the environmental aspects of sustainability and a lack of studies that analyse the other dimensions. This implies that, despite the availability of the relevant information, research in IPSA is limited and greater analysis is required of aspects such as the profitability and economic–financial feasibility of the use of IPs, or the perception of the different parties interested in their benefits and drawbacks.

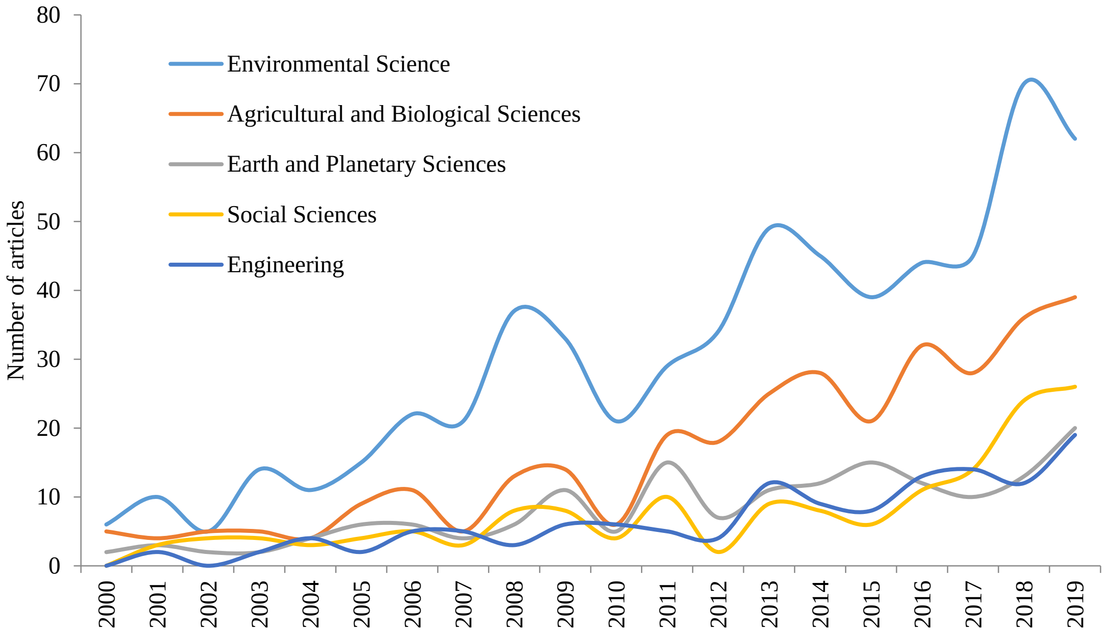

Figure 3. Comparative trends of IPSA research.

3.3. Most Relevant Journals in IPSA Research

Table 2 shows the most prolific journals in IPSA in the period 2000-2019 and the principal characteristics of their articles. The group as a whole published a total of 164 of the articles making up the sample analysed, representing 17% of the total. This highlights the wide dispersion with respect to the journals that publish articles on this topic. The journal with the highest number of articles published is Water with a total of 23. This journal has an H index of 8, a total of 143 citations, and its average number of citations per article is 6.2. Its SCImago Journal Rank (SJR) impact factor is 0.670, and it has been publishing on IPSA since 2009, when its first article on this topic was printed. Nongye Gongcheng Xuebao Transactions of the Chinese Society of Agricultural Engineering is in second place with a total of 21 articles. This Chinese journal has an H index of 6, a total of 92 citations, and its average number of citations per article is 4.4. Its SJR impact factor is 0.422. This journal is the only one that has not published any articles on the subject since 2017. In third position is Agricultural Water Management with a total of 19 articles. This journal published its first article on IPSA in the year 2000 and is therefore the most veteran in the table. It currently maintains this line of publication. The H index of this journal is 11, it has a total of 323 citations, and the average number of citations per article is 17.1. Journal of Hydrology is in seventh place with 15 articles. It is the journal with the highest SJR impact factor—1.830. This journal also accumulates the highest number of citations,588, and the highest average number of citations per article, with 39.2 and an H index of 10. Sustainability and Journal of Cleaner Production are the most recent newcomers to the subject, given that, in both cases, their first articles within the sample analysed were published in 2015. Despite this, these two journals are in fifth and ninth position, with 16 and 12 articles, respectively.

