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Review

Rainwater Harvesting and Treatment Systems in South America: A Bibliometric Analysis (2000-2021)

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Abstract: The objective of this study was to review the main rainwater harvesting and treatment systems through a bibliometric analysis from 2000-2021. A bibliometric analysis was used in the R program and VOS viewer, the query involved titles, abstracts, and keywords during the last 20 years (2000-2021). The results indicate that from 2013 onwards, interest in this topic increased. 13% of the publications belong to the academic journal Journal of Cleaner Production. The main author leading the publications is Ghisi, from Brazil, who conducted 24 types of research and one of his papers reached 95 citations. In conclusion, there is evidence of the need to strengthen research in developing countries to contribute to water saving and supply in areas that do not have drinking water.

Keywords: Rainwater, Bibliometrics, Evolution, Co-Occurrence, Frequency

Introduction

Globally, there is an increase in the annual demand for water for different uses, due to population expansion and domestic, agricultural, and industrial purposes (Krishna *et al*., 2020). Therefore, rainwater harvesting systems are an ancient practice, to cope with water scarcity, being one of the alternatives in many countries (León Agatón *et al*., 2016). Rainwater harvesting for domestic use and human consumption is feasible according to technical and economic validation (Morales Rojas *et al*., 2021). The practice of rainwater harvesting varies according to the needs and the degree of its modern implementation varies greatly around the world, in many cases focusing only on conserving water without considering other benefits associated with nature (Campisano *et al*., 2017).

Rainwater harvesting is a key water conservation strategy for the future in vulnerable regions that are located in dry, wet, semi-arid, and arid climatic regions (Akpinar Ferrand and Cecunjanin, 2014). In addition, stormwater is also used as a stormwater control measure designed to address flood risk by capturing and storing stormwater runoff and supplying collected rainwater to households (Melville-Shreeve *et al*., 2016). The threat of water scarcity is also sought to be curbed, with research through applications aimed at providing a sustainable solution to ensure water security in both rural and urban areas being of great interest (Okoye *et al*., 2015). In this sense, bibliometric analyses are necessary to visualize the advances in research according to the thematic addressed (Jimenez *et al*., 2021).

The bibliometric analysis presents information regarding the growth of publications, international

collaboration, main active countries, institutes, and authors (Cobo *et al*., 2011). Therefore, studies on the diffusion of science focus their attention on industrialized countries. However, in recent years, due to the incorporation of Scopus databases, which has proven to be the largest refereed database, citations and high-quality sources on the Web (Andalia *et al*., 2010), justify the analysis of scientific production in the thematic of rainwater harvesting and treatment systems.

Based on the above, the objective of this study was to review the main rainwater harvesting and treatment systems through a bibliometric analysis from 2000-2021.

Materials and Methods

Literature Review

A literature review was conducted for South America (Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, and Venezuela) through academic Google search, as well as confirmation in the Scopus database since it covers a wide number of journals worldwide (Ma and McGroarty, 2017). On the other hand, the authors have applied the bibliometric analysis method pursuing methodological novelty concerning studies of rainwater harvesting systems (Cuevas-Molano *et al*., 2019).

Search Strategy

The strategy used to determine the search criteria was through exact matches of keywords, using the English terms: "Rainwater harvesting", and "Rainwater harvesting systems". The query involved the titles, abstracts, and keywords.

Selection Criteria and Indicators Evaluated

After applying the search criteria, a total of 130 documents were obtained, of which those that were not in English or Spanish, review articles, technical notes, and articles whose corresponding author does not belong to the area of study were excluded for the bibliometric analysis, thus reducing the total number of documents processed to 97. Evolution of publications during the last 20 years in South America, main sources, most relevant authors, co-citation of authors, a network of documents and citations, network map of co-occurrence of keywords, frequency of keywords, and networks of co-authored countries, related to rainwater harvesting and treatment studies. To measure the annual scientific growth rate in South America, the Compound Annual Growth Rate (CAGR), widely used as an indicator of economic growth was used (Castillo and Powell, 2019; Minhas and Potdar, 2020).

Data Analysis

The descriptive analyses of the items associated with the evolution of publications by country, by thematic axis, were carried out using the R v4.1 software (Elosua, 2010). For the keyword co-occurrence analysis graphs, network maps were constructed using the "complete count" method of the VOSviewer v.1.6.17 software (Van Eck and Waltman, 2010).

Results and Discussion

The results for the CAGR were 26.66% during the last 20 years, which is related to the annual increase of publications (Gu and Blackmore, 2016; Horta and Veloso, 2007), thus 97 scientific types of research related to the subject of rainwater harvesting and treatment systems during the last two decades published in the Scopus database were recovered. Figure 1 shows the growth of research since the year 2000 with the publication of Ortiz V, Anglica Rubuio M., and Lissi EA, for the years 2001, 2003, 2004, 2006, 2007, and 2011 there is no evidence of scientific research articles because in those years urban expansion was not so pronounced (FAO, 2013), however, from the year 2013 the interest in this topic increased considerably reaching 17 published manuscripts, publications in the year 2019 was with a focus on rainwater harvesting in rural areas and water saving urban areas, while in the last two years (2020-2021) only 14 and 13 types of research were published respectively. The importance of rainwater harvesting lies in being a sustainable alternative to mitigate water scarcity (Lee *et al*., 2016).

Most Productive Journals and Authors

There were 50 journals, Fig. 2 shows the top 10 most relevant sources, where 13% of publications belong to the academic journal Journal of Cleaner Production (13 articles) in the discipline of environmental sciences, its publications address rainwater harvesting for drinking water saving and economic analysis, 10% comes from the journal Resources Conservation and Recycling (10 articles) showing a conservation approach, sustainable management, circular economy, and resource sustainability, 6% comes from the Swiss journal Water (6 articles) linked to water science and technology, ecology and water resources management, 4% belong to the journals Atmospheric Environment, Engenharia Sanitaria e Ambiental, Urban Water Journal and Water Science and Technology: Water Supply with 4 articles published by each and 3 and 2% of publications were by the journals Journal Of Environmental Management (3 articles), Revista Ambiente e Agua (3 articles) and Atmospheric Pollution Research (2 articles).

A total of 319 authors were identified in the total production of documents during the period analyzed. Of these, we present the most productive authors, with at least 3 publications (Fig. 3), the main author being Ghisi E. researcher from the Federal University of Santa Catarina-Brazil, who conducted 24 types of research, giving the main emphasis on the technical feasibility of rainwater and its relationship with the catchment area, followed by the authors; Calijuri ML of the Federal University of Viçosa - Brazil, Gabarrell X of the Autonomous University of Barcelona-Spain, Heller L of the Federal University of Minas Gerais-Brazil, Oviedo-Ocaña ER of the Industrial University of Santander-Colombia, Pena JL Federal University of Minas Gerais-Brazil, Rieradevall J of the Autonomous University of Barcelona-Spain, Rupp RF of the Federal University of Santa Catarina-Brazil, Torres A of the Pontificia Universidad Javeriana-Colombia and Ward S of the University of Exeter-United Kingdom, with 3 publications respectively. Most rainwater harvesting and treatment research they have evaluated technical and economic feasibility as an important factor (Pacheco and Campos, 2017).

To determine which authors, based on the co-citations of the others, represent in a more relevant way the studies on rainwater harvesting and treatment systems, a network of co-citations of authors was made (Fig. 4). The co-citation analysis is based on the assumption that between two or more documents that are co-cited (cited together) in a third and subsequent work, there is a thematic similarity; and that the higher the frequency of co-citation, the greater the affinity between them (Córdoba-Cely *et al*., 2012). The intensity of this relationship is given, then, by the number of citing papers that have the same pair of papers in their references (Miguel *et al*., 2007).

The size of a node reflects the number of citations an author has received from the analyzed papers, the top five most co-cited authors are; Ghisi E. with 252 citations representing the largest node size concerning their peers, followed by Butler D., WardS., Rahman A., and Imteaz MA with 63,55,52 and 50 citations respectively.

Referenced researchers who are in visualization close to each other tend to be more strongly related (based on co-citations) than researchers located far away from each other. For example, Ghisi and Rahman have a high co-citation relationship, unlike Guisi and Morales-Pinzon who are farther apart. It shows 5 groups or clusters well differentiated by colors of which green and red are the largest with 6 authors respectively and the smallest is the lilac color with 3 authors. The map shows the 238 links or arcs between the nodes with the highest TEF (Total Link Strength).

Citation between Documents

Figure 5, shows the network of documents and citations and their different connections, the purple to yellow color scale indicates the number of citations received per document, along with the year of publication, and the diameter of the dots shows the normalization of citations (Perianes-Rodriguez *et al*., 2016). The large circles indicate the papers with the highest number of citations, the 5 most cited papers during the study period belong to; *Ghisi E*. (95 citations) with his publication "Rainwater harvesting at gas stations in Brasilia: Drinking water saving potential and investment feasibility analysis" in 2009, the second paper with the highest number of citations belongs to *Morales Pinzón T*. (73 citations), "Modeling for economic cost and environmental analysis of rainwater harvesting systems" published in 2015, the third most cited manuscript also belongs to author Ghisi (64 citations) published in 2010, "Parameters influencing the sizing of rainwater tanks for residential use", the fourth most cited paper (49 citations) is "Chemical characteristics of rainwater at a site in southeastern Brazil" by Fracchini Cerqueira M. R. published in 2014, and the fifth paper with 41 citations belongs to Coelho C.H. named "Dissolved organic carbon in rainwater from areas heavily impacted by sugarcane burning" published in 2008.

Keyword Analysis

Figure 6, shows the network of co-occurrences of keywords and their different connections, the words that appear most often in the analyzed articles is the word rainwater, Brazil, and potable water savings, this word makes sense with the large number of studies applied in urban areas to save drinking water (Rahman *et al*., 2014) and we have the word sustainability (sustainability).

Figure 7 shows the frequency of keywords, during the study period, where the word rainwater harvesting was repeated from 2016 to 2019, with higher frequency in 2018 and the word with lower frequency was "rainwater use" in the interval 2017-2019 with higher intensity in the year 2018.

Figure 8, shows the countries in co-authorship, referred to in this research, resulting in networks between the years 2010 to 2021, shown in green color. So far, 6 countries have co-authored documents related to rainwater harvesting and treatment systems. Brazil leads the list, followed by Colombia, the United States, Spain, the United Kingdom, and Argentina. The analysis of scientific collaboration networks can help determine the main areas of specialization of universities and research centers (Montoya *et al*., 2018).

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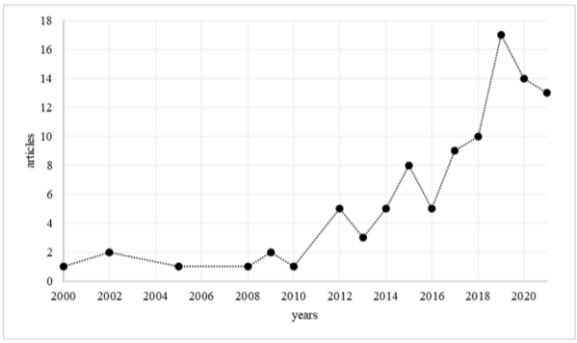

Fig. 1: Growth of global publications on rainwater harvesting and treatment systems in South America 2000 – 2021

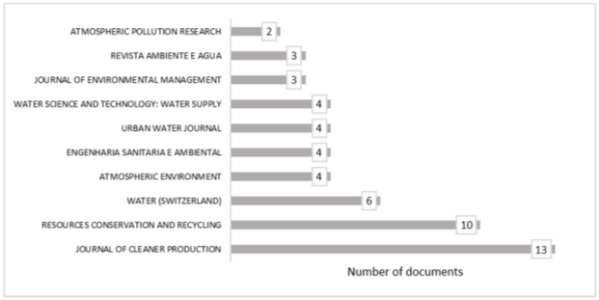

Fig. 2: Top ten most relevant sources

Fig. 3: Top 10 most relevant authors

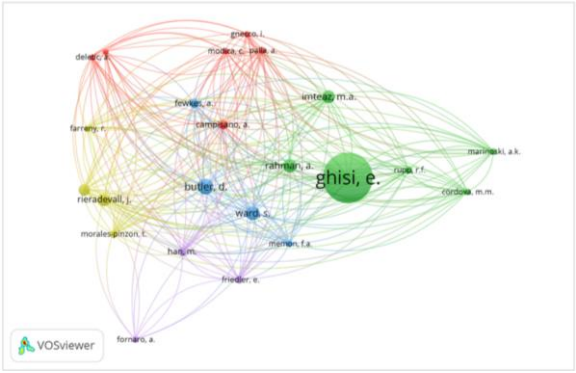

Fig. 4: Co-citation of authors

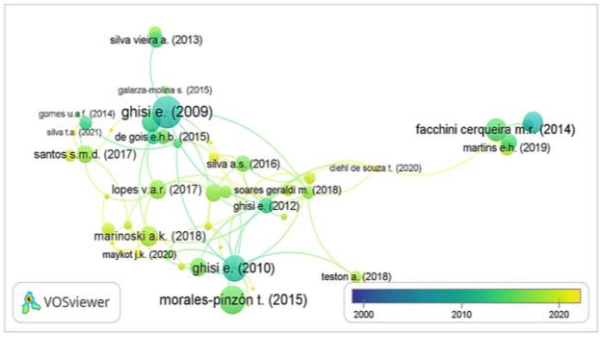

Fig. 5: Document and citation network

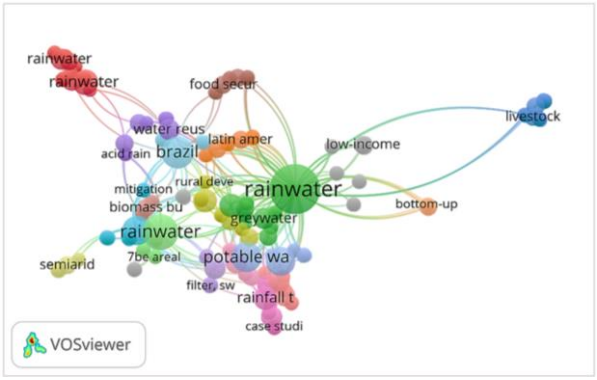

Fig. 6: Keyword co-occurrence network Map

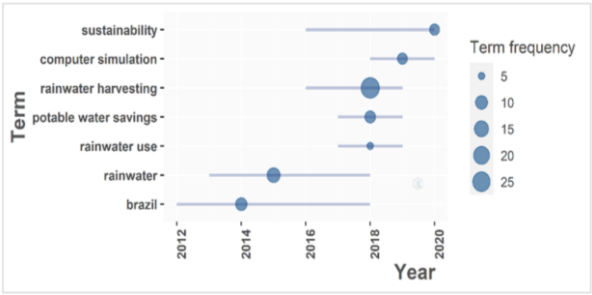

Fig. 7: Frequency of keywords

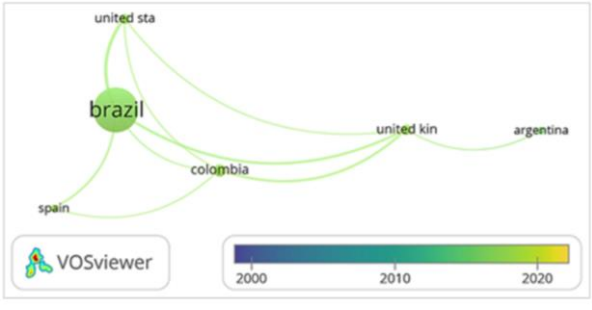

Fig. 8: Networks of co-authored countries in rainwater harvesting and treatment studies

Conclusion

From the bibliometric analysis, the evolution of scientific production was more intense from 2013 to 2021, Brazil was one of the leading countries in research related to rainwater harvesting systems in South America. Finally, collaboration networks should be increased in public and private institutions so that developing countries have environmentally friendly alternatives, encouraging water saving in rural and urban areas.

In this sense, the governments of each country have a great investment challenge to improve the quality of water for human consumption in rural towns through installation and treatment. Given that the great limitation is the initial investment for these systems. Water-saving policies should also be implemented in rural areas through the implementation of rainwater systems to be used for garden irrigation, laundry, and other purposes.

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Author's Contributions

Eli Morales Rojas, Manuel E. Reátegui-Inga, Reiner Reátegui Inga and Pierina Lizbeth Neyra Vargas: Conceptualization, drafting, and revision of the final version.

Meliza del Pilar Bustos Chavez: Methodology, project management, resources, software, validation, and data visualization.

Alberto Franco Cerna Cueva, Lenin Quiñones Huatangari, Alex Lenin Guivin Guadalupe and Jorge Luis Vargas Espinoza: Manuscript writing, data collection, analysis and project management. Finally, all authors have read and accepted the final version of the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all authors have read and approved the manuscript and that there are no ethical issues.

References

Akpinar Ferrand, E., & Cecunjanin, F. (2014). Potential of rainwater harvesting in a thirsty world: a survey of ancient and traditional rainwater harvesting applications. *Geography Compass*, *8*(6), 395-413. https://doi.org/10.1111/gec3.12135

Andalia I, R. C., LabradaII, R. R., & Castells, M. M. (2010). The largest database of peer-reviewed scientific literature available to underdeveloped countries. *Revista Cubana de Información en Ciencias de la Salud (ACIMED)*, *21*(3), 270-282.

Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, E., DeBusk, K., ... & Han, M. (2017). Urban rainwater harvesting systems: Research, implementation, and future perspectives. *Water Research*, *115*, 195-209. https://doi.org/10.1016/j.watres.2017.02.056

Castillo, J. A., & Powell, M. A. (2019). Análisis de la producción científica del Ecuador e impacto de la colaboración internacional en el periodo 2006-2015. *Revista Española de Documentación Científica*, *42*(1), e225-e225. https://doi.org/10.3989/redc.2019.1.1567

Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for Information Science and Technology*, *62*(7), 1382-1402. https://doi.org/10.1002/asi.21525

Córdoba-Cely, C., Alpiste, F., Londoño, F., & Monguet, J. (2012). Análisis de cocitación de autor en el modelo de aceptación tecnológico, 2005-2010. *Revista Española de Documentación Científica*, *35*(2), 238-261. https://doi.org/10.3989/redc.2012.2.864

Cuevas-Molano, E., Cid, M. S., & Matosas-López, L. (2019). Análisis bibliométrico de estudios sobre la estrategia de contenidos de marca en los medios sociales. *Comunicación y Sociedad*, 1-25. https://doi.org/10.32870/cys.v2019i0.7441

Elosua, P. (2010). Introducción al entorno R. Servicio Editorial de la Universidad del País Vasco/Euskal Herriko Unibertsitatearen Argitalpen Zerbitzua.

FAO. (2013). Captación Y Almacenamiento De Agua De Lluvia. In Santiago de Chile. https://www.fao.org/3/i3247s/i3247s.pdf

Gu, X., & Blackmore, K. L. (2016). Recent trends in academic journal growth. *Scientometrics*, *108*(2), 693-716. https://doi.org/10.1007/s11192-016-1985-3

Horta, H., & Veloso, F. M. (2007). Opening the box: Comparing EU and US scientific output by scientific field. *Technological Forecasting and Social Change*, *74*(8), 1334-1356. https://doi.org/10.1016/j.techfore.2007.02.013

Jimenez, P. H. P., Diestra, K. E. M., Álvarez, C. H. L., Romaní, J. M. L., & Chaviano, O. G. (2021). Análisis bibliométrico y de redes sociales de la Revista Peruana de Medicina Experimental y Salud Pública (2010-2019). *e-Ciencias de la Información*, *11*(1), 8. https://doi.org/10.15517/eci.v11i1.42082

Krishna, R. S., Mishra, J., & Ighalo, J. O. (2020). rising demand for rain water harvesting system in the world: A case study of Joda Town, India. *World Scientific News*, *146*, 47-59.

Lee, K. E., Mokhtar, M., Hanafiah, M. M., Halim, A. A., & Badusah, J. (2016). Rainwater harvesting as an alternative water resource in Malaysia: Potential, policies and development. *Journal of Cleaner Production*, *126*, 218-222. https://doi.org/10.1016/j.jclepro.2016.03.060

León Agatón, A., Córdoba Ruiz, J. C., & Carreño Sayago, U. F. (2016). Revisión del estado de arte en captación y aprovechamiento de aguas lluvias en zonas urbanas y aeropuertos. *Tecnura*, *20*(50), 141-153. https://doi.org/10.14483/udistrital.jour.tecnura.2016.4.a10

Ma, T., & McGroarty, F. (2017). Social Machines: How recent technological advances have aided financialisation. *Journal of Information Technology*, *32*(3), 234-250. https://doi.org/10.1057/s41265-017-0037-7

Melville-Shreeve, P., Ward, S., & Butler, D. (2016). Rainwater harvesting typologies for UK houses: A multi criteria analysis of system configurations. *Water*, *8*(4), 129. https://doi.org/10.3390/w8040129

Miguel, S., Moya-Anegón, F., & Herrero-Solana, V. (2007). El análisis de co-citas como método de investigación en Bibliotecología y Ciencia de la Información. *Investigación Bibliotecológica*, *21*(43), 139-155. https://doi.org/10.22201/iibi.0187358xp.2007.43.4129

Minhas, M. R., & Potdar, V. (2020). Decision support systems in construction: A bibliometric analysis. *Buildings*, *10*(6), 108. https://doi.org/10.3390/BUILDINGS10060108

Montoya, F. G., Alcayde, A., Baños, R., & Manzano-Agugliaro, F. (2018). A fast method for identifying worldwide scientific collaborations using the Scopus database. *Telematics and Informatics*, *35*(1), 168-185. https://doi.org/10.1016/j.tele.2017.10.010

Morales Rojas, E., Díaz Ortiz, E. A., Medina Tafur, C. A., García, L., Oliva, M., & Rojas Briceño, N. B. (2021). A Rainwater Harvesting and Treatment System for Domestic Use and Human Consumption in Native Communities in Amazonas (NW Peru): Technical and Economic Validation. *Scientifica*, *2021*. https://doi.org/10.1155/2021/4136379

Okoye, C. O., Solyalı, O., & Akıntuğ, B. (2015). Optimal sizing of storage tanks in domestic rainwater harvesting systems: A linear programming approach. *Resources, Conservation and Recycling*, *104*, 131-140. https://doi.org/10.1016/j.resconrec.2015.08.015

Pacheco, G. C., & Campos, M. A. (2017). Economic feasibility of rainwater harvesting systems: A systematic literature review. *Journal of Water Supply: Research and Technology—AQUA*, *66*(1), 1-14. https://doi.org/10.2166/aqua.2016.048

Perianes-Rodriguez, A., Waltman, L., & Van Eck, N. J. (2016). Constructing bibliometric networks: A comparison between full and fractional counting. *Journal of Informetrics*, *10*(4), 1178-1195. https://doi.org/10.1016/j.joi.2016.10.006

Rahman, S., Khan, M. T. R., Akib, S., Din, N. B. C., Biswas, S. K., & Shirazi, S. M. (2014). Sustainability of rainwater harvesting system in terms of water quality. *The Scientific World Journal*, *2014*. https://doi.org/10.1155/2014/721357

Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523-538. https://doi.org/10.1007/s11192-009-0146-3