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Review

Rainwater Harvesting for Agricultural Irrigation: An Analysis of Global Research

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Abstract: Within a context of scarce water resources for agriculture, rainwater harvesting constitutes a promising alternative that has been studied by different disciplines in recent years. This article analyses the dynamics of global research on rainwater harvesting for agricultural irrigation over the last two decades. To do this, qualitative systematic analysis and quantitative bibliometric analysis have been carried out. The results reveal that this line of research is becoming increasingly important within research on irrigation. Environmental sciences and agricultural and biological sciences are the most relevant subject areas. *Agricultural Water Management*, *Physics and Chemistry of the Earth*, and *Irrigation and Drainage* are the journals that have published the most articles on the subject. India, China, the United States (USA), South Africa, and the Netherlands are the countries that lead this line of research. Although significant progress has been made in this subject area, it is necessary to increase the number of studies on the capacity of rainwater harvesting systems to cover irrigation needs in different farming contexts, the factors that determine their adoption by farmers, the economic and financial feasibility of their implementation, and their contribution to mitigating global climate change.

Keywords: rainwater; harvesting; irrigation; sustainability; unconventional water resources

1. Introduction

The supply of food is one of the greatest challenges faced by humankind in the 21st century [1]. Agricultural ecosystems are the principal suppliers of food, but they are also the main consumers of water resources on a global level [2,3]. These ecosystems use between 60–90% of available water, depending on the climate and economic development of the region [4,5]. The global area dedicated to irrigated crops is estimated at 275 million hectares with an upward growth trend of 1.3% per year [6]. This accounts for just 23% of farmed land; however, 45% of total food production is obtained through these types of crops [7,8]. It has been estimated that in order to satisfy food demand in 2050, world production must increase by 70% [9]; this implies an increase in the consumption of water resources on a global level of 53% [10,11]. More and more regions throughout the world are facing severe water shortages. Water resources are subject to severe degradation due to many factors, such as the consequences of global climate change, rapid population growth, changes in land use, agricultural and urban expansion, the increase in the demand for water from different productive sectors, the inadequate distribution of water resources, regional hydropolitical conditions, the deterioration of the quality of water due to overexploitation, rainwater scarcity, and the high rate of evaporation and aridity resulting from the increase in temperatures [12,13].

Rural development, particularly in countries with emerging or underdeveloped economies, is based on agriculture; therefore, water scarcity is a limiting factor [14–16]. Climate variables, especially precipitation and temperature, have both direct and indirect impacts on agriculture and on the rest of the productive sectors. This, in turn, affects economic growth and the livelihoods of mainly the poorest populations [17]. The climate is changing and increases of up to 5 °C are forecast over the next few decades [18–20]. Climate change is characterised by frequent and severe droughts, heatwaves, storms, floods and other extreme weather phenomena that are causing severe water stress, giving rise to a decline in agricultural productivity [21–23]. Countries with a low technological and institutional capacity to adapt to the rapid climate changes—such as those in sub-Saharan Africa, the Middle East, or Latin America, will suffer the negative impacts more intensely on all levels [24]. Within this context, food production systems that are more efficient in managing resources are required, particularly with respect to water [25,26]. Some authors recommend the joint use of different water resources and the development of infrastructures for the provision of non-conventional water sources [27–31]; considering this, one of the best alternatives is to adapt to the impacts of climate change using better rainwater management systems [32]. Therefore, rainwater harvesting for irrigation (RWHI) is proposed as a solution to address scarcity [15,33,34].

According to Qadir et al. [35], rainwater harvesting is defined as the management, control, and use of rainwater in situ or its storage for future use. Rainwater harvesting comprises all of the methods by which rainwater and run-off are managed effectively for different uses [36,37]. Rainwater harvesting is a practice that dates back to prehistoric times, and still forms an integral part of many domestic and agricultural systems throughout the world, particularly in arid and semiarid regions [35]. RWHI implies harvesting, storing, and conserving rainwater (or the run-off derived from a catchment area of a reservoir) directly, in a farmed area that is generally smaller than the size of the catchment area [15,38]. Rainwater harvesting is commonly practised in areas where the rainfall is insufficient for crop growing. The most widespread use is that of supplementary irrigation, complementing rainfall during periods of water scarcity or stress during the growth stages of plants. The principal objective of RWH as supplementary irrigation is to collect run-off from outlying areas or from areas where it is not used, store it, and make it available where and when there is a scarcity of water. Therefore, due to the intermittent nature of run-off events, it is necessary to store the maximum possible amount of rainwater during the rainy season so that it may be used at a later date [35,39].

As well as the characteristics of the rainfall, other variables related to the landscape also influence the efficiency of the different rainwater harvesting techniques: the slope of the land, which enables the run-off water to flow downwards where it can be intercepted and harvested [39]; the texture and structure of the soil [40]; the availability status of soil nutrients, which is essential to improve the effects of water harvesting as it increases crop yields [41]; and the depth of the soil in the cultivated area [35]. Fiaz et al. [13] indicated that three common elements of the landscape should be considered in rainwater harvesting for its use in situ: the condition of the soil or landscape run-off, the elevation change that causes the water to flow, and a sufficient area of deep soil for collecting rainwater.

The use of rainwater harvesting systems has a series of advantages. Capturing water ensures part of the water demand for irrigation and alleviates the periods of scarcity due to droughts and dry seasons, thanks to storage [35,42]. Bruins et al. [43] estimated that, in arid regions where water is the only limiting factor to the expansion of arable land, an additional 3–5% of the surface area could be farmed using run-off for irrigation. Different experiences with these types of irrigation practices have given rise to increases in crop yields and water-use efficiency in different parts of the world, and their contribution to mitigating the impacts of climate change on agriculture [42,44–46]. Furthermore, certain practices are based on simple, low-cost techniques that require a low level of qualification [47,48]. An appropriate management of these types of systems is useful in processes for controlling erosion and preventing soil degradation [35,49], contributing to the development of agriculture and the conservation of resources in marginal areas [33,50]. Studies have been conducted to estimate the potential of these types of system for supplying water. Jaber and Mohsen [51] showed that the amount of water harvested in Jordan is 6×10^6 m^3 $year^{-1}$. Oweis and Hachum [39] estimated that between 30–50% of rainwater in the driest regions could be used for irrigation if the appropriate harvesting techniques will implemented. Walraevens et al. [52] researched the capacity of rainwater collection systems to recharge overexploited aquifers and their contribution to agriculture sustainability in the Abraha plain, Atsbaha, Ethiopia. Lebel et al. [53] assessed the rainwater collection systems for maize crops in sub-Saharan Africa as an adaptation strategy facing climate change. Amos et al. [54] reviewed the potential of collected rainwater from the roofs for urban agriculture. The work focuses on Australia and Kenya.

The main disadvantages of the different types of harvesting systems are that they depend on limited and uncertain precipitations; the catchment area is more efficient when it is free of vegetation, which may require a large amount of labour input; the systems could be damaged during storms and require regular maintenance; they require wide catchment areas that could be otherwise used for crops, except in the case of steep slopes; the systems only allow for low-density and low-yield crops compared with conventional irrigation systems; and the success of these systems depends on many factors, including climate, economic, sociocultural, or political factors [35,55,56].

The interest in the use of rainwater harvesting and conservation strategies has given rise to a significant increase in the number of studies on this research topic in recent years. However, to the best of our knowledge, there is no existing research that analyses these studies jointly and on a global level. The objective of this article is to study the dynamics of the research on RWHI in agriculture over the last 20 years. To do this, a qualitative systematic analysis and a quantitative bibliometric analysis were carried out. The results of this study are of interest for researchers in this field as they identify the most relevant driving agents, the most prominent lines of research, and the research needs that have yet to be covered.

2. Methodology

Similar to other review studies related to topics in the area of water for irrigation, the database Scopus was selected to obtain the sample of studies to be analysed [57–59]. The search parameters used were all of the frequently used terms related to rainwater, agriculture, and irrigation. Their selection was based on previous studies on the same subject [60,61]. These parameters were used in the search fields of title, keyword, and abstract. The study period selected was 1999 to 2018. The greatest development in this field of study took place during these years. Only documents until 2018 were included so that complete annual periods can be compared. Given that the results of a study are frequently published as conference papers, book chapters, and articles, in order to avoid duplications, only articles were included in the sample [62]. It is worth pointing out that different search queries can give rise to different results. The search for this study was carried out in January 2019. The final sample analysed was composed of 525 articles. In addition, a search of articles on Irrigation was also carried out with the same restrictions in place in order to analyse the relative importance of RWHI within this general theme.