Table 2. Major characteristics of the most active journals related to IPSA research.

Journal	Articles	SJR [1]	H Index [2]	Country	Citations	Average Citations [3]	First Article	Last Article
Water	23	0.670 (Q2)	8	Switzerland	143	6.2	2009	2019
Nongye Gongcheng Xuebao	21	0.422 (Q2)	6	China	92	4.4	2011	2017
Agricultural Water Management	19	1.403 (Q1)	11	Netherlands	323	17.1	2000	2019
Water Resources Management	17	1.097 (Q1)	13	Netherlands	404	23.8	2007	2019
Acta Ecologica Sinica	16	0.197 (Q4)	5	China	83	5.2	2010	2018
Sustainability	16	0.549 (Q2)	4	Switzerland	54	3.4	2015	2019
Journal of Hydrology	15	1.830 (Q1)	10	Netherlands	588	39.2	2008	2019
Environmental Earth Sciences	13	0.625 (Q2)	6	Germany	95	7.3	2012	2019
Environmental Monitoring and Assessment	12	0.623 (Q2)	8	Netherlands	116	9.7	2004	2019
Journal of Cleaner Production	12	1.620 (Q1)	7	Netherlands	129	10.8	2015	2019

[1] SCImago Journal Rank 2018; [2] only sample documents; [3] total number of citations divided by the total number of articles.

3.4. Most Relevant Countries in IPSA Research

Table 3 shows the most prolific countries in IPSA research in the period 2000–2019 and the principal characteristics of their articles. This group includes a very heterogeneous series of countries, located in every continent except Africa. It is worth mentioning that practically all of these countries began to participate in this line of research at the beginning of the period analysed and continue to do so today. China holds the first position with a total of 186 articles. This is followed by the USA with 174, India with 103, the UK with 58, and Germany with 50. In order to determine the relative weight of each country in the research on IPSA in the global context, the number of articles per million inhabitants was calculated. Based on this variable, Australia is the most productive country with 1.961 articles per million inhabitants. This is followed by the UK with 0.872, France with 0.731, Spain with 0.706, and Germany with 0.603. With respect to the relevance of the research, measured through the number of citations obtained by the articles, the USA holds the first position with a total of 5597 citations. This is followed by China with 2272, Italy with 1852, the UK with 1.551, and France with 1512. However, if we consider the average number of citations per article, Italy is the most prominent country with 52.9. This is followed by Spain with 38.5, the USA with 32.2, France with 30.9, and the UK with 26.7.

Table 3. Main characteristics of the most active countries related to IPSA research.

Country	Articles	Average per Capita Articles [1]	Citations	Average Citations [2]	H Index [3]	First Article	Last Article
China	186	0.134	2272	12.2	29	2000	2019
USA	174	0.532	5597	32.2	33	2000	2019
India	103	0.076	1283	12.5	18	2000	2019
UK	58	0.872	1551	26.7	21	2000	2019
Germany	50	0.603	982	19.6	16	2000	2019
Australia	49	1.961	1082	22.1	16	2001	2019
France	49	0.731	1512	30.9	18	2003	2019
Brazil	36	0.172	540	15.0	10	2001	2019
Italy	35	0.579	1852	52.9	16	2001	2019
Spain	33	0.706	1269	38.5	15	2000	2019

[1] Total number of articles per million inhabitants; [2] total number of citations divided by the total number of articles; [3] only sample documents.

The results of the analysis of the collaboration networks established between the most prolific countries with respect to research on IPSA are shown in Table 4. The average percentage of articles carried out through international collaboration by the group of the 10 countries is 47.79%. The average size of the collaboration networks is 25 countries. The country with the highest percentage of studies carried out through international collaboration is France with 67.35%. This is followed by the UK with 67.24% and the USA with 60.34%. The USA has the largest collaboration network with 45 different collaborators. This is followed by France with 36, the UK with 34, and Germany with 30. The table also shows the five principal collaborators of each country. The USA forms part of the group of the most important partners of the rest of the countries, except Spain, which is the principal collaborator of seven of them (China, India, UK, Germany, France, Brazil, and Italy). The articles written in collaboration obtained an average of 36.1 citations, while those without collaboration obtained 19.1.

Figure 4 shows a network map depicting the collaboration relationships established between the different countries. The size of the circle varies depending on the number of articles of each country, and the lines represent the relationships established between countries, the thickness of which depends on the number of collaborations. The different colours identify the collaboration groups, with three clusters being distinguished. The red cluster is led by China in terms of the number of articles and includes the USA, India, the UK, Canada, and the Netherlands among its principal collaborators. The green cluster is led by Germany and includes countries such as Italy, Brazil, Spain, and Portugal. Finally, the blue cluster is led by Australia, which appears together with France, Turkey, Belgium, and South Africa.

Table 4. Major characteristics in the collaboration of the most active countries related to IPSA research.

Country	Percentage of Collaboration [1]	Number of Collaborators	Main Collaborators	Average Citation	
				Collaboration [2]	Non-Collaboration [3]
China	29.1	26	USA, Australia, Netherlands, Canada, Germany	17.6	10.0
USA	60.3	45	China, Mexico, France, Germany, Netherlands	40.2	19.9
India	20.4	14	USA, Netherlands, France, Germany, Canada	38.9	5.7
UK	67.2	34	USA, Italy, Australia, South Africa, China	22.7	35.0
Germany	60.1	30	USA, China, Italy, Brazil, India	19.5	19.9
Australia	40.8	23	China, USA, UK, Canada, France	34.7	13.4
France	67.4	36	USA, Italy, Tunisia, India, UK	33.9	24.6
Brazil	38.9	11	USA, Germany, Canada, France, Spain	30.4	5.2
Italy	51.4	22	USA, UK, France, Germany, Netherlands	90.7	12.9
Spain	42.4	16	Germany, Italy, UK, Brazil, Portugal	32.3	43.0

[1] Number of articles written through international collaboration divided by the total number of articles; [2] number of citations obtained by articles made through international collaboration divided by the number of articles; [3] number of citations obtained for articles not made through international collaboration divided by the number of articles.

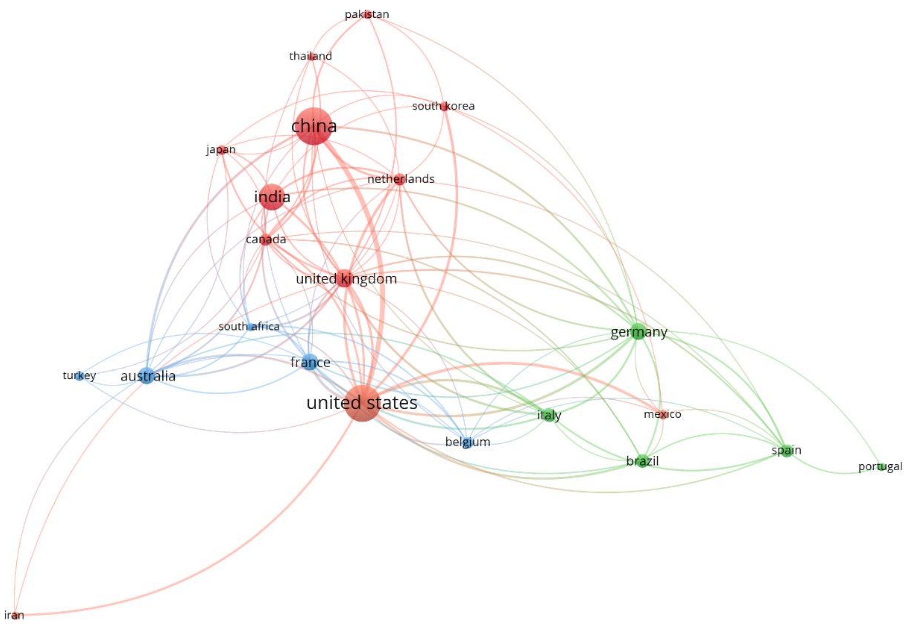

Figure 4. Major characteristics in the collaboration of the most active countries related to IPSA research.

