

Original Article

Rural Sanitation and Sustainable Development Analysis from a Bibliometric Perspective Based on Global Scientific Production, Emphasizing Latin America

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Abstract - A bibliometric analysis is conducted to identify trends, stakeholders, prominent methodologies, and less studied topics in the scientific literature related to rural sanitation and sustainable development, with an emphasis on Latin America. The quantitative, descriptive, and longitudinal bibliometric techniques employed in the current research utilized the Scopus and Web of Science records until early 2026. The three research queries are related to SDG 6, sustainability, technology, performance, and equity and inclusion. The sample was obtained after exporting the metadata and filtering in spreadsheets; the data was exported in .ris format and subsequently analyzed in VOSviewer, considering productivity indicators such as leading production countries, and keyword co-occurrence. The results showed that studies related to SDG 6 started in 2008, showing a moderate increasing trend and then reaching a peak in 2024 (with 5 publications) and thereafter one publication in early 2026. The other series started in 1976, reaching its peak in 2025 (with 19 research papers) and registered four publications so far in 2026. Regarding equity, production started in 2005 and showed an inconsistent trend, reaching five publications in 2024 and three in the current year. The results show that Asia is the leading region in research production—with China and India being the key contributors—and outpacing the Latin American region, where Brazil, Chile, and Guatemala (in that order) are the most representative countries in research production. Thematically, the technocentric and the economic-normative clusters were the most common; the topics related to governance, operation, and maintenance, post-implementation monitoring, and equity are less studied. It is concluded that rural sanitation sustainability is currently partially studied and unevenly addressed, as the efforts are mainly directed to technical performance and economic viability; this approach fails to consider continuity of the service or inclusion, which limits the link between rural sanitation and sustainability, especially in Latin America.

Keywords - Rural Sanitation, Bibliometrics, SDG 6, Sustainability, Latin America.

1. Introduction

Rural sanitation is a critical component of sustainable development because of its direct influence on public health, reduction of inequalities, productivity, and environmental implications. As a consequence, the implementations and advances in rural sanitation constitute an axis of the SDG (sustainable goal) 6.

Rural areas present gaps associated with geographical dispersion, financial limitations, institutional weaknesses, and low community participation in the management of WASH (Water, Sanitation, and Hygiene). The main problem is that improvements in sanitation coverage do not always guarantee

the long-term sustainability of rural services, particularly when operation, maintenance, financing, monitoring, and community governance remain weak. In Peruvian rural areas, the absence of basic sanitary services is associated with a higher rate of diarrhea and urinary diseases, especially in children, which evidences the link between sanitary infrastructure and public health [1].

Figure 1 depicts a rural sanitation infrastructure in poor conditions, which reflects the need not only for infrastructure coverage, but service continuation and post-implementation management in the long-term for an appropriate functioning of the sanitary systems.



The word sustainability implies that the infrastructure is used, maintained, paid for, and owned by the community. However, communities in rural areas often lack the financial resources and technical knowledge to maintain the sanitation systems, which ultimately causes the deterioration of these systems [2]. The implementation of enhanced or novel solutions may fail for the same reason, as any solution requires maintenance and social organization, which, as mentioned earlier, these characteristics are part of the definition of sustainability [3]. For example, the "Open Defecation Free" designation, which is a distinction given to communities where every household uses a safe and environmentally friendly toilet, can be lost if the community lacks maintenance practices and institutional support. [4]. In summary, rural sanitation is intrinsically linked to sustainability rather than just a one-time implementation of infrastructure achievement.



Fig. 1 Deterioration of rural sanitary infrastructure as evidence of challenges in sustainability and maintenance [1]

In the realm of sustainability, recent research has shown various points of view. For instance, the work [12] of in rural indigenous communities in Canada created a risk-benefit management framework for drinking water systems. This framework showed how community perception, water quality, and health risks affect the long-term viability and effectiveness of the service. In a similar way, in the rural setting of northwestern Togo, the hydrostructural characterization of crystalline aquifers markedly enhances the accuracy of borehole siting and fortifies sustainable water resource management [13]. Solutions based on nature, such as built wetlands for reusing wastewater in rural schools, have shown efficiency in waste removal and operational sustainability through community participation and local materials [14]. These studies evidence that guaranteeing safe water access requires integral approaches that encompass technical aspects, risk management, and long-term sustainability.

Studies focused on technological solutions oriented to operational efficiency can be found. For instance, Kumarasaravanan et al. [5] developed a smart photovoltaic

pumping system with IoT integration for dry and no-grid connection areas; the system demonstrated efficiency and stability. Similarly, Z. Zhu et al [6] proposed a wetland integrated with an iron-carbon enhanced microbial fuel cell to attain superior removal efficiencies and bioenergy recovery from rural greywater. These improvements make the technological and environmental aspects stronger, but there are still gaps in the analysis of institutional sustainability, community ownership, and service continuity.

Although there is abundant research on coverage, technologies, and health risks reductions, the knowledge remains dispersed, with important gaps in sub-implementation sustainability, participatory governance, equity, environmental resilience, and integral performance evaluation, particularly in rural areas of Latin America. In the same geographical context, it has been reported problems with monitoring systems, limitations in sustainability metrics, and structural issues with financing and operation that affect the continuity of service in community systems [7].

Previous literature has shown that rural sanitation has been widely studied from technological, environmental, and public health perspectives. However, it is limited to the bibliometric evidence regarding how scientific production has addressed long-term sustainability, governance, operation and maintenance, equity and service continuity, particularly in Latin America. Recent empirical studies have increasingly emphasized the relevance of governance structures, community engagement, economic sustainability, and maintenance capacity as critical dimensions for achieving sustainable rural sanitation services [3, 8]. International evidence has also shown that WASH interventions can help lower the number of diarrheal diseases in low- and middle-income countries. This strengthens the connection to the 2030 Agenda [10]. Research on rural services in Latin America has highlighted the importance of the institutional framework, post-construction assistance, and financial mechanisms for the maintenance of community systems [11]. Analogously, previous studies presented the state of the art of sanitation governance and its relation with socio-environmental conflicts in different territories of the global South and in traditional communities [9].