After selecting the sample, the data were downloaded and processed using different tools. First, the data were refined to eliminate duplications, omissions, and errors, and search for incomplete information. The variables analysed were the number of articles, their year of publication, all of the authors of the articles, the institutions and countries of all of the authors, the subject area in which Scopus classifies the studies, the name of the journals in which they have been published, and the keywords. The different tools used for the processing and subsequent analysis of the data 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), which are commonly used for this type of studies [63]. Finally, a keyword analysis was used to extract the principal research trends and needs. Figure 1 shows the methodology followed in this study.

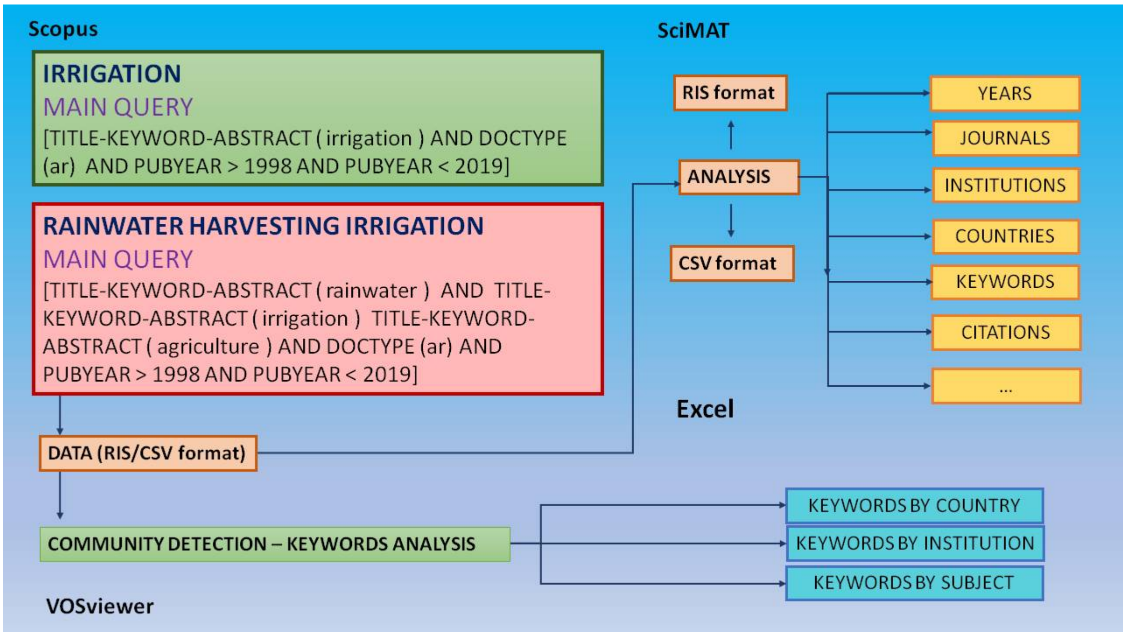

Figure 1. Summary of the methodology.

3. Results

3.1. Evolution of the General Characteristics of Research on Rainwater Harvesting Irrigation (RWHI)

Table 1 shows the evolution of the principal variables related to the research on rainwater harvesting irrigation (RWHI) in the period 1999–2018. The number of articles grew from two in 1999 to 57 in 2018. It is noteworthy that almost 50% of the articles in the sample were published in the period between 2014–2018. In order to contextualise this increase in articles on RWHI with the trend followed by the articles published on Irrigation, the annual percentage variation in the number of articles published in both lines of research was calculated, with the first year of the period analysed taken as a base (Figure 2). The number of articles on irrigation increased at an average annual rate of 0.82% throughout the period; meanwhile, the articles on RWHI grew by 2.31%. Therefore, it can be established that RWHI as a line of research is gaining relevance within irrigation research.

Table 1. Major characteristics of rainwater harvesting irrigation (RWHI) research.

Year	Articles	Authors	Journals	Countries	Citations	Average Citations [1]
1999	2	3	2	2	0	0.0
2000	7	18	7	6	5	0.6
2001	5	10	5	3	3	0.6
2002	4	13	4	6	13	1.2
2003	8	20	7	4	14	1.3
2004	12	29	10	10	14	1.3
2005	16	44	11	8	32	1.5
2006	25	67	15	15	42	1.6
2007	27	84	19	22	96	2.1
2008	12	39	11	8	99	2.7
2009	19	63	18	11	197	3.8
2010	30	103	22	22	224	4.4
2011	29	86	21	18	290	5.3
2012	40	109	24	21	392	6.0
2013	35	138	31	25	565	7.3
2014	44	159	36	27	564	8.1
2015	56	244	43	33	693	8.7
2016	45	181	37	37	818	9.8
2017	52	235	45	25	1037	10.9
2018	57	234	43	33	1229	12.1

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

The rest of the variables in Table 1 also reflect the dynamic nature of this line of research. The number of journals in which articles on RWHI have been published has increased from two in 1999 to 43 in 2018. The number of countries participating in studies on RWHI increased from two in 1999 to 33 in 2018. The average annual number of citations obtained for all of the studies published to date increased from 0.6 in 2000 to 12.1 in 2018.

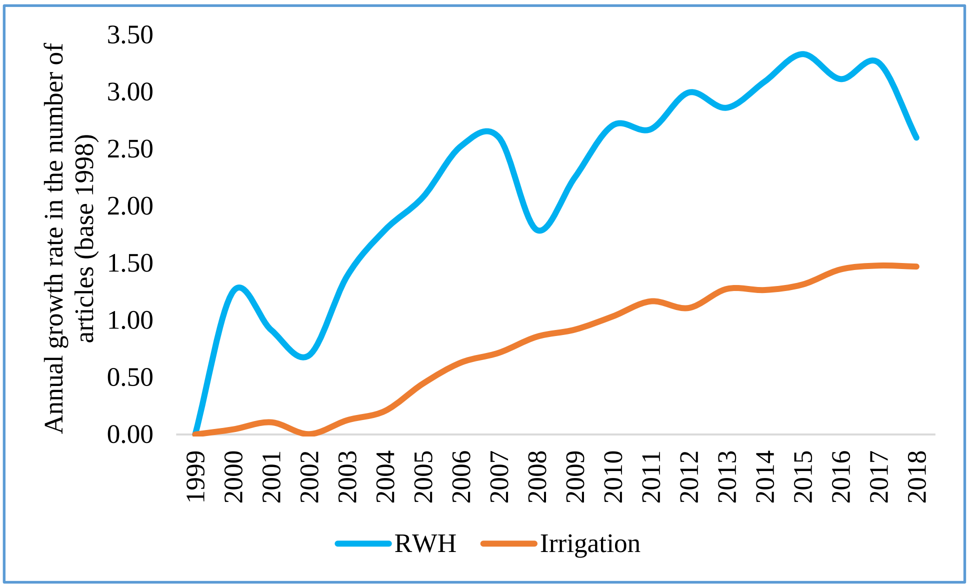

Figure 2. Comparative trends in rainwater harvesting irrigation (RWHI) and irrigation research.

3.2. Evolution of RWHI Research by Subject Area

The Scopus database classifies studies based on subject areas. This classification enables the different disciplines involved in RWHI research to be analysed. Figure 3 shows the evolution of the number of studies based on this classification. It should be taken into account that the same study may be classified in more than one category simultaneously. The category that accumulated the highest number of studies was *Environmental Sciences*, with 59.1% of the total sample. This is followed by *Agricultural and Biological Sciences* with 46.9%, *Earth and Planetary Sciences* with 22.5%, *Engineering* with 16.6%, *Social Sciences* with 15.8%, and *Energy* with 7.4%. Less than 5% of studies in the sample are classified in the rest of the categories. *Environmental Sciences* and *Agricultural and Biological Sciences* are the dominant categories throughout the whole period, and these disciplines are the main drivers of the research in this subject area. The low number of studies classified under the categories *Economy* and *Business, Management, and Accounting* is noteworthy. This highlights the lack of studies that conduct a cost–benefit analysis or address the profitability or economic feasibility of the implementation of rainwater harvesting systems for agricultural irrigation.

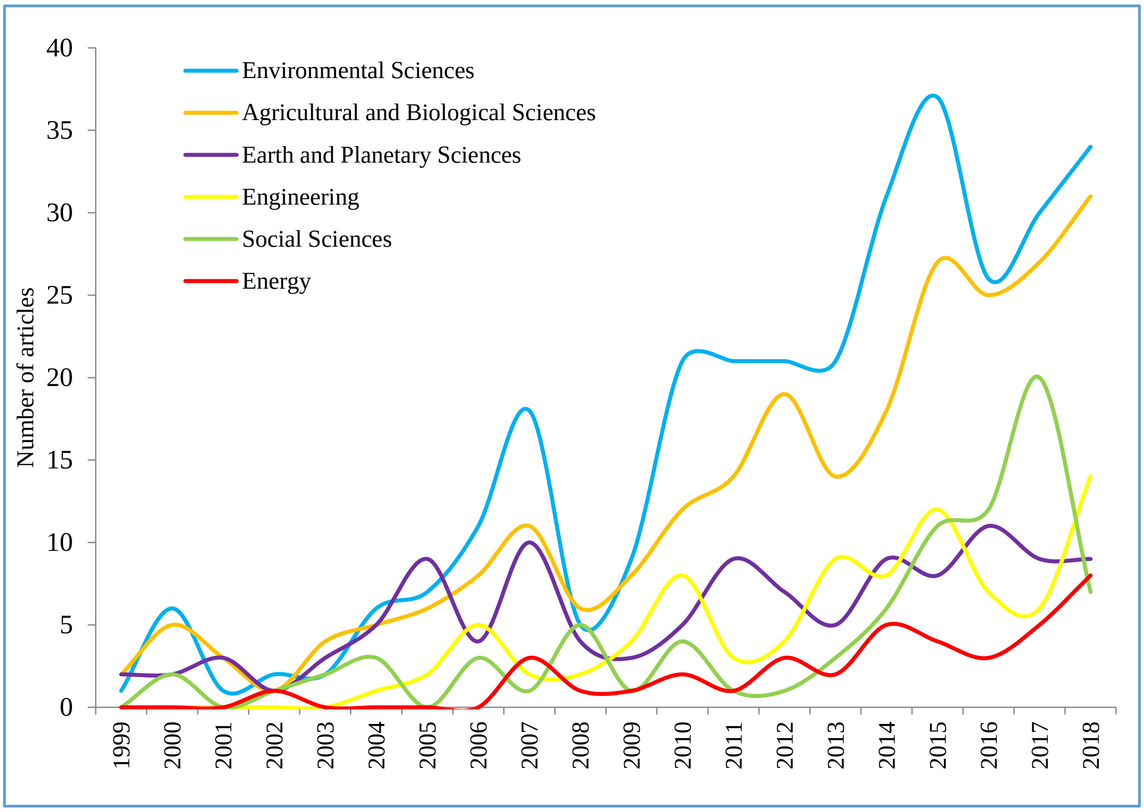

Figure 3. Comparative trends of subject categories related to RWHI research.

3.3. Most Relevant Journals in RWHI Research

Table 2 shows the journals that published the most articles on RWHI in the period 1999–2018. This group of journals accumulates more than 30% of the total number of articles in the sample and almost 50% of the total citations obtained by all the studies in the sample. Therefore, these journals constitute the central core of journals that promote RWHI research.

The journal with the highest number of articles published on RWHI is *Agricultural Water Management*, with a total of 43. Furthermore, this journal has the highest H index and the highest total number of citations in the group. Its average number of citations per article is 27.9, and its Scimago Journal Rank (SJR) factor is 1.272. The oldest article on the subject was also published by this journal in 1999. *Physics and Chemistry of the Earth* holds the second position with a total of 22 articles. This journal also holds the second position in terms of the number of citations per article and H index. Its average number of citations per article is 27.5, and its SJR factor is 0.621. *Irrigation and Drainage* holds the third position with a total of 17 articles. However, its average number of citations per article and its H index are the lowest. The journal with the highest average number of citations per article is *Resources, Conservation, and Recycling* with a total of 40.1. *Field Crops Research* is the journal with the highest SJR factor: 1.474. *Water* is the most recent newcomer, given that its first article on the subject was published in 2014.

Table 2. Main characteristics of the most active journals in RWHI research.

Journal	Articles	SJR [1]	H Index [2]	Country	Citation	Average Citation [3]	First Article	Last Article
Agricultural Water Management	43	1.272(Q1)	20	Netherlands	1201	27.9	1999	2018
Physics and Chemistry of the Earth	22	0.621(Q2)	15	UK	605	27.5	2003	2016
Irrigation and Drainage	17	0.342(Q2)	4	USA	50	2.9	2009	2017
Transactions of the Chinese Society of Agricultural Engineering	14	0.386(Q2)	6	China	97	6.9	2006	2017
Journal of Cleaner Production	13	1.467(Q1)	8	Netherlands	226	17.4	2011	2018
Water Resources Management	13	1.185(Q1)	9	Netherlands	209	16.1	2009	2018
Field Crops Research	11	1.474(Q1)	7	Netherlands	251	22.8	2003	2018
Water	11	0.637(Q1)	5	Switzerland	75	6.8	2014	2018
Resources, Conservation and Recycling	10	1.462(Q1)	8	Netherlands	400	40.1	2007	2018
Water Science and Technology Water Supply	9	0.258(Q3)	4	UK	40	4.4	2012	2018

[1] Scimago Journal Rank 2017; [2] Only sample documents; [3] Total number of citations divided by the total number of articles. UK: United Kingdom, USA: United States.

3.4. Most Relevant Countries in RWHI Research

Table 3 shows the countries that published the most articles on RWHI between 1999–2018. India holds the first position with a total of 112 articles. This is followed by China with 105 articles, the United States (USA) with 55 articles, South Africa with 49 articles, and the Netherlands with 30 articles. The rest of the countries published less than 5% of the total sample analysed. In order to contextualise the relevance of each country, the number of articles per million inhabitants was calculated. Based on this new variable, the country holding the first position is the Netherlands with 1.751 articles, followed by South Africa with 0.864, Australia with 0.705, and Canada with 0.552. With respect to the average number of citations obtained per article, the most noteworthy countries are Australia with 21.7, Canada with 20.1, the Netherlands with 18.9, and Germany with 17.7.

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

Country	Articles	Average per Capita Articles [1]	Citations	Average Citations [2]	H Index [3]	First Article	Last Article
India	112	0.085	1243	11.1	17	2000	2018
China	105	0.076	1436	13.7	22	2000	2018
USA	55	0.170	898	16.3	16	2000	2018
South Africa	49	0.864	550	11.2	15	2005	2018
Netherlands	30	1.751	567	18.9	16	2005	2018
Germany	25	0.303	442	17.7	10	2006	2018
UK	25	0.381	253	10.1	11	2002	2017
Canada	20	0.552	400	20.1	8	2004	2017
Kenya	19	0.382	300	15.8	9	2003	2018
Australia	17	0.702	369	21.7	9	2010	2018

[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 collaboration networks established between the different countries are shown in Table 4. The country with the highest percentage of studies carried out through international collaboration is the Netherlands with 93.3%. This is followed by Canada with 85.1% and Australia with 82.3%. The countries with the lowest percentage of international collaboration are India with 20.5%, South Africa with 24.5%, and China with 29.5%. The country with the largest collaboration networks is the United States (USA) with a total of 19. This is followed by the Netherlands, Germany, and the United Kingdom (UK) with 17 each, India with 15, and China with 14. The table also shows the five main collaborators for each of the countries that published the most articles on RWHI. In all cases, the presence of African and Asian countries is noteworthy. These countries are usually the object of priority studies. The average number of citations of the studies carried out through international collaboration is higher than that of the studies carried out without collaboration, in all the countries except for the Netherlands, the UK, and Australia.

Table 4. International collaboration of the most active countries in RWHI research.

Country	Percentage of Collaboration [1]	Number of Collaborators	Main Collaborators	Average Citations	
				Collaboration [2]	Non-Collaboration [3]
India	20.54	15	USA, UK, Australia, China, Egypt	27.0	7.0
China	29.52	14	Canada, Australia, Kenya, Pakistan, USA	18.1	11.8
USA	45.45	19	India, Canada, China, Germany, Tanzania	20.7	12.7
South Africa	24.49	8	Netherlands, Zimbabwe, Sweden, Malaysia, Indonesia	15.8	9.8
Netherlands	93.33	17	Sweden, Ethiopia, South Africa, Zimbabwe, Kenya	18.4	26.0
Germany	72.00	17	Tanzania, USA, Mexico, Brazil, Colombia	18.1	16.6
UK	60.00	17	India, Netherlands, Bahrain, Belgium, Cameroon	9.5	11.0
Canada	85.10	11	China, USA, Saudi Arabia, Switzerland, Egypt	23.2	2.0
Kenya	63.16	9	China, Netherlands, Australia, Sweden, Rwanda	18.0	12.0
Australia	82.35	13	China, India, Kenya, Malaysia, Sri Lanka	18.1	38.7

[1] Number of articles made 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 by articles not made through international collaboration divided by the number of articles.

Figure 4 shows the collaborative relationships established between the different countries. On the resulting map, the size of the circle varies depending on the number of articles of each country; the lines represent the links established between countries, where the thickness depends on the number of collaborations, and the different colours identify the main collaboration groups. Three clusters can be distinguished. The green cluster is led by India, China, and the USA in terms of the number of articles. This cluster includes Canada and the UK and some of their principal partners, such as Egypt, Pakistan, and Saudi Arabia. The blue cluster is led by South Africa. It includes countries such as the Netherlands, Kenya, and Australia as well as Thailand, Sri Lanka, and Sweden. Finally, the red cluster is led by Germany, which has ties with countries such as Spain, Belgium, Italy, Brazil, Tanzania, and Japan.

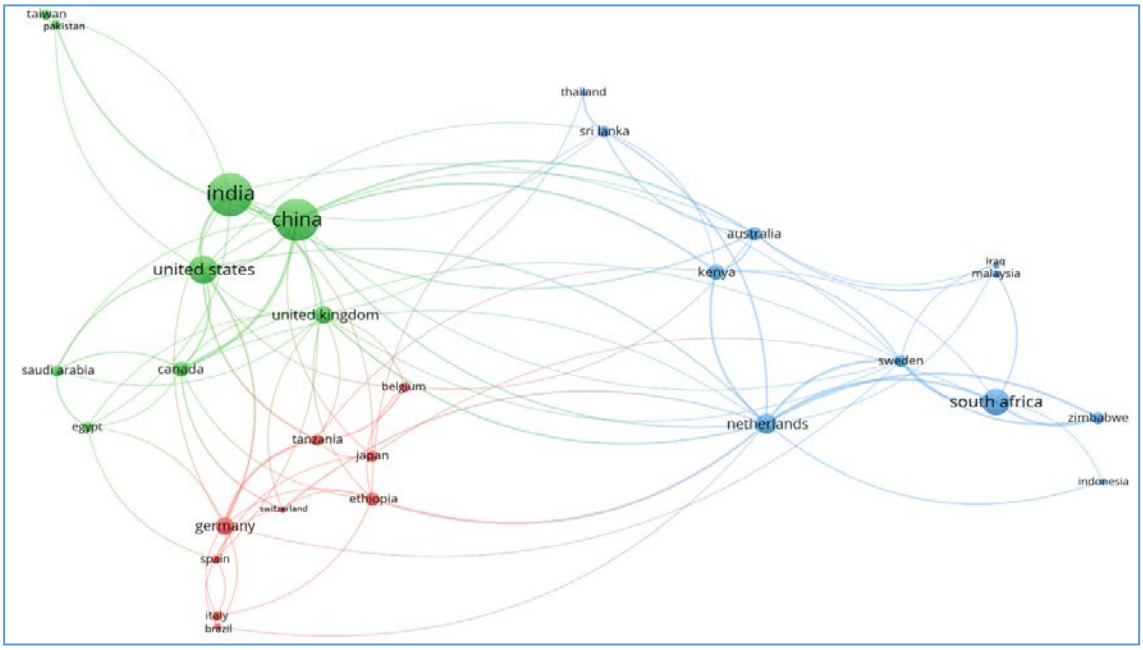

Figure 4. Main relationships between countries in RWHI research.

A keywords analysis was used to detect the preferences in the research conducted by the countries included in Table 4 (Table 5). A group of terms that make up a general line, from which the different specific topics are derived, was identified. The research of the group of developed countries is strongly conditioned by the collaborative relationships established for undertaking studies. Therefore, most of the studies analyse regions with arid or semiarid climates in countries with emerging or under-developed economies, such as China, India, Brazil or countries in sub-Saharan Africa. The countries with the highest level of concern for food safety and the availability of water for human consumption are India, the United States (USA), Germany, Canada, and Australia. India and Australia face the most serious problems of deteriorating underground water bodies in regions where these types of resources are practically the only sources. Therefore, for these two countries, the management, recharging, and recovery of these water bodies is a priority subject in which RWHI can contribute positively. In developed countries and in China, the development and innovation of systems for harvesting rainwater and highly efficient irrigation systems is remarkable.

In the case of India, the combined use of hydrological models and remote sensing can be highlighted. Chemistry is one of the dominant disciplines in the studies produced by this country, particularly in the monitoring of the composition of degraded water (both ground and surface) and the conservation of soils with a high level of salinity due to irrigation with brackish water. Economic analyses are also frequent in Indian studies. China stands out for experimental studies and analyses of different types of irrigation techniques, agricultural practices, and crops. The studies conducted in the USA analyse different aspects related to storm water and the economic and financial issues derived from irrigation projects. In the case of South Africa, priority topics include water–soil interaction processes, such as levels of evaporation and infiltration, and agriculture adaptation and modernisation processes, such as the adoption of machinery. Meanwhile, Germany is the country with the highest number of articles on climate models. The dominant topics of the studies carried out by the UK and Kenya are the different aspects of sustainability.

Table 5. Main keywords for the most active countries in RWHI research.

Country	Keywords
India	groundwater resources, rice, supplemental irrigation, surface waters, remote sensing, water quality, water storage, economic analysis, hydrological modelling, chemistry, drinking water, soil conservation
China	water-use efficiency, mulching, soil water, rice, maize, triticum aestivum, efficiency, furrow irrigation, irrigation system, plastic films, water storage, rainwater harvesting system
USA	potable water, irrigation system, water demand, water planning, water quality, cost–benefit analysis, storm water management, water budget, water storage, water-use efficiency, hydrological modelling, investments
South Africa	tillage, agricultural machinery, infiltration, water availability, evaporation, precipitation intensity, dry land farming, rainfall run-off modelling, soil water, water-use efficiency, adaptive management
Netherlands	water availability, irrigation system, groundwater, cost–benefit analysis, maize, water balance, agricultural machinery, economic analysis, rainwater harvesting system, smallholder, soil water, supplemental irrigation
Germany	food security, drinking water, irrigation system, water use, participatory approach, surface run-off, water demand, water scarcity, agricultural production, biomass, climate models, crop water productivity
UK	desalination, developing countries, environmental protection, sustainability, water planning, water use, adaptive management, alternative agriculture, alternative water sources, biodiversity, conservation of natural resources, decision making
Canada	mulching, water use, water-use efficiency, ecology, food security, furrow irrigation, irrigation system, maize, soil conservation, water recycling, water scarcity, biological materials
Kenya	agricultural production, ecosystems, sustainability, cost–benefit analysis, technology, adaptive management, agricultural land, agro-ecological zone, economic analysis, environmental impact, evaporation, farmers attitude
Australia	water management, tanks, roofs, controlled study, water budget, groundwater/recharging, reliability, rural area, sustainable development, agricultural management, cost–benefit analysis, drinking water

3.5. Most Relevant Institutions in RWHI Research

Table 6 shows the 10 institutions that published the most articles on RWHI between 1999–2018. These institutions account for more than 30% of the studies in the sample and six of them are in China. The institution with the highest number of articles is Northwest A&F University with a total of 29. This is followed by the University of the Free State with 27, the Chinese Academy of Sciences with 26, and Lanzhou University with 19. The highest average number of citations per article corresponds to the Chinese Academy of Sciences with 24.5, followed by Lanzhou University with 24.4, and Delft University of Technology of the Netherlands with 24.1.

A very high percentage of the studies carried out by Dutch institutions are based on international collaboration. In fact, 100% of the articles published by Delft University of Technology were done so through international collaboration, as were 90% of the articles published by Delft Institute for Water Education. These institutions are followed by Lanzhou University with 47.4% and Gansu Agricultural University with 46.2%. Less than 40% of the articles published by the rest of the institutions were produced through international collaboration. In all of the institutions, the studies conducted through international collaboration obtained a higher number of citations, except in the case of Northwest A&F University, Lanzhou University, Gansu Agricultural University and Delft Institute for Water Education.

Table 6. Main characteristics of the most active institutions in RWHI research.

Institution	Country	Articles	Citations	Average Citations [1]	H Index [2]	Percentage of Collaboration [3]	Average Citations	
							Collaboration [4]	Non Collaboration [5]
Northwest A&F University	China	29	325	11.2	11	24.14	8.7	12.0
University of the Free State	South Africa	27	158	5.9	8	22.22	6.5	5.7
Chinese Academy of Sciences	China	26	638	24.5	9	34.62	36.3	18.3
Lanzhou University	China	19	464	24.4	8	47.37	12.8	34.9
Gansu Agricultural University	China	13	264	20.3	7	46.15	16.3	23.7
Delft University of Technology	Netherlands	12	288	24.1	10	100.00	24.0	0.0
Ministry of Agriculture of the People's Republic of China	China	12	89	7.4	6	25.00	13.3	5.4
Ministry of Education China	China	11	103	9.4	6	18.18	33.0	4.1
Indian Institute of Technology Kharagpur	India	11	149	13.5	7	36.36	15.3	12.6
Delft Institute for Water Education	Netherlands	11	234	21.3	9	90.91	20.2	32.0

[1] Total number of citations divided by the total number of articles; [2] Only sample documents; [3] Number of articles made 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 by articles not made through international collaboration divided by the number of articles.

3.6. Most Relevant Authors in RWHI Research

Table 7 shows the authors with the highest number of articles published on RWHI between 1999–2018. In first place is Leon Daniel Van Rensburg with a total of 15 articles. This author accumulates a total of 85 citations, which came to an average of 5.7 citations per article and an H index of 5. The author has undertaken some field research on aspects related to rainwater collection, such as the rainfall characterization, implications for crops, and the management of hydric resources in the basin. Furthermore, he has carried out a review work on water available to plants regarding water-use efficiency under irrigated and dryland conditions [64]. His investigations take place in South Africa. His most recognized work assesses the effects of tillage on run-off from a bare clayey soil on a semiarid ecotope in the limpopo province of South Africa [65]. In second place is Zhikuan Jia with 13 articles. This researcher has 144 citations, which came to an average of 11.1 citations per article and an H index of 7. These author's works are devoted to agronomics. All the studies were empirical and took place in China. His investigation aimed at analyzing the impacts of rainwater use on the land and on some crop types. His most relevant paper studied the effects of rainfall harvesting and mulching technologies on soil water, temperature, and maize yield in the Loess Plateau region of China [66]. In third place is Malcolm Hensley with 12 articles. This author accumulated a total of 63 citations, which came to an average of 5.3 citations per article and an H index of 5. Hensley worked on run-off processes and the collection on the field. Among his publications, we can only find a review work [64]. His field research has been developed in South Africa and in Ethiopia. His most relevant work assessed the collection of rainwater to broaden agriculture surfaces along the river Basin Modder in South Africa [67].

The researcher with the highest number of accumulated citations is Johan Rockström, with a total of 319. This author also has the highest average number of citations per article with 39.6 and the highest H index of 8. This author's research includes empirical studies in sub-Saharan Africa, mainly in Kenya, Zimbabwe and Tanzania; no review works were included. Rockström, in his most quoted work, defended measures to increase water productivity such as rainwater collection, complementary watering, vapor shift, and treating soils and nutrients [68]. Savenije is the author with the second highest average number of citations per article with 26.6 citations, followed by Xiaolong Ren with 11.7. Johan Rockström, together with Hubert H.G. Savenije, are the most veteran authors of the group, given that they co-authored an article on RWHI published in 2005. Shahzad M. Ali is a newcomer to this line of research, publishing his first article on RWHI in 2016. The research conducted by Savenije studied agriculture in Sub-Saharan Africa. His most relevant article is devoted to an agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation [69]. On the other side, Ren worked on the impact assessment of systems such as microcatchment, ridge, or furrow rainwater harvesting on crops. His most cited publication compares the two latter systems of maize crops [70].

Table 7. Major characteristics of the most active authors in RWHI research.

Author	Articles	Citations	Average Citations [1]	H Index [2]	Country	Affiliation [3]	First Article	Last Article
Van Rensburg, Leon Daniel	15	85	5.7	5	South Africa	University of the Free State	2006	2016
Jia, Zhikuan	13	144	11.1	7	China	Northwest A&F University	2010	2018
Hensley, Malcolm	12	63	5.3	5	South Africa	University of the Free State	2006	2012
Ren, Xiaolong	11	89	8.1	6	China	Northwest A&F University	2010	2018
Zhang, Peng	9	68	7.6	5	China	Northwest A&F University	2015	2018
Rockström, Johan	8	319	39.6	8	Sweden	Stockholm Resilience Centre	2005	2011
Savenije, Hubert H.G.	8	213	26.6	7	Netherlands	Delft University of Technology	2005	2013
Ali, Shahzad M.	7	29	4.1	4	China	Qingdao University	2016	2018
Mo, Fei	7	31	4.4	4	China	Lanzhou University	2011	2018
Chen, Xiaoli	7	82	11.7	5	China	Northwest A&F University	2008	2018
Xiong, Youcai	7	54	7.7	5	China	Lanzhou University	2007	2018

[1] Total number of citations divided by the total number of articles; [2] Only sample documents; [3] Last verified affiliation.

Figure 5 shows a graphic representation of the collaborative relationships established between the different authors participating in the publication of articles on RWHI. The central part of the graph shows the group of authors with at least three publications where a considerable number of clusters represented in different colours can be observed. Due to the large number of authors, the labels with the names of each of them cannot be identified. Therefore, the clusters including the authors in the table have been magnified. Among the group of most prolific authors on RWHI, we can find some sub-groups sharing co-authorship in most articles. In this sense, Van Rensburg (green cluster) shared six articles with Hensley; both come from the University of the Free State. Out of the 13 publications by Jia (blue cluster), in 11 works, Ren was the co-author, Zhang was the co-author of nine, Ali was the co-author of six, and Chen was the co-author of four. In the purple cluster, we find Rockström and Savenije, who shared six articles.

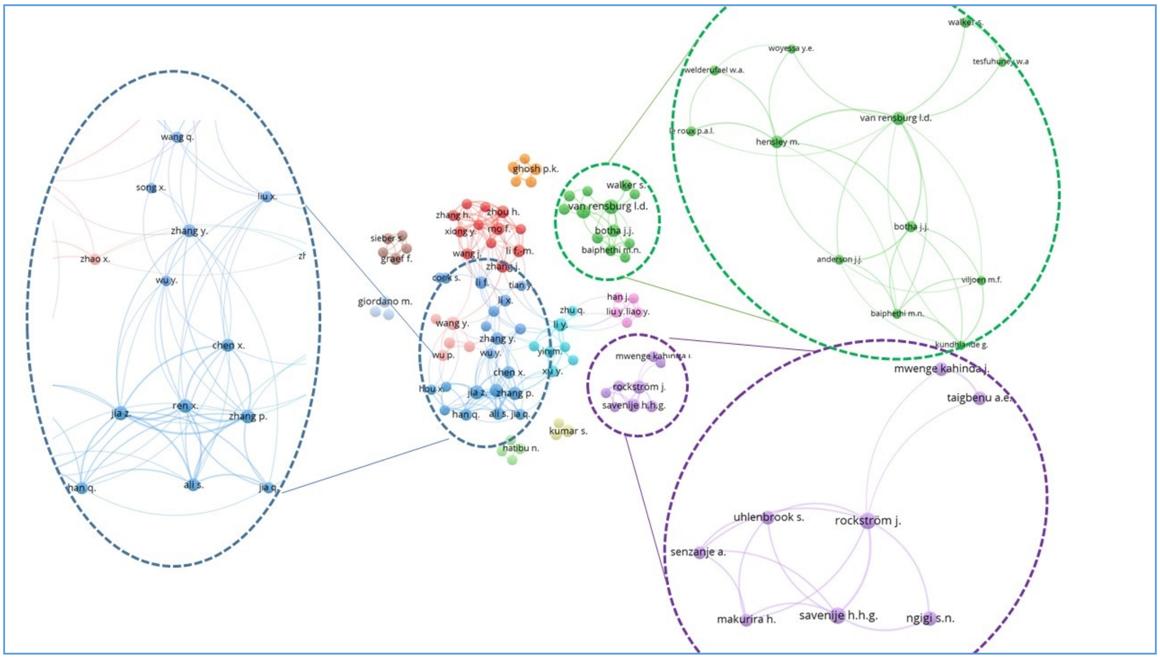

Figure 5. Main relationships between authors in RWHI research.

3.7. Issues to be Analysed in RWHI Research

Based on the analysis of keywords, the most relevant issues in RWHI research were determined. The preferred subject areas include food production for feeding an ever-increasing population; the use of unconventional water resources and their implications on economic, social, and environmental levels; the improvement of efficiency in the use of water resources, which are becoming increasingly scarce and more highly valued; the development of irrigation systems that are capable of improving efficiency and combining the use of different water sources; and the improvement and conservation of natural resources for future generations, particularly underground water bodies, which are the most deteriorated due to overexploitation in arid and semiarid environments, and soil, which is affected by salinisation processes.

Great efforts have been made in the research in these fields as well as for other topics. However, greater knowledge is still needed of different issues related to rainwater harvesting for its use in agriculture. The potential of this type of system for the supply of water for irrigation is absolutely dependent on the characteristics of the area of study: location, climate, orography, type of crop, type of irrigation system, and type of productive system, etc. [13,14,33,35]. On the other hand, the success of the implementation of rainwater harvesting systems largely depends on socioeconomic characteristics such as the tenancy regime of the farms, the harvesting and storage capacity of the system, the productivity of the water, the availability of alternative water sources, the cost–benefit ratio, the types of technology and infrastructures available, the inclination of the farmers to adopt new technologies, administrative support or obstacles, etc. [15,24,36,71,72]. It should be remembered that the need for rainwater harvesting systems for use in agriculture is derived from the lack of synchrony between the rainy season and the irrigation needs of crops [15,21,33,39,46]. This is not just the case in arid or semiarid climates. Therefore, there is a need for case studies that evaluate the potential of rainwater harvesting systems to cover the water needs of different crops in different possible contexts. Furthermore, these studies should address the wide range of circumstances that exist in different agricultural regions with water scarcity problems [11,35,38,41].

One major issue is to analyse the ability of this type of system to cover irrigation needs in regions where the fundamental resource is groundwater [15,17,34–36]. In many regions with arid and semiarid climates, agriculture has developed enormously thanks to the extraction of water from aquifers [21,37,45,73]. The continued overexploitation of these water bodies has given rise to their deterioration, salinisation processes, the intrusion of seawater, pollution by nitrates, etc. [4,21]. The use of alternative water resources for irrigation could reduce the consumption of these types of water sources and contribute to both environmental and agricultural sustainability [74,75]. In many regions, particularly in the Near East, the use of water derived from alternative sources, such as the reuse of inadequately treated wastewater, has given rise to soil salinity processes that have placed the continuity of agriculture at great risk [76]. Supplementary irrigation with harvested rainwater can contribute to mitigating the deterioration of soil.

Rainwater storage capacity for future use is a particularly relevant issue [15,32,35,60]. Being able to store water during periods of abundance for moments when there is scarcity is one of the fundamental advantages of this type of system. To do this, the systems need to be able to store as much rainfall as possible at the lowest possible cost for farmers and governments. In some regions, such as the Mediterranean basin, the occurrence of extreme phenomena that give rise to overflowing rivers and the flooding of towns and crop fields is becoming more frequent [19,20]. The development of infrastructures that are able to channel and store all of this water will also help control its adverse effects. The combination of remote sensing techniques, geographic information systems, and climate forecasting models, together with economic and financial feasibility studies, is necessary to analyse areas that are eligible for the development of large capacity infrastructure projects [6,59,77].

The majority of studies focus on countries with emerging or underdeveloped economies and small-scale, rain-fed subsistence agriculture as the main object of study. Developed countries have expanded super-intensive systems that have a large production capacity throughout the year but consume a large amount of water [4,26]. Many of these agricultural regions use underground water resources that are currently overexploited, such as the northern Mediterranean basin, California, or Australia [30,31,57]. Greenhouse agriculture, which is representative of this type of system, has a huge potential to harvest rainwater with a low level of investment. However, the level of adoption of these systems is very low [26,31]. Therefore, a greater knowledge is needed of the factors that determine the adoption of RWH systems by farmers and their storage potential and economic and financial feasibility [23,71,72,78].

Finally, rainwater harvesting systems for irrigation have the potential to help combat climate change. This is because, in regions where there is a scarcity of water for agricultural consumption, systems for the reuse of urban and industrial water and seawater desalination systems are proliferating [28,50,51,61,79]. These other systems make intensive use of energy for their processes. Harvesting rainwater does not use processes with high energy requirements and can cover part of the irrigation needs that are currently satisfied by desalinated or reused water [26,33], with consequent energy saving. Therefore, there is a need for studies that assess the potential of these types of systems to save water derived from energy intensive sources, and therefore their potential to contribute to the fight against global climate change.

4. Conclusions

The study of rainwater harvesting for agricultural irrigation has become a line of research with increasing relevance within irrigation research. This line of research is partly driven by rainwater harvesting for irrigation having strong potential as a source of supplementary water for the sustainability of agriculture, within a context in which the supply of food is a challenge for today's society. Furthermore, the correct use of this resource will contribute to restoring deteriorated aquatic ecosystems, particularly overexploited aquifers, and mitigating global climate change. On the other hand, rainwater redistribution systems can be used to extend the crop area in regions where water resources are the only limiting factor. However, it is necessary to increase research efforts in order to gain a greater knowledge of the ability of these systems to cover irrigation needs in different farming contexts, the factors that determine their adoption by farmers, the economic and financial feasibility of their implementation and their contribution to mitigating global climate change.

The results of this study will be of interest to researchers studying irrigation, given that rainwater harvesting for agricultural irrigation is becoming an increasingly relevant topic. Furthermore, these results can also be useful for governments and public policy makers when designing programmes and strategies aimed at contributing to the sustainability of agriculture.

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References

1. Hasan, M.K.; Desiere, S.; D'Haese, M.; Kumar, L. Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh. *Food Sec.* **2018**, *10*, 1073. [CrossRef]
2. Forouzani, M.; Karami, E. Agricultural water poverty index and sustainability. *Agron. Sustain. Dev.* **2011**, *31*, 415–432. [CrossRef]
3. Damkjaer, S.; Taylor, R. The measurement of water scarcity: Defining a meaningful indicator. *Ambio* **2017**, *46*, 513–531. [CrossRef]
4. Velasco-Muñoz, J.V.; Aznar-Sánchez, J.A.; Belmonte-Ureña, L.J.; Román-Sánchez, I.M. Sustainable water use in agriculture: a review of worldwide research. *Sustainability* **2018**, *10*, 1084. [CrossRef]
5. Adeyemi, O.; Grove, I.; Peets, S.; Norton, T. Advanced monitoring and management systems for improving sustainability in precision irrigation. *Sustainability* **2017**, *9*, 353. [CrossRef]
6. Hedley, C.B.; Knox, J.W.; Raine, S.R.; Smith, R. Water: Advanced irrigation technologies. In *Encyclopedia of Agriculture and Food Systems*, 2nd ed.; Elsevier (Academic Press): San Diego, CA, USA, 2014; pp. 378–406, ISBN 978-0-444-52512-3.
7. Zhang, Y.; Zhang, Y.; Shi, K.; Yao, X. Research development, current hotspots, and future directions of water research based on MODIS images: A critical review with a bibliometric analysis. *Environ. Sci. Pollut. Res. Int.* **2017**, *24*, 15226–15239. [CrossRef]
8. Gago, J.; Douthe, C.; Coopman, R.E.; Gallego, P.P.; Ribas-Carbo, M.; Flexas, J.; Escalona, J.; Medrano, H. UAVs challenge to assess water stress for sustainable agriculture. *Agric. Water Manag.* **2015**, *153*, 9–19. [CrossRef]
9. Wu, W.; Ma, B. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. *Sci. Total Environ.* **2015**, *512–513*, 415–427. [CrossRef]
10. De Fraiture, C.; Wichelns, D. Satisfying future water demands for agriculture. *Agric. Water Manag.* **2010**, *97*, 502–511. [CrossRef]
11. Fischer, G.; Tubiello, F.N.; van Velthuizen, H.; Wiberg, D.A. Climate change impacts on irrigation water requirements: Effects of mitigation, 1990–2080. *Technol. Forecast. Soc.* **2007**, *74*, 1083–1107. [CrossRef]
12. Liu, J.; Wang, Y.; Yu, Z.; Cao, X.; Tian, L.; Sun, S.; Wu, P. A comprehensive analysis of blue water scarcity from the production, consumption, and water transfer perspectives. *Ecol. Indic.* **2017**, *72*, 870–880. [CrossRef]
13. Fiaz, S.; Noor, M.A.; Aldosri, F.A. Achieving food security in the Kingdom of Saudi Arabia through innovation: Potential role of agricultural extensión. *J. Saudi Soc. Agric. Sci.* **2018**, *17*, 365–375. [CrossRef]
14. Zheng, H.; Gao, J.; Xie, G.; Jin, Y.; Zhang, B. Identifying important ecological areas for potential rainwater harvesting in the semi-arid area of Chifeng, China. *Plos One* **2018**, *13*, e0201132. [CrossRef] [PubMed]
15. Kiggundu, N.; Wanyama, J.; Mfitumukiza, D.; Twinomuhangi, R.; Barasa, B.; Katimbo, A.; Kyazze, F.B. Rainwater harvesting knowledge and practice for agricultural production in a changing climate: A review from Uganda's perspective. *Agric. Eng. Int.* **2018**, *20*, 19–36.
16. Uwizeyimana, D.; Mureithi, S.M.; Karuku, G.; Kironchi, G. Effect of water conservation measures on soil moisture and maize yield under drought prone agro-ecological zones in Rwanda. *Int. Soil Water Conserv. Res.* **2018**, *6*, 214–221. [CrossRef]
17. Wu, R.S.; Molina, G.L.L.; Hussain, F. Optimal Sites Identification for Rainwater Harvesting in Northeastern Guatemala by Analytical Hierarchy Process. *Water Resour. Manag.* **2018**, *32*, 4139. [CrossRef]

18. Water and Environment Sector and Performance Report 2016 (MWE 2016). Available online: http://envalert.org/wp-content/uploads2016/09/SPR-2016_final.pdf (accessed on 18 March 2019).
19. IPCC. *Climate Change, 2013—The Physical Science Basis. In Proceedings of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Stockholm, Sweden, September 2013*; Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA.
20. Hoegh-Guldberg, O.; Jacob, D.; Taylor, M.; Bindi, M.; Brown, S.; Camilloni, I.; Diedhiou, A.; Djalante, R.; Ebi, K.L.; Engelbrecht, F.; et al. 2018: Impacts of 1.5 °C Global Warming on Natural and Human Systems. In *Global Warming of 1.5 °C*; An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty; Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., et al., Eds.; IPCC: Geneva, Switzerland, 2018.
21. Aznar-Sánchez, J.A.; Velasco-Muñoz, J.F.; Belmonte-Ureña, L.J.; Manzano-Agugliaro, F. The worldwide research trends on water ecosystem services. *Ecol. Indic.* **2019**, *99*, 310–323. [CrossRef]
22. Kihila, J.M. Indigenous coping and adaptation strategies to climate change of local communities in Tanzania: A review. *Clim. Dev.* **2018**, *10*, 406–416. [CrossRef]
23. Hajani, E.; Rahman, A. Characterizing changes in rainfall: A case study for New South Wales, Australia. *Int. J. Climatol.* **2018**, *38*, 1452–1462. [CrossRef]
24. Urama, K.C.; Ozor, N. Impacts of climate change on water resources in Africa: The role of adaptation. *Afr. Technol. Policy Stud. Network* **2010**, *29*, 1–29. [CrossRef]
25. Mango, N.; Makate, C.; Tamene, L.; Mponela, P.; Ndengu, G. Adoption of Small-Scale Irrigation Farming as a Climate-Smart Agriculture Practice and Its Influence on Household Income in the Chinyanja Triangle, Southern Africa. *Land* **2018**, *7*, 49. [CrossRef]
26. Alamdari, N.; Sample, D.J.; Liu, J.; Ross, A. Assessing climate change impacts on the reliability of rainwater harvesting systems. *Resour. Conserv. Recycl.* **2018**, *132*, 178–189. [CrossRef]
27. Singh, A. Conjunctive use of water resources for sustainable irrigated agriculture. *J. Hydrol.* **2014**, *519*, 1688–1697. [CrossRef]
28. Aznar-Sánchez, J.A.; Belmonte-Ureña, L.J.; Velasco-Muñoz, J.V.; Valera, D.L. Aquifer Sustainability and the Use of Desalinated Seawater for Greenhouse Irrigation in the Campo de Níjar, Southeast Spain. *Int. J. Environ. Res. Public Health* **2019**, *16*, 898. [CrossRef] [PubMed]
29. Melo-Zurita, M.L.; Thomsen, D.C.; Holbrook, N.J.; Smith, T.F.; Lyth, A.; Munro, P.G.; de Bruin, A.; Seddaiu, G.; Roggero, P.P.; Baird, J.; et al. Global water governance and climate change: Identifying innovative arrangements for adaptive transformation. *Water* **2018**, *10*, 29. [CrossRef]
30. Jodar-Abellan, A.; Fernández-Aracil, P.; Melgarejo-Moreno, J. Assessing Water Shortage through a Balance Model among Transfers, Groundwater, Desalination, Wastewater Reuse, and Water Demands (SE Spain). *Water* **2019**, *11*, 1009. [CrossRef]
31. Aznar-Sánchez, J.A.; Belmonte-Ureña, L.J.; Valera, D.L. Perceptions and Acceptance of Desalinated Seawater for Irrigation: A Case Study in the Níjar District (Southeast Spain). *Water* **2017**, *9*, 408. [CrossRef]
32. Yosef, B.A.; Asmamaw, D.K. Rainwater harvesting: An option for dry land agriculture in arid and semi-arid Ethiopia. *Int. J. Water Resour. Environ. Eng.* **2015**, *7*, 17–28. [CrossRef]
33. Irshad, M.; Inoue, M.; Ashraf, M.; Al-Busaidi, A. The Management Options of Water for the Development of Agriculture in Dry Areas. *J. Appl. Sci.* **2007**, *7*, 1551–1557. [CrossRef]
34. Leong, J.Y.C.; Chong, M.N.; Poh, P.E.; Vieritz, A.; Talei, A.; Chow, M.F. Quantification of mains water savings from decentralised rainwater, greywater, and hybrid rainwater-greywater systems in tropical climatic conditions. *J. Clean Prod.* **2018**, *176*, 946–958. [CrossRef]
35. Qadir, M.; Sharma, B.R.; Bruggeman, A.; Choukr-Allah, R.; Karajeh, F. Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. *Agric. Water Manag.* **2007**, *87*, 2–22. [CrossRef]
36. Baguma, D.; Loiskandl, W. Rainwater harvesting technologies and practises in rural Uganda: a case study. *Mitig. Adapt. Strateg. Glob. Chang.* **2010**, *15*, 355–369. [CrossRef]

37. Biazin, B.; Sterk, G.; Temesgen, M.; Abdulkedir, A.; Stroosnijder, L. Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa–a review. *Phys. Chem. Earth, Parts A/B/C* **2012**, *47*, 139–151. [CrossRef]
38. Boers, T.M.; Ben-Asher, J. A review of rainwater harvesting. *Agric. Water Manag.* **1982**, *5*, 145–158. [CrossRef]
39. Oweis, T.Y.; Hachum, A. *Improving Water Productivity in the Dry Areas of West Asia and North Africa*; Kijne, J.W., Barker, R., Molden, D., Eds.; Water Productivity in Agriculture: Limits Opportunities for Improvement, CABI Publishing: Wallingford, UK, 2003; pp. 179–198.
40. Tabor, J.A. Improving crop yields in the Sahel by means of water-harvesting. *J. Arid. Environ.* **1995**, *30*, 83–106. [CrossRef]
41. Rockström, J.; Falkenmark, M. Semiarid crop production from a hydrological perspective: Gap between potential and actual yields. *Crit. Rev. Plant Sci.* **2000**, *19*, 319–346. [CrossRef]
42. Bafdal, N.; Dwiratna, S. Water Harvesting System as an Alternative Appropriate Technology to Supply Irrigation on Red Oval Cherry Tomato Production. *Int. J. Adv. Sci. Eng. Inf. Technol.* **2018**, *8*, 561–566. [CrossRef]
43. Bruins, H.J.; Evenari, M.; Nessler, U. Rainwater-harvesting agriculture for food production in arid zones: The challenge of the African famine. *Appl. Geogra.* **1986**, *6*, 13–32. [CrossRef]
44. Pandey, D.N.; Gupta, A.K.; Anderson, D.M. Rainwater harvesting as an adaptation to climate change. *Curr. Sci.* **2003**, *85*, 46–59.
45. Yin, M.; Li, Y.; Xu, Y.; Zhou, C. Effects of mulches on water use in a winter wheat/summer maize rotation system in Loess Plateau, China. *J. Arid Land* **2018**, *10*, 277. [CrossRef]
46. Saoub, H.M.; Al-Tabini, R.; Al-Khalidi, K.; Ayad, J.Y. Effect of Three Water Harvesting Techniques on Forage Shrub and Natural Vegetation in the Badia of Jordan. *Int. J. Bot.* **2011**, *7*, 230–236. [CrossRef]
47. Rockström, J. Water resources management in smallholder farms in eastern and southern Africa: An overview. *Phys. Chem. Earth Pt B-Hydrol. Oceans Atmos.* **2000**, *25*, 275–283. [CrossRef]
48. Roman, D.; Braga, B.; Shetty, N.; Culligan, P. Design and Modeling of an Adaptively Controlled Rainwater Harvesting System. *Water* **2017**, *9*, 974. [CrossRef]
49. Karamage, F.; Zhang, C.; Fang, X.; Liu, T.; Ndayisaba, F.; Nahayo, L.; Kayiranga, A.; Nsengiyumva, J.B. Modeling Rainfall-Runoff Response to Land Use and Land Cover Change in Rwanda (1990–2016). *Water* **2017**, *9*, 147. [CrossRef]
50. Kumar, T.; Jhariya, D.C. Identification of rainwater harvesting sites using SCS-CN methodology, remote sensing and Geographical Information System techniques. *Geocarto Int.* **2017**, *32*, 1367–1388. [CrossRef]
51. Jaber, J.O.; Mohsen, M.S. Evaluation of non-conventional water resources supply in Jordan. *Desalination* **2001**, *136*, 83–92. [CrossRef]
52. Walraevens, K.; Gebreyohannes-Tewolde, T.; Amare, K.; Hussein, A.; Berhane, G.; Baert, R.; Ronsse, S.; Kebede, S.; Van Hulle, L.; Deckers, J.; et al. Water Balance Components for Sustainability Assessment of Groundwater-Dependent Agriculture: Example of the Mendae Plain (Tigray, Ethiopia). *Land Degrad. Dev.* **2015**, *26*, 725–736. [CrossRef]
53. Lebel, S.; Fleskens, L.; Forster, P.M.; Jackson, L.S.; Lorenz, S. Evaluation of In Situ Rainwater Harvesting as an Adaptation Strategy to Climate Change for Maize Production in Rainfed Africa. *Water Resour. Manag.* **2015**, *29*, 4803. [CrossRef]
54. Amos, C.; Rahman, A.; Karim, F.; Gathenya, J.M. A Scoping Review of Roof Harvested Rainwater Usage in Urban Agriculture: Australia and Kenya in Focus. *J. Clean Prod.* **2018**, *202*, 174–190. [CrossRef]
55. Prinz, D. Water Harvesting: Past and Future. In Proceedings of the NATO Advanced Research Workshop, Balkema, Rotterdam, The Netherlands, 21–23 March 1994; Pereira, L.S., Ed.; pp. 135–144.
56. Wenhua, J.; Jianming, C.; van Veenhuizen, M. Efficiency and economy of a new agricultural rainwater harvesting system. *Chin. J. Popul. Resour. Environ.* **2010**, *8*, 41–48. [CrossRef]
57. Velasco-Muñoz, J.F.; Aznar-Sánchez, J.A.; Belmonte-Ureña, L.J.; López-Serrano, M.J. Advances in water use efficiency in agriculture: a bibliometric analysis. *Water* **2018**, *10*, 377. [CrossRef]
58. Wang, M.H.; Li, J.; Ho, Y.S. Research articles published in water resources journals: A bibliometric analysis. *Desalin. Water Treat.* **2011**, *28*, 353–365. [CrossRef]
59. Aznar-Sánchez, J.A.; Belmonte-Ureña, L.J.; Velasco-Muñoz, J.F.; Manzano-Agugliaro, F. Economic analysis of sustainable water use: A review of worldwide research. *J. Clean Prod.* **2018**, *198*, 1120–1132. [CrossRef]

60. Liang, X.; Van Dijk, M.P. Identification of Decisive Factors Determining the Continued Use of Rainwater Harvesting Systems for Agriculture Irrigation in Beijing. *Water* **2016**, *8*, 7. [CrossRef]
61. Helmreich, B.; Horn, H. Opportunities in rainwater harvesting. *Desalination* **2009**, *248*, 118–124. [CrossRef]
62. Cossarini, D.M.; MacDonald, B.H.; Wells, P.G. Communicating marine environmental information to decision makers: enablers and barriers to use of publications (grey literature) of the Gulf of Maine Council on the Marine Environment. *Ocean Coastal Manag.* **2014**, *96*, 163–172. [CrossRef]
63. Aznar-Sánchez, J.A.; Velasco-Muñoz, J.F.; Belmonte-Ureña, L.J.; Manzano-Agugliaro, F. Innovation and technology for sustainable mining activity: A worldwide research assessment. *J. Clean Prod.* **2019**, *221*, 38–54. [CrossRef]
64. Hensley, M.; Bennie, A.T.P.; van Rensburg, L.D.; Botha, J.J. Review of 'plant available water' aspects of water use efficiency under irrigated and dryland conditions. *Water SA* **2011**, *37*, 771–779. [CrossRef]
65. Mzezewa, J.; van Rensburg, L.D. Effects of tillage on runoff from a bare clayey soil on a semi-arid ecotope in the Limpopo Province of South Africa. *Water SA* **2011**, *37*, 165–172. [CrossRef]
66. Li, R.; Hou, X.; Jia, Z.; Han, Q.; Yang, B. Effects of rainfall harvesting and mulching technologies on soil water, temperature, and maize yield in Loess Plateau region of China. *Soil Res.* **2012**, *50*, 105–113. [CrossRef]
67. Woyessa, Y.E.; Pretorius, E.; Hensley, M.; Van Rensburg, L.D.; Van Heerden, P.S. Up-scaling of rain-water harvesting for crop production in the communal lands of the Modder River basin in South Africa: Comparing upstream and downstream scenarios. *Water SA* **2006**, *32*, 223–228. [CrossRef]
68. Hoff, H.; Falkenmark, M.; Gerten, D.; Gordon, L.; Karlberg, L.; Rockström, J. Greening the global water system. *J. Hydrol.* **2010**, *384*, 177–186. [CrossRef]
69. Ngigi, S.N.; Savenije, H.H.G.; Thome, J.N.; Rockström, J.; De Vries, F.W.T.P. Agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. *Agric. Water Manag.* **2005**, *73*, 21–41. [CrossRef]
70. Wu, Y.; Jia, Z.; Ren, X.; Zhang, Y.; Chen, X.; Bing, H.; Zhang, P. Effects of ridge and furrow rainwater harvesting system combined with irrigation on improving water use efficiency of maize (Zea mays L.) in semi-humid area of China. *Agric. Water Manag.* **2015**, *158*, 1–9. [CrossRef]
71. Tohidyan-Far, S.; Rezaei-Moghaddam, K. Attitudes of farmers toward participation in irrigation and drainage projects: the structural equations modelling analysis. *Iran Agric. Resear.* **2015**, *34*, 80–91. [CrossRef]
72. Bagheri, A.; Ghorbani, A. Adoption and non-adoption of sprinkler irrigation technology in Ardabil Province of Iran. *Afr. J. Agric. Res.* **2011**, *6*, 1085–1089. [CrossRef]
73. Palacios-Vélez, O.L.; Escobar-Villagrán, B.S. Sustainable Crop Irrigation and Overexploitation of Aquifers. *Tecnol. Cienc. Agua* **2016**, *7*, 5–16.
74. Chatterjee, R.; Jain, A.K.; Chandra, S.; Tomar, V.; Parchure, P.K.; Ahmed, S. Mapping and management of aquifers suffering from over-exploitation of groundwater resources in Baswa-Bandikui watershed, Rajasthan, India. *Environ. Earth. Sci.* **2018**, *77*, 157. [CrossRef]
75. Andreu, J.M.; Pulido-Bosch, A.; Llamas, M.R.; Bru, C.; Martínez-Santos, P.; García-Sánchez, E.; Villacampa, L. Overexploitation And Water Quality In The Crevillente Aquifer (Alicante, SE Spain). *WIT Trans. Ecol. Environ.* **2008**, *111*, 75–84. [CrossRef]
76. Assouline, S.; Shavit, U. Effects of management policies, including artificial recharge, on salinization in a sloping aquifer: The Israeli Coastal Aquifer case. *Water Resour. Res.* **2004**, *40*, W04101. [CrossRef]
77. Richey, A.S. Moving from Aquifer Stress to Sustainable Management with Remote Sensing and Local Knowledge. *San Francisco Estuary Watershed Sci.* **2015**, *13*, 3. [CrossRef]
78. Yu, M.; Ge, X. Effects of rain flood control about low impact development system in West 10 Plot of Shougang based on the SWMM simulation. *J. Beijing For. Univ.* **2018**, *40*, 97–109. [CrossRef]
79. Reca, J.; Trillo, C.; Sánchez, J.A.; Martínez, J.; Valera, D. Optimization model for on-farm irrigation management of Mediterranean greenhouse crops using desalinated and saline water from different sources. *Agric. Syst.* **2018**, *166*, 173–183. [CrossRef]