3.5. Most Relevant Institutions in IPSA Research

Table 5 shows the most prolific institutions in IPSA in the period 2000–2019 and the principal characteristics of their articles. These institutions belong to China, Netherlands, Belgium, Germany, and Ethiopia. It is worth pointing out the low number of articles per institution. The institutions as a whole account for 17% of the total number of articles forming the sample, and only two of them have published more than 10 articles on IPSA. The Chinese Academy of Sciences holds the first position with 62 articles. This institution also has the highest number of citations, with a total of 1097, an average of 17.7 citations per article, and an H index of 16. The institution with the second largest number of articles is the Ministry of Education China with a total of 11 articles published. This institution has 244 citations, an average of 22.2 citations per article and an H index of 6. In third place is the Wageningen University and Research Centre with 10 articles in total, 360 citations, an average of 36.1 citations per article, and an H index of 6. The Belgian institute KU Leuven has the highest average number of citations of those included in the table with 42.9.

With respect to the international collaboration of the institutions, the average percentage of articles carried out through collaboration with other institutions is 48.62%. In two of these institutions, KU Leuven and Mekelle University, 100% of their articles published have been carried out through international collaboration. They are followed by Wageningen University and Research Centre and Universiteit Gent, each with 80%. The institutions with the highest number of citations in the jointly written articles were KU Leuven, Ministry of Education China, and Wageningen University and Research Centre.

Table 5. Major characteristics of the most active institutions related to IPSA research.

Institution	Country	Articles	Citations	Average Citations [1]	H Index [2]	Percentage of Collaboration [3]	Average citation	
							Collaboration [4]	Non-Collaboration [5]
Chinese Academy of Sciences	China	62	1097	17.7	16	33.9	19.5	16.8
Ministry of Education China	China	11	244	22.2	6	18.2	36.5	19.0
Wageningen University and Research Centre	Netherlands	10	360	36.1	6	80	29.9	60.5
Universität Bonn	Germany	10	125	12.5	6	60	16.0	7.3
Universiteit Gent	Belgium	10	189	18.9	5	80	23.1	2.0
China Institute of Water Resources and Hydropower Research	China	9	33	3.7	4	11.1	2.0	3.9
Beijing Forestry University	China	9	83	9.2	5	22.2	27.5	4.0
Beijing Normal University	China	9	99	11.0	5	33.3	4.7	14.2
KU Leuven	Belgium	9	386	42.9	6	100	42.9	0.0
Northwest A&F University	China	9	81	9.0	4	22.2	3.0	10.7
Mekelle University	Ethiopia	9	179	19.9	6	100	19.9	0.0
Southwest University	China	9	33	3.7	4	22.2	7.5	2.6

[1] Total number of citations divided by the total number of articles; [2] only sample documents; [3] number of articles written through international collaboration divided by the total number of articles; [4] number of citations obtained by articles made through international collaboration divided by the number of articles; [5] number of citations obtained for articles not made through international collaboration divided by the number of articles.

3.6. Keywords Analysis in IPSA Research

Figure 5 shows the grouping of the principal keywords used in the sample of articles as a whole, based on the network analysis. The colour represents the group in which the keyword is included depending on the number of co-appearances. The most used keywords in the period as a whole and, therefore, which constitute the central focus of the research in this topic are "sustainable development", "water management, "water supply", "groundwater", "water resources", "environment", "land use", and "rural development". The use of these terms became widespread between 2012 and 2013. The terms "water conservation" and "climate change" gained weight after 2015, revealing the current growing concern over water resources and the effects of climate change.

In this figure we can see the terms grouped into clusters, showing different lines of research in IPSA. The first (violet) refers to the management of water resources, including terms such as "adaptive management", "resources management", "water management", "water planning", "decision making", and "optimization". Within the current context of scarce water resources, this line of research is particularly relevant as it is necessary to carry out a correct management of the available water resources, creating plans to ensure an optimum combination of conventional resources and other alternative resources such as desalinated or reused water, thanks to the use of IPs [57–60]. More specifically, this line of research focuses on the use of the new information technologies for developing programs to obtain reliable data regarding the number of IPs, spatial distribution, and potential storage volume with the objective of increasing the availability and quality of the water and reducing the costs of the agricultural farms [61–68].

The second cluster (yellow) focuses on groundwater resources and includes concepts such as "groundwater abstractions", "groundwater resources", or "groundwater recharge". The growing concern for conserving groundwater resources has led to the construction of more IPs on agricultural farms, giving rise to the development of a line of research based on the study of the contribution of the IPs to the recharging of aquifers [33,69] and the management and joint use of different water sources to guarantee the sustainability of groundwater without affecting the agricultural yields [70–73].