Based on the conducted review, a bibliometric analysis is necessary to identify the evolution of the field, high-relevance countries, the dominant themes, the underexplored dimensions of rural sanitation, and its sustainable development. This study conducts a bibliometric analysis of global scientific output regarding rural sanitation and sustainable development, focusing on Latin America, and identifying trends, prevailing methodologies, research networks, and thematic deficiencies. This interdisciplinary field includes sustainable development, public health, environmental management, service governance, and rural planning. As a key contribution, the conducted bibliometric

approach combines three complementary lenses: SDG 6 and sustainability, technological performance, and equity and inclusion. In addition to identifying publication trends and leading countries, it is presented the imbalance between technical efficiency and sustainability of rural sanitation services in Latin America. The results of this review can help shape research agendas and public policy decisions that go beyond covering larger areas. Thus, this study aims to characterize the evolution, the actors, and dominant topics in the field, while also identifying deficiencies related to the genuine sustainability of the service, with a particular focus on Latin America.

2. Materials and Methods

2.1. Study Design

Following the same scheme of bibliometric studies [15]—where the focus is on water and sanitation aligned with SDG 6, and identifying topic trends, collaboration patterns, and knowledge gaps—a descriptive-longitudinal bibliometric study of worldwide scientific production on rural sanitation and sustainable development is carried out. The methodological scheme includes productivity indexes, impact, collaboration networks, and co-occurrence analysis of

keywords; this review aims to identify topic trends, research networks, and gaps in scientific literature.

2.2. Information Sources

The bibliometric search was conducted in leading scientific databases, Scopus and Web of Science. These databases are multidisciplinary and widely used in bibliometric studies, making them suitable for the present study. It is well-known that rural sanitation and sustainable development involve multiple fields, including environmental engineering, public health, government policies, rural planning, and social equity. Aligned with a global bibliometric search strategy, no geographical filters were applied in the databases. However, a special focus was placed on the Latin American region as part of the analysis stage of the resulting records, identifying country information of the region, author affiliations, and regional participation. Subsequently, the results reflect the visibility of Latin America's scientific production within the selected databases. A flowchart that explains the methodological process is shown in Figure 2. The phases include literature search, data export, data cleaning and standardization, processing in VOSviewer, and results presentation.

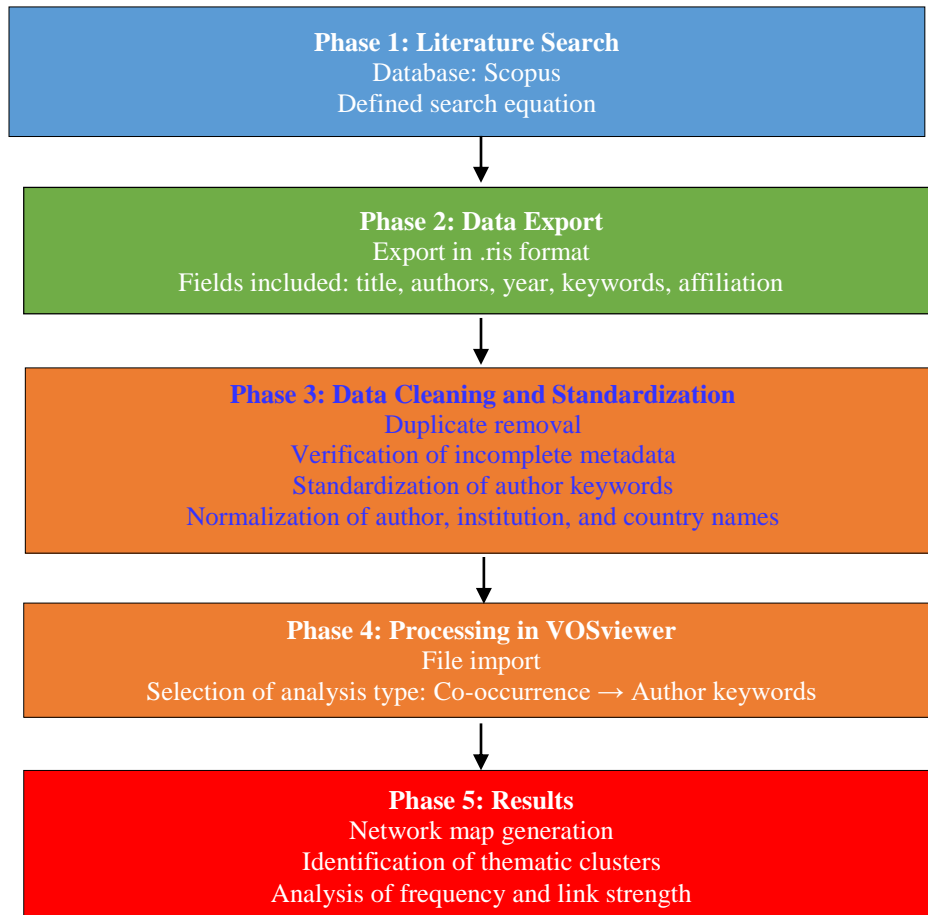


Fig. 2 Flowchart of the bibliometric analysis methodological process

On February 19, 2026, bibliographic records were extracted. Metadata from both databases was exported, including the title, abstract, keywords, authors, affiliations, country, source, DOI, language, references, and funding data when available.

2.3. Search Strategy

The extraction stage of the bibliographic was performed in February 2026; the available metadata in both databases was exported (title, abstract, keywords, authors, affiliations, country, source, DOI, language, references, and data finance when corresponded).

2.3.1. Sustainability of Rural Sanitation in the Context of SDG 6

Query 1: ("rural sanitation" OR "sanitation in rural areas" OR "rural sanitation systems" OR "onsite sanitation" OR "decentralized sanitation") AND (sustainability OR "sustainable development" OR "SDG 6" OR "Sustainable Development Goal 6")

The combination of used terms captures the heart of the literature about sanitation in rural areas by including well-known phrases in the field. The incorporation of “onsite sanitation” and “decentralized sanitation” is key, due to the fact that in rural contexts, onsite solutions or decentralized ones are the predominant (latrines, septic tanks, or systems at the household or community level) more than traditional sewerage systems. Besides, many technical studies employ these specific terms instead of general expressions like “rural sanitation”, so their inclusion makes the search broader and more precise. On the other side, the block “sustainability/sustainable development/SDG6” binds the analysis with the 2030 agenda, which is the main axis of this study. From the bibliometric perspective, this collection of words works as a research base or mother since it allows you to evaluate the productivity, country leadership, and temporary evolution in the field, as well as the identification of global trends and the analysis of the SDG 5 discourse consolidation in the area of rural sanitation.