The third cluster (dark blue) studies the rainwater harvesting and runoff systems, including terms such as "rainwater harvesting", "runoff", "catchment areas", or "rain". These systems usually require the use of a pond or tank to store the water, so studies have been developed to determine the appropriate location and structure for their implementation [74–77]. The correct implementation of these systems has favourable implications for the area in which they are located, going beyond agriculture, namely flood prevention and the conservation of infrastructures. However, it is still necessary to improve the knowledge regarding their use, their capacity to cover irrigation needs based on the characteristics of the area of study, and the perception of the farmers therein.

The fourth cluster (green) refers to sustainable development, with terms such as "development", "rural population", or "household income". Along these lines we can find studies on the capacity of the IPs to act as systems to boost certain areas or regions, particularly in countries with fewer resources which are those that are expected to be harder hit by the effects of climate change. The use of IPs may provide a whole host of benefits derived from the possibility of increasing the availability of water, both for its use in the home and for agriculture and cattle farming [78–81]. However, more studies are required related to the limitations that may exist in implementing these systems and the possible impacts on the areas in which they are located.

The fifth (light blue) analyses the effects that the construction and use of IPs can have on natural resources and the environment, including concepts such as "environmental impact", "environmental protection", "biodiversity", "ecology", or "ecosystem service". Along these lines we can find studies that show that IPs are one of the freshwater habitats with the greatest biodiversity and ecological importance, providing valuable ecosystemic services for society [82,83]. Other studies focus on the assessment of the negative impacts, such as the reduction of river flows [84,85].

The sixth (red) focuses on the agronomic environment, including terms related to crops, such as "crop yield", "crop plant", "crop production", "wheat", or "rice". With respect to the IPs, the study from an agronomic perspective has been based on the analysis of the possible effects that these can have on the production capacity of the agricultural ecosystems in a certain area [86,87]. However, it is difficult to determine the possible increase in the yields due to the fact that there are no data with respect to the irrigation capacity of the IP as well as the variability in rainfall, the principal supply source of the IP.

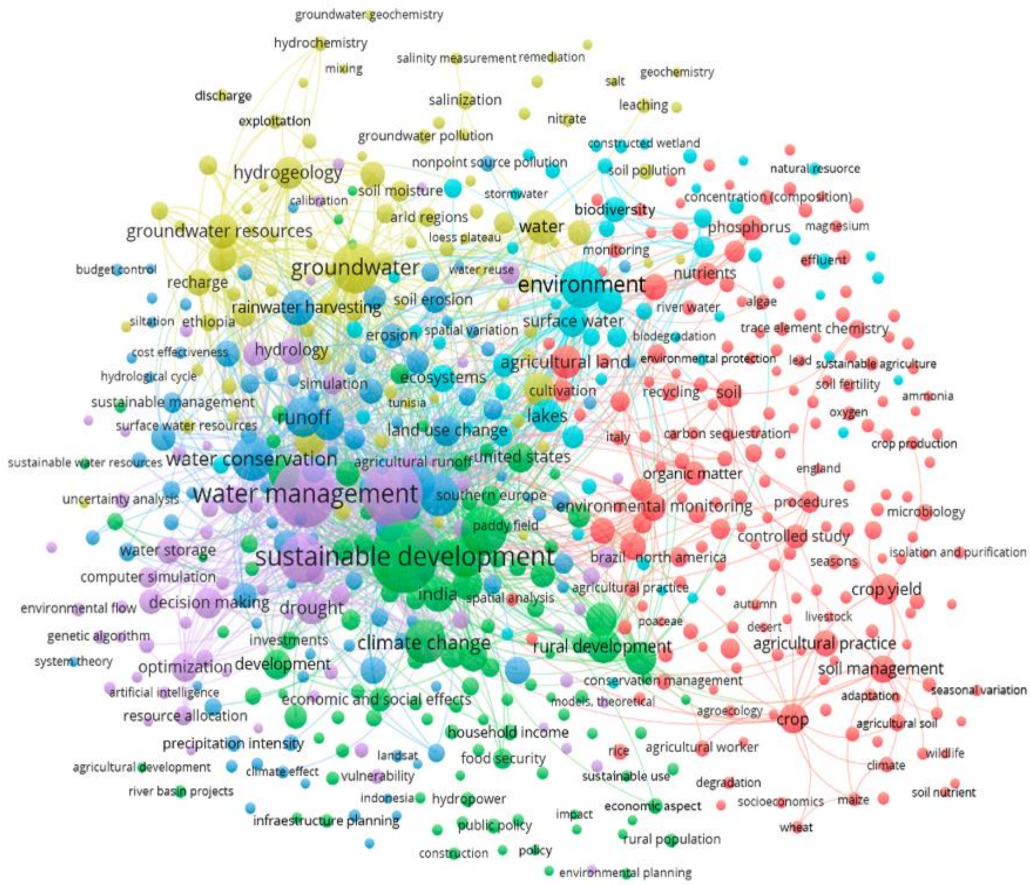

Figure 5. Main keywords related to IPSA research.

4. Discussion

Currently, water resources are suffering from a severe degradation process due to global climate change, demographic growth, the modification in the use of land, and overexploitation derived from economic development [88–91]. As a result, an increase in the competition for the available water will arise in the near future, which represents a threat to ensuring the resources necessary to guarantee the food supply [92,93]. In this context, the objective is sustainable development, defined as that which satisfies the needs of the current generation without compromising the capacity of future generations to satisfy theirs, considering the environmental, economic, and social dimensions [94]. The use of IPs has positive impacts on these three dimensions to be considered to reach sustainable development in agriculture.

From an economic perspective, an irregular and insufficient supply of water can limit agricultural production, compromising the stability of income and the survival of many families who rely on a subsistence agricultural model [95]. Therefore, the construction and use of IPs can positively influence the maintenance of the activity in agricultural areas as it provides an alternative source of water and guarantees supply when the distribution of rainfall over time does not coincide with the crop seasons [14,23]. Different studies have shown that the use of IPs can be translated into increases in cultivated areas, a diversification of production to adapt it to market demand, and an increase in yields [22,28,31,65].

On an environmental level, the IPs can have different positive effects. The development of agricultural activity in certain areas has fundamentally been based on the use of water drawn from underground sources, leading to a current state of overexploitation of these sources [8,9]. This is the case of the arid and semi-arid areas where between 60% and 100% of the water supply for agriculture depends on groundwater resources [96,97]. It is estimated that the overexploitation of groundwater resources on a global level amounts to 163 km^3 each year [5,98]. The IPs can contribute to recharging the aquifers and to reducing the extractions of groundwater, reducing the pressure that these water bodies are subjected to. Ouyang et al. [30] determine that the irrigation of 10,000 hectares of crops in Mississippi with water accumulated in IPs could reduce the use of groundwater by 11%. Carvajal et al. [29] conclude that the use of water collected in IP systems in an agricultural area in Southeast Spain enabled the water needs from other sources to be reduced by 53%. On the other hand, the IPs can help to mitigate the effects of climate change as they act as carbon sinks. Downing [99] indicates that "carbon sequestration by ponds may be as great as or greater than that of forests, grasslands, and all the world's oceans". More specifically, it is estimated that a 500 m^2 IP can sequester up to 1000 kg of carbon per year [20]. Thus, the IPs can offer diverse ecosystemic services and favourably influence the biodiversity [100].

No studies have been found that specifically analyse the impact of the use of IPs in the social context. However, the availability of these systems has been associated with a reduction in the vulnerability of the population to the effects of climate change and an improvement in the livelihoods of the poorest areas of developing countries [37]. The greater availability of water resources derived from the use of IPs would guarantee the supply of water and food. The possibility of extending the agricultural areas would facilitate the generation of employment and the increase in wealth in the most disadvantaged areas. Furthermore, the construction of IPs close to inhabited areas and crops could represent an increase in schooling and the incorporation of women into the labour market, as these groups, which are in danger of exclusion, would be liberated from the task of collecting water [101].

On the other hand, the use of IPs contributes to achieving the objectives proposed in the United Nations Agenda 2030 for Sustainable Development [102]. Water plays a fundamental role in all aspects of sustainable development, as it is an essential natural resource on which all social and economic activities depend as do the different types of ecosystem [103]. Thus, water directly or indirectly influences the achievement of the 17 objectives included in this Agenda. The increase in the availability of water as a result of the use of IPs can help to mitigate poverty (Objective 1), as it enables an increase in agricultural yields and the income derived from extending the crop area and/or the diversification of production. Currently, there are more than 820 million people who suffer from hunger throughout the world. Therefore, Objective 2 of the Agenda is to eradicate hunger and improve nutrition [104]. The use of IPs enables the growing of food for small scale supply, thanks to the availability of water for irrigating an orchard and covering cattle needs. The generation of employment and economic growth are also objectives for sustainable development (Objective 8). The use of IPs contributes to this objective as it guarantees the survival of the agricultural activity, particularly in those areas in which it is an essential activity and through the possibility of extending the crop area. The different positive effects on the environment derived from IPs, such as carbon sequestration or the reduction in the overexploitation of aquifers, can contribute to the fight against climate change (Objective 13).

IPs have positive impacts on achieving agricultural sustainability, but we must consider a series of limitations. Although new approaches have been developed to estimate the number of IPs, their volume, and capacity based on the new technologies and techniques of remote sensing and geographic information systems (GISs), it is not simple to carry out these quantifications and determine their possible environmental impacts [67]. The difficulty in estimating these data is derived from the need to conduct them on a local or regional level, given the influence of a series of factors that vary in accordance with the area such as the soil conditions, the slope, or the climate [22,40]. Furthermore, the non-existence of a common method to carry out these studies gives rise to heterogeneous results in the same area of study. This difficulty in quantifying the number, area, and volume of these water bodies means that, in many cases, they are not taken into account as part of the hydrological system [64]. On the other hand, with respect to estimating the irrigation capacity of the ponds, this will vary depending on the area and the type of crop, which requires the development of specific studies that analyse these aspects jointly [105]. Therefore, it will be necessary to consider alternatives to the factors that can limit the benefits derived from the use of the ponds and study their possible effects on a regional scale and how to address the possible consequences that climate change may have on them. Furthermore, it is necessary to analyse the contribution of the IPs to the achievement of the Sustainable Development Objectives in order to obtain all of the information necessary to design specific action plans on a local, regional, and national scale.

5. Conclusions

The development of alternative sources of water resources is one of the most promising options for addressing the challenge of satisfying the future demand for irrigation water. The use of IPs has been shown to be a relevant practice to increase the availability of water resources for agricultural use, as they enable the storage of water during the rainy season for its subsequent use in accordance with crop needs and they allow the mixture of water from different origins. Furthermore, the use of these systems can have a favourable impact on sustainable development. From an economic sustainability point of view, they can help the survival of the agricultural sector in areas with scarce water resources, particularly small farms, and enable the extension of the crop area and the diversification of production, which can translate into an increase in income. With respect to the environment, the use of IPs can contribute to mitigating the effects of climate change, as they act as regulators of greenhouse gases. They can also contribute to the conservation of groundwater as they reduce extractions and favour infiltration. Finally, the use of IPs enables the settlement of the population and literacy and the incorporation into the labour market of people in danger of exclusion in poor rural areas. However, the significance and quantification of the possible effects of the IPs on the three dimensions of sustainability will vary depending on the characteristics of the area of study. Therefore, it is necessary to undertake studies that analyse in depth the use of IPs, particularly in the poorest regions prone to suffering the effects of climate change.

The keywords analysis reveals that the research in IPSA has continually evolved over the period analysed, with a predominance of the development of very recent research topics. This indicates that this is a very new line of study. It has also revealed the principal lines of research and certain gaps in the knowledge with respect to each of them. In general, the main gaps, which constitute possible future lines of study, correspond to the technical development of the reservoir systems, including the measurement of their capacity based on rainfall prediction models; the quantification of the impact of the use of IPs, both positive and negative, for agriculture and for the environment as a whole, for example groundwater; the capacity to increase the crop yields in different agricultural contexts; and the possibility of diversifying them depending on the characteristics of the geographic area. On the other hand, it is particularly relevant to analyse the level of knowledge on the use of IPs by farmers, as well as the study of the different aspects related to the socio-economic characteristics of these farmers as the perception of adopting this system, the economic–financial feasibility of its application, willingness to pay, or whether government incentives are required.

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