2.3.2. Performance and Sustainability of Rural Sanitation Technologies:

Query 2: ("rural sanitation" OR rural) AND ("pit latrine" OR latrine* OR "septic tank*" OR "composting toilet*" OR "ecological sanitation" OR ecosan OR "urine diversion" OR "constructed wetland*" OR "decentralized wastewater") AND (sustainability OR performance OR "service level")

In rural areas, many types of technologies are presented. The terms “pit latrine”, “latrine” (or latrine variants), “septic tank”, phrases related to “composting toilet”, “ecological sanitation”, “ecosan”, and “urine diversion”, are included; the terms related to “constructed wetlands”, and “decentralized wastewater” are also considered. Consideration is given to other terms such as “performance” and “service level” since

some studies do not explicitly use the term “sustainability”; these studies often assess performance through service levels, efficiency, or failures, and are categorized as “functional sustainability”. The addition of this point will provide a view of the most important technologies, growth patterns, specialized lines, and gaps in the literature with an emphasis on Latin America. Finally, it must be mentioned that the inclusion of the word “rural” often encompasses technology-related studies but may include studies that are not strictly related to rural sanitation.

2.3.3. Sustainability and Social Justice in Rural Sanitation

Query 3: ("rural sanitation" OR WASH) AND (gender OR women OR equity OR inequality OR inclusion OR "social inclusion" OR "indigenous" OR "vulnerable population*" OR "disability") AND (sustainability OR access OR "service level")

The keyword selection—which includes the equity aspect and WASH approach of “leaving no one behind” — is aligned with the 2030 Agenda. The words “gender” and “women” are included to depict the relation between safety, privacy, and menstrual hygiene management, reflecting the diverse needs of users. The words "equity," "inequality," and "inclusion" also help find studies on service quality and access gaps.

The word "indigenous" is especially important in Latin America, where many rural inequalities are found in remote areas and among indigenous people. "Disability" is also included because it is related to accessibility and the removal of physical barriers, as well as being a common but underrepresented aspect that can help find gaps. Finally, "access" and "service level" are terms that studies use to talk about service continuity and quality without using the word "sustainability." This follow-up would allow the evolution of the field to be examined over time in terms of thematic and geographical shifts, emerging research lines to be identified, and the likelihood of the previously identified gaps being addressed in the near future to be assessed.

2.4. Data Processing and Analysis

Bibliographic records were sent out in a format that could be used for analysis (.ris). Microsoft Excel spreadsheets were used for initial data cleaning and organization, following steps similar to those applied in recent bibliometric studies based on databases such as Scopus and specialized tools for managing large volumes of scientific literature [15]. Bibliometric analysis and visualization of co-authorship networks, keyword co-occurrence, and institutional collaboration were performed using VOSviewer software, which generates scientific relationship maps based on frequency and link strength.

The following indicators were used:

- Annual publication rate
- Top productivity countries
- Keyword co-occurrence analysis

- Collaboration networks
- Subject areas classification

Annual publication rate provides growing trends, while productivity at a country level allows a comparison between Latin America and other regions; the keyword co-occurrence analysis depicts dominant themes and research gaps. The collaboration networks are useful to show the interaction degree among authors, institutions, and countries. Lastly, the subject areas are helpful to determine the role of civil engineering in the retrieved literature. In general, the aforementioned indicators allow the study and evaluation of the temporal evolution, geographical distribution, thematic structure, and collaborative patterns of scientific production related to rural sanitation and sustainable development.

The analysis was done on a global scale, with the Latin American aspect included by looking at the regional participation seen in country rankings, finding the Latin American countries in the sample, and unraveling the relevance of these in the broad annual production.

No initial year restriction was applied during the search process. Therefore, the publication window extended from the earliest record retrieved by each search strategy to February 19, 2026, which was the date of data extraction. This approach made it possible to observe both the historical development and the recent growth of scientific production on rural sanitation and sustainable development, including recent studies addressing inequalities in sanitation access and context-specific management challenges in vulnerable rural territories [16, 17]. However, the results should be interpreted considering possible language and indexing bias. Scopus and Web of Science provide broad international coverage, but they tend to give greater visibility to English-language journals and publications from countries with stronger scientific indexing systems. This limitation is especially relevant for Latin America, where part of the evidence on rural sanitation may

be published in Spanish or Portuguese, as well as in technical reports, institutional documents, theses, government publications, and regional journals not indexed in the selected databases. Therefore, the low visibility of Latin American countries in the retrieved records should not be understood as the absence of regional experience, but as a limitation of the indexed scientific production captured by the selected databases.

2.5. Thematic Analysis and Categorization

Repeatedly appearing words and keywords were organized in groups based on the following themes:

- Rural sanitation technologies.
- Governance and community management.
- Financial sustainability and Operation/Maintenance (O&M).
- Equity and gender focus.
- Public health and risk reduction.
- Environmental resilience and climate adaptation.

This analysis reveals the most prominent themes in the field and the least studied. For instance, nature-based solutions and passive treatment systems such as water-purifying wetlands (which can be affected by extractive technologies) are rural sanitation technologies whose efficiency depends on physicochemical factors and microbial activity [18].

3. Results

3.1. Evolution and Trends in Research on Rural Sanitation and Sustainable Development (SDG 6)

The results of Query 1 (which aimed to obtain studies related to rural sanitation and its relationship with SDG6) are presented. The research documents show the relationship between rural sanitation and sustainable development; the impact on the 2023 Agenda and current directions of scientific research are also included.

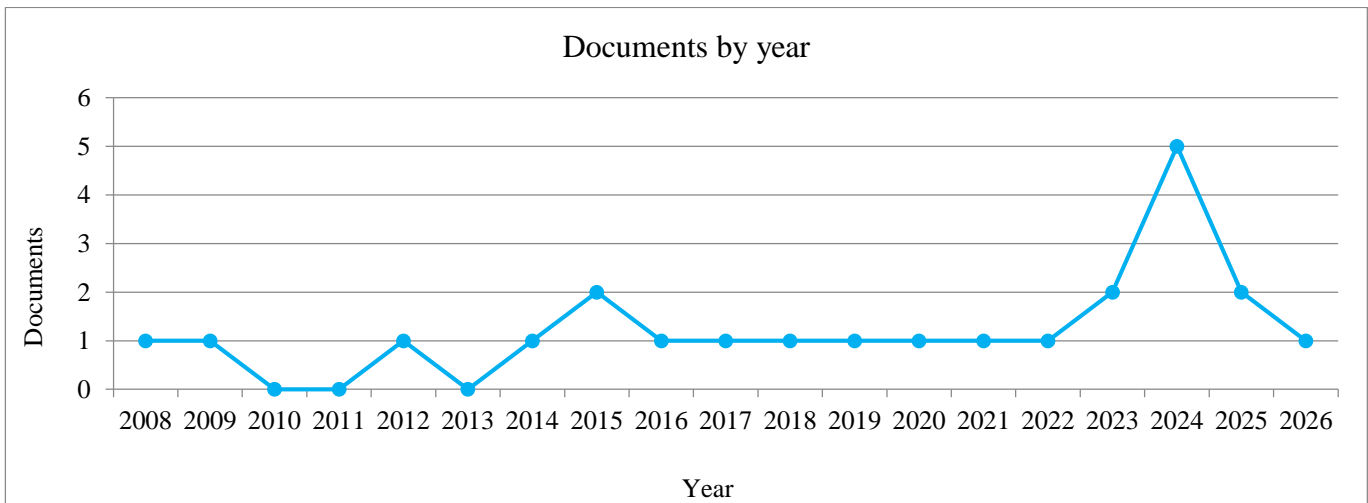


Fig. 3 Temporal trend of rural sanitation sustainability in the context of SDG 6

literature is formulated, predominantly, from the public policy language and the 2030 agenda, and not exclusively from the technical perspective. The term sewage is relevant—even though the search was mostly about rural-related issues—because many documents still have ideas that are similar to sewerage/wastewater, which shows that they fit into more general categories. The fact that economics is so important shows that most studies conceptualize sustainability in terms of its economic viability, such as costs, financing, efficiency, tariffs, and life-cycle costs. Onsite sanitation systems show that rural solutions (such as in-situ systems) are included, even though they are used with general wastewater terminology. Finally, less predominant terms are governance, community management, operation and maintenance, post-implementation, equity, gender, indigenous populations, and monitoring. These terms represent a unique opportunity for researchers to expand knowledge on novel thematic combinations.

3.2. Performance Evaluation of Rural Sanitation Technologies: Trends and Research Gaps

The results of Query 2—which are related to studies of sanitation technologies in rural areas and their long-term sustainability and performance—reveal the most prominent technologies, growing adoption, specialized research areas, and knowledge gaps.

Figure 6 shows that the use of the keyword started in 1976, in which one document was found. Subsequently, the 1980s and early 1990s evidenced few documents, and then a gap was observed until 2002. Thereafter, a peak in 2004, 2009, and 2016 clearly shows an increasing trend in previous years. Recently, from 2024 until the highest peak reached in 2025 (with 19 research papers), along with the four research papers in early 2026, highlights the increasing global trend since its beginning.

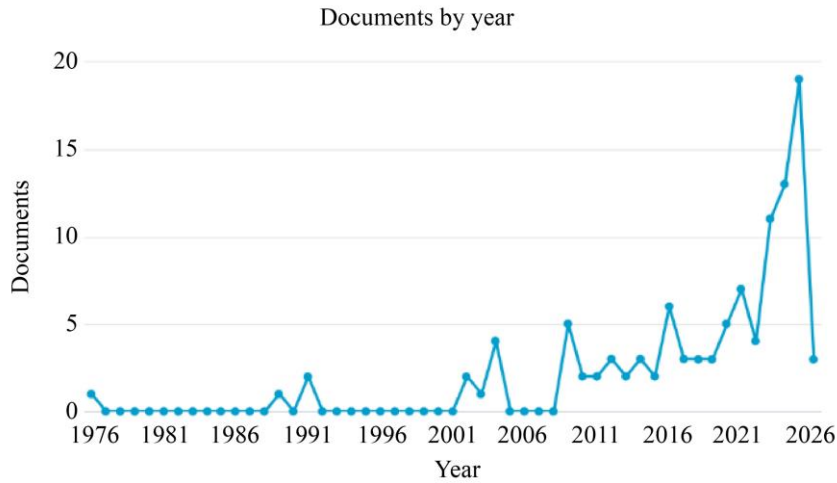


Fig. 6 Temporal trend of performance and sustainability of rural sanitation technologies

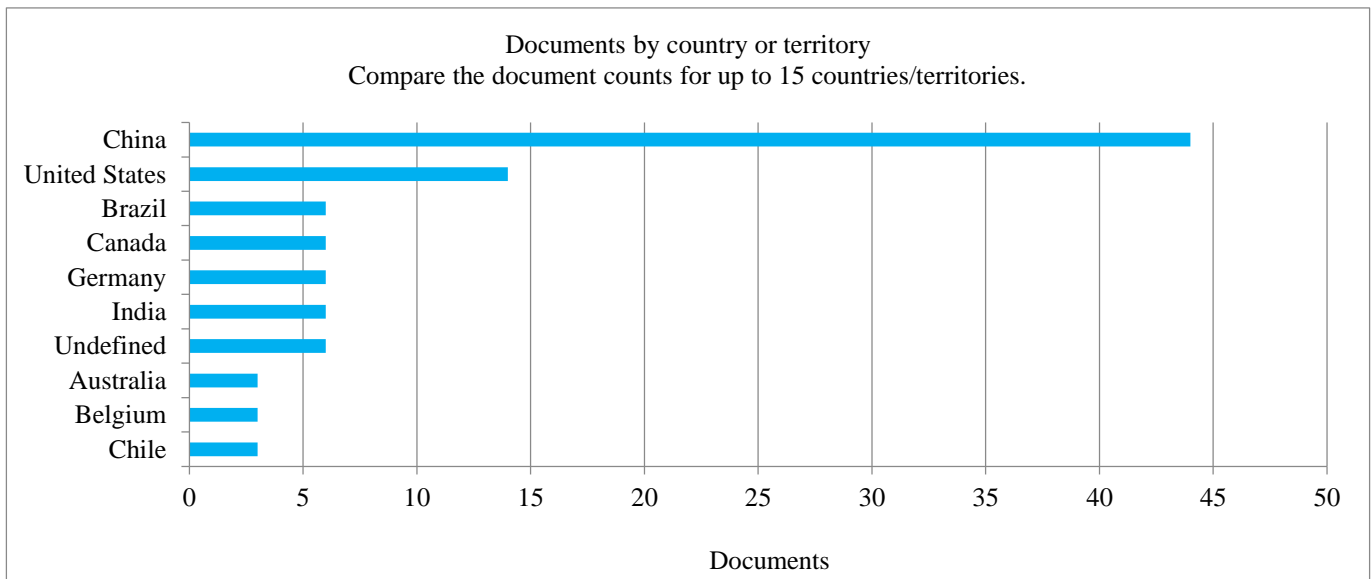


Fig. 7 Country ranking of scientific production on performance and sustainability of rural sanitation technologies

Figure 7 shows that Asia is the leader in production, with China in first place (44 publications), ahead of all the other countries. The U.S. is in second place (14). Brazil, Canada, Germany, and India are all at an intermediate level, with six publications each. There are also records with unknown

origins. Germany and Belgium are in Europe, while Australia is in Oceania. Brazil and Chile are the only Latin American countries on the list, which shows that there is less regional participation compared to Asian leadership.

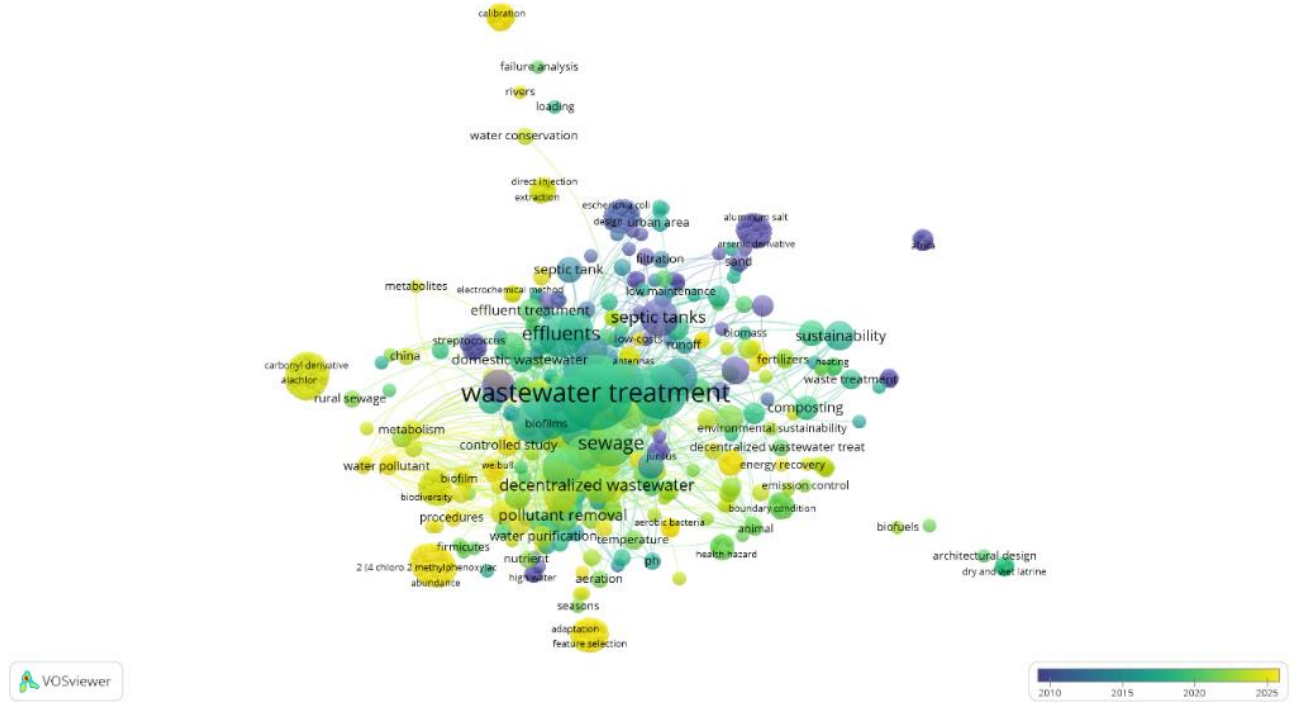


Fig. 8 VOSviewer map of performance and sustainability of rural sanitation technologies

As can be seen in Figure 8, the main clusters were wastewater treatment, effluents, sewage, septic tanks, decentralized wastewater, pollutant removal, water purification, and controlled study. This puts in evidence the predominant orientation in engineering and sustainability, mainly focused on treatment processes and removal efficiency. The strong presence of septic tanks and decentralized wastewater suggests that the septic tanks and decentralized systems constitute the most studied solutions. Nonetheless, the low presence of terms like maintenance, management, affordability, user acceptance, behavior, or governance suggests that technological literature prioritizes performance and effluents over social and institutional dimensions of sustainability. Due to the constant overlap with sewage, the incorporation of more specific terms in future research is recommended (e.g., "onsite," "fecal sludge management," and "non-sewered sanitation") with the purpose of differentiating, with more clarity, onsite/decentralized sanitation from general urban approaches.

3.3. Scientific Production on Sustainability and Social Justice in Rural Sanitation

The exposed outcomes in this section were obtained from Query 3, designed for examining the integration of the social

and equity dimensions in the research on rural sanitation. This strategy permitted to identify the studies that covered gender, social inclusion, inequalities, indigenous towns, vulnerable populations, and disabled people, in relation to sustainability, access, and service level. The retrieved set facilitates the assessment of the degree to which scientific production integrates the principle of "leaving no one behind," as advocated by the 2030 Agenda and the WASH approach, and enables an analysis of how the literature reconciles social justice and service provision with predominantly technical methodologies. This is how trends, gaps in themes, and levels of integration of the equity perspective in the area of rural sanitation are found.

Figure 9 shows that production started in 2005 with one publication and then stopped for a while. It continued to act in a sporadic way after 2015. There was another break from 2018 to 2020. The first big change happened in 2021 and 2022, and it was clear that things were getting better compared to previous years. The biggest rise happened in 2024, when there were five articles. In 2025, production went down but stayed the same. So far in 2026 (as of February), three articles have already been published, which suggests that production is on the rise again.

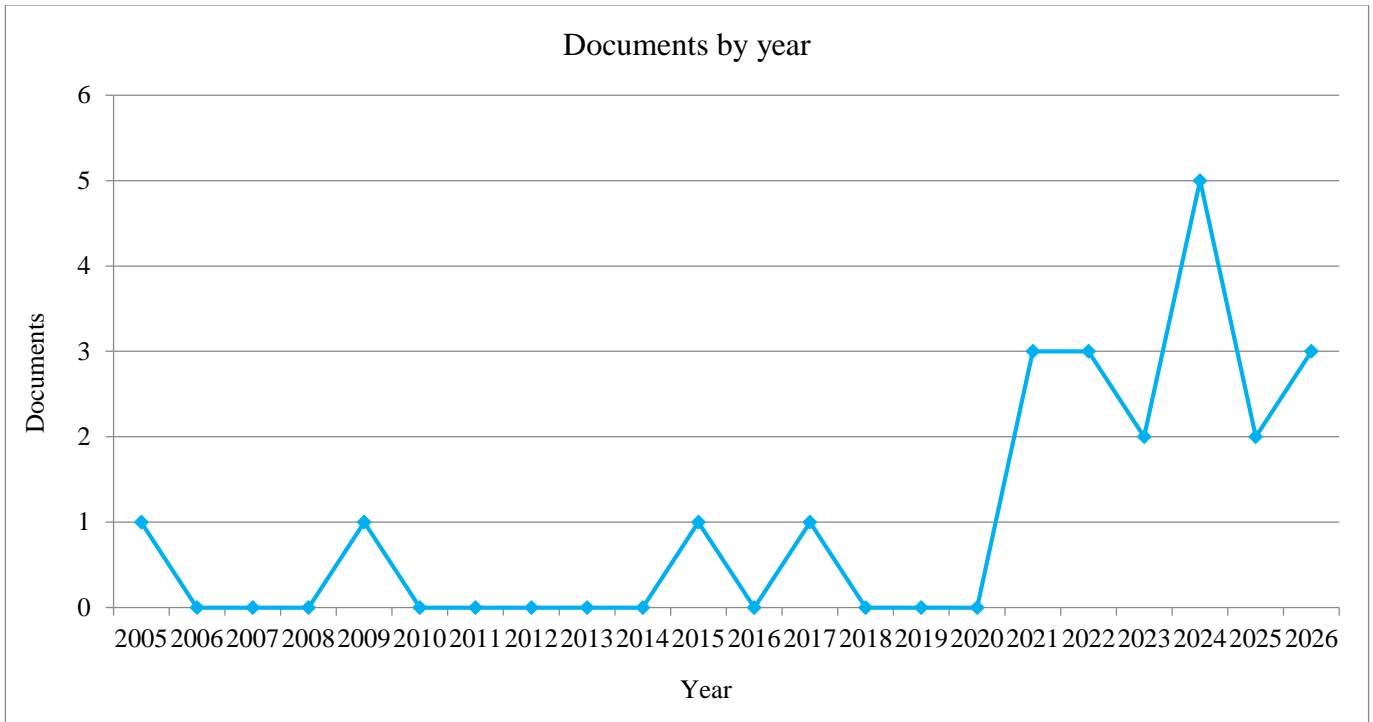


Fig. 9 Temporal trend of sustainability and social justice in rural sanitation

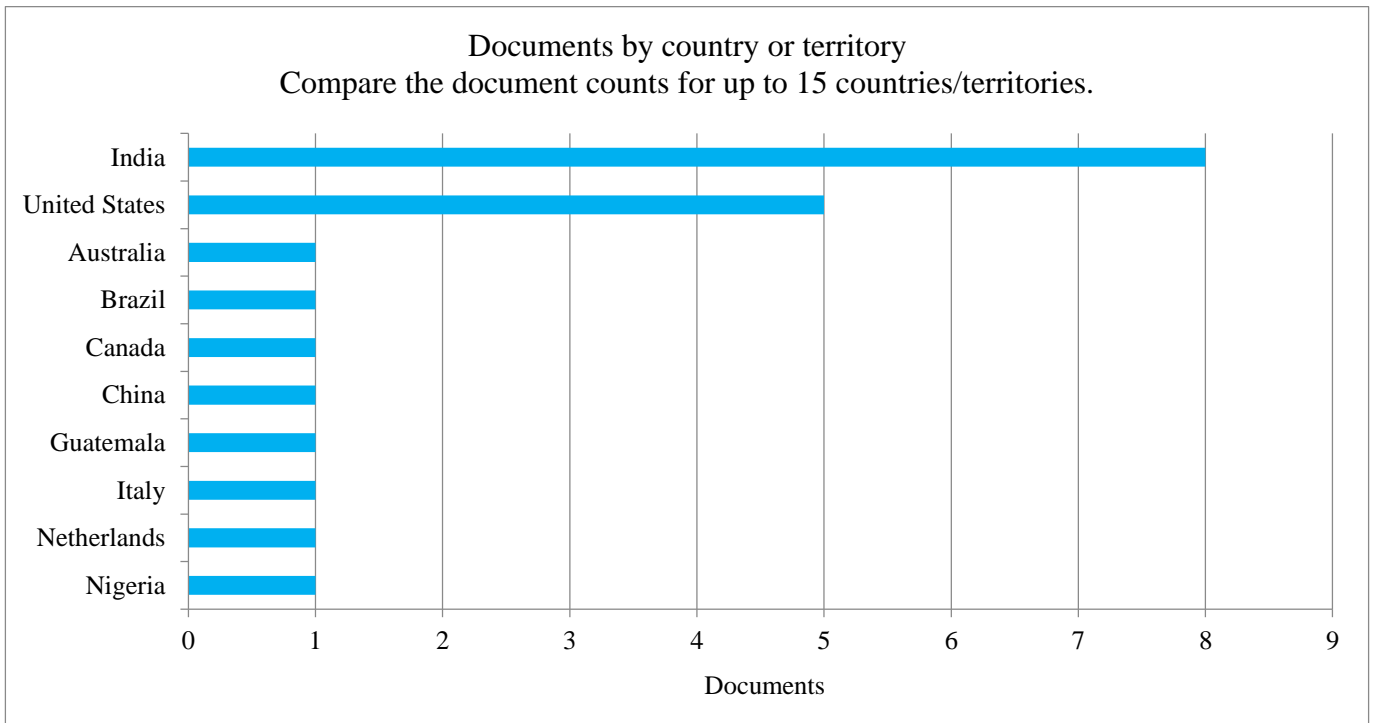


Fig. 10 Country ranking of scientific production on sustainability and social justice in rural sanitation

Figure 10 shows that Asia has the most participation, with India having eight documents and China having only a few. The United States is the only country in North America with five publications. Italy and the Netherlands are in Europe. Brazil and Guatemala are known for making only small

contributions in Latin America. Nigeria stands for Africa, and Australia stands for Oceania. In general, Asia is in the lead, followed by North America. The rest are only present in small amounts and spread out.

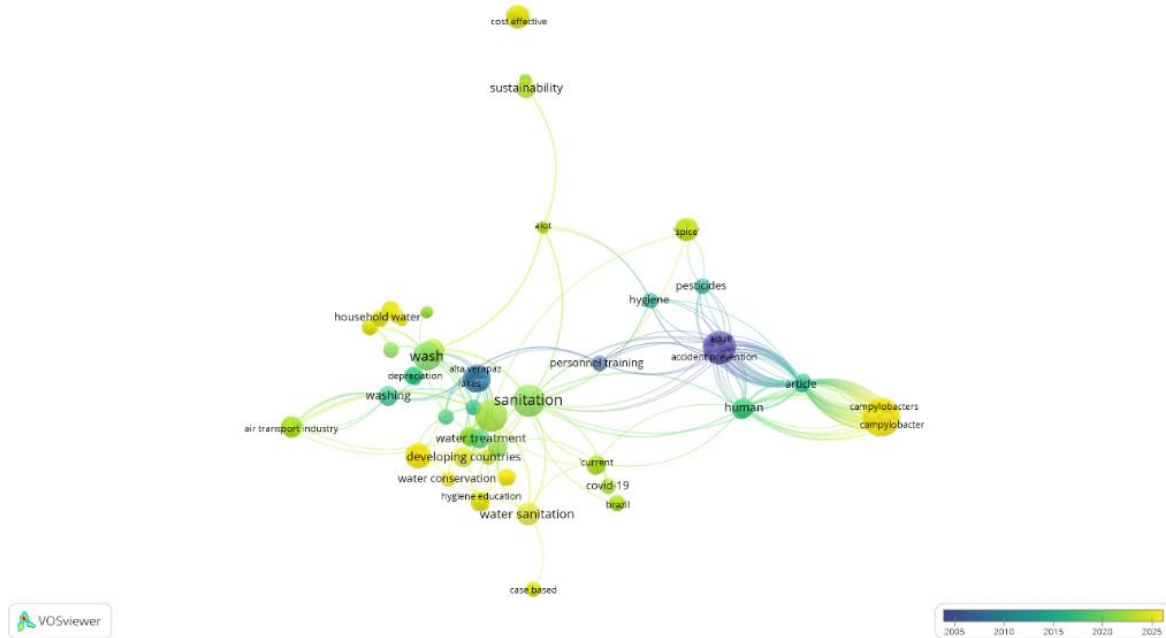


Fig. 11 VOSviewer map of sustainability and social justice in rural sanitation

Figure 11 shows that the main terms associated with sustainability and social justice in rural sanitation are sanitation, WASH, water treatment, hygiene, personnel training, developing countries, household water, and water and sanitation. The central position of sanitation and WASH indicates that the social dimension is mainly addressed through hygiene education, training, service access, and public health interventions. However, terms directly related to structural equity, such as gender, indigenous populations, disability, inequality, and social inclusion, do not appear as central elements in the map. This suggests that equity is still treated indirectly in the literature, mostly through WASH implementation and hygiene promotion, rather than as a dominant analytical dimension of sustainable rural sanitation.

4. Discussion

The bibliometric data show that there has been more study on rural sanitation and sustainable development in the last few years, but not always in the same way, depending on the "lens" used. This inequality is not just about numbers; it's also about knowledge. The field tends to focus on the most measurable and publishable aspects (efficiency, removal rates, effluents) while ignoring important factors for real sustainability, such as governance, Operation and Maintenance (O&M), post-construction support, and social justice. This disparity between infrastructure investment and sustainable service delivery has been demonstrated in African contexts, where, despite substantial investments in WASH, only approximately 40% of interventions incorporate sustainability features, largely attributable to inadequacies in management and public policy orientation [17]. In this way, the observed patterns suggest that a technocentric bias characterizes the prevalent

terminology: sustainability is often discussed in terms of technological performance or economic viability rather than service continuation within specific social and institutional contexts.

Table 1 demonstrates that each search approach encompasses a unique aspect of the field: Query 1 organizes the discussion based on the SDG/economic sustainability framework; Query 2 shows that the technological-environmental dimension (treatment, effluents, and removal) is the most important. Query 3 looks at the social dimension mostly through the use of WASH programs. In general, the comparison shows that there is a theme imbalance: the literature focuses on technical performance and generic wastewater terminology, whereas features like governance, O&M, post-implementation monitoring, and explicit equity are less visible in the dominating clusters.

Compared with previous bibliometric studies on SDG 6, WASH, and wastewater treatment, this study confirms the growing scientific interest in sanitation and sustainability. However, unlike previous studies that mainly describe publication growth, country productivity, collaboration patterns, or technological trends, the present research identifies a more specific imbalance in rural sanitation literature. The findings show that technological performance and economic sustainability are more visible than governance, operation, and maintenance, post-implementation monitoring, equity, and service continuity. Regionally, the study also shows that Latin America remains less visible in indexed scientific production when compared with Asia, North America, and Europe.

Table 1. Comparison of bibliometric approaches and dominant gaps (Source: Author's own)

| Comparative dimension | SDG 6 and sustainability | Technologies and performance | Equity and inclusion (WASH) |
|--------------------------------------|---|--|---|
| Dominant “lens” of the field | Sustainable development and sustainability (economics) | Environmental Engineering and efficiency (removal/effluents) | Social implementation (education/training) |
| Main clusters observed | sustainable development, economics, onsite sanitation systems, sewage | wastewater treatment, effluents, septic tanks, pollutant removal, controlled study | hygiene education, personnel training, and developing countries |
| Most visible evidence | Normative approaches/SDG policy + service economy | Technical/experimental evidence and performance | Evaluation of interventions and capacity building |
| Interpretive risk | “Sustainability” reduced to costs/feasibility | “Sustainability” reduced to environmental efficiency | “Equity” reduced to implementation (not structural inequality) |
| Most likely gaps (according to maps) | Governance, O&M, post-implementation monitoring | Adoption, affordability, community management, governance | Gender/indigenous/disability with low centrality |
| Reading for Latin America | Low visibility in indexed databases and under the filter applied in the SDG/sustainability framework. | Localized technical evidence (Brazil/Chile) in the analyzed records. | Limited recoverable production and thematic dispersion in the recovered sample. |

The novelty of this study lies in the integration of three complementary bibliometric lenses-SDG 6 and sustainability, technological performance, and equity and inclusion-to evaluate rural sanitation not only as a technical or environmental issue, but also as a long-term service sustainability problem. Previous studies have mainly examined SDG 6 and WASH-related research, [9, 15], sanitation technologies and wastewater treatment performance, [5, 6, 19-21], or rural service sustainability and management challenges, [7, 10] as relatively separate lines of inquiry. In contrast, the present study compares these dimensions within a single analytical framework and shows that the literature remains structurally imbalanced: techno-environmental and economic-normative approaches are more visible than governance, operation and maintenance, post-implementation monitoring, explicit equity, and service continuity. Therefore, this work contributes by demonstrating that the sustainability of rural sanitation is only partially represented in global scientific production, with a particularly low visibility of Latin America in indexed databases.

Compared with previous bibliometric or thematic approaches, the present study achieved a more comprehensive interpretation of rural sanitation sustainability for three main reasons. First, instead of relying on a single general search equation, the analysis used three complementary bibliometric lenses: SDG 6 and sustainability, technological performance, and equity and inclusion. This strategy made it possible to distinguish the specific contribution and limitations of each research stream, which would be less visible in a single-query approach. Second, the combined use of Scopus and Web of Science, together with metadata cleaning and keyword co-occurrence analysis, allowed a broader and more consistent identification of temporal trends, country participation, and

dominant thematic clusters. Third, the comparison among the three maps enabled the identification of structural absences in the literature, particularly governance, operation, and maintenance, post-implementation monitoring, explicit equity, and service continuity. Therefore, the advantage of this study is not related to reporting higher technical performance than existing sanitation technologies, but to providing a more integrated and policy-relevant diagnosis of the scientific field. While previous studies have mainly reported technological efficiency, WASH intervention outcomes, wastewater treatment performance, or SDG-related trends separately [5, 6, 9, 15, 19-21], this research shows why those lines of inquiry remain insufficiently connected and how this fragmentation limits the understanding of long-term rural sanitation sustainability, especially in Latin America.

In Query 1, which captures the explicit link between rural sanitation and sustainability/SDG 6, production appears recent and low in volume within the applied filter, with an upsurge toward 2024. This behavior is consistent with the progressive consolidation of SDG language in the literature, where "sustainability" operates as a framework for legitimacy and alignment with global agendas. Nevertheless, the co-occurrence map shows a concentrated nucleus on sustainable development and economics, suggesting that sustainability is operationalized mainly as an economic viability (costs, financing, efficiency) and not as sustained service performance. This trend is observed in recent studies that, while presented as sustainable solutions, prioritize technical performance and removal efficiency or resource recovery, such as decentralized fecal sludge management systems using drying beds and natural coagulants [22] in the Journal of Water Process Engineering, with an emphasis on low cost and byproduct recovery. This is critical because, in rural

sanitation, the main breaking point is usually the post-implementation gap: systems that are built but do not function, are not maintained, or are not owned by the community [2-4]. The low prominence of terms like governance, monitoring, or maintenance indicates a disconnection between the sustainability discourse and the real determinants of continuous operation.

In Query 2, the pattern differs: there is a robust technical base and accelerated growth since 2020. The dominant clusters (treatment, effluents, removal, controlled studies) evidence that the technological subfield is guided by environmental efficiency metrics and experimental evidence. This finding is valuable because it confirms solid production about treatment processes and physicochemical performance, as shown in laboratory studies that evaluate the attenuation of organic compounds in treatment onsite units under different hydraulic loads and controlled conditions, prioritizing removal percentages and operative parameters as central performance indexes [19]. Nonetheless, it also exposes a structural limit: when the field is defined primarily by effluents, pollutant removal, or controlled study, sustainability may be reduced to the capacity to remove contaminants in controlled or pilot conditions. In rural scenarios, where systems depend on local capacities and community financing, service continuity may fail even if the technology is "efficient". As a consequence, a central field tension is observed: technical efficiency does not guarantee the sustainability of the service.

A transversal finding is the recurrent presence of the term sewage in more than one approach. This suggests conceptual overlaps: although the study focuses on decentralized rural sanitation, part of the indexed literature remains anchored in broad wastewater categories historically associated with urban approaches. This ambiguity makes it difficult to differentiate in-situ/decentralized rural sanitation from centralized systems

[23]. In contrast, recent investigations about decentralized systems underscore that sustainability depends on socio-ecological, cultural appropriation, and co-construction with user interaction, indicating that technical solutions fail when these are not integrated into local and dynamic practices. In bibliometric terms, low visibility on these topics replaces the attention over specific rural topics, like community management, appropriation, post-construction support, and maintenance, and reinforces the dominance of technical, predominant frameworks.

In Query 3, which was designed to capture equity and inclusion, the production is lower and intermittent, but with some growth in recent years. The dominant clusters linked to hygiene education and personnel training suggest that the social dimension appears mainly through the operational logic of WASH program implementation. However, despite including terms such as gender, indigenous peoples, and disability, these do not emerge as central nodes, reinforcing an "implicit equity". It is assumed that education or training resolves inequalities without necessarily addressing the material, territorial, or economic barriers that condition access and service continuity [24].

Figure 12 synthesizes the relative emphasis of the sustainability dimensions captured by each search equation. Query 2 concentrates evidence on techno-environmental performance, while Query 1 privileges the SDG framework and economic viability. Query 3 approaches the social dimension mainly through the WASH (education/training) implementation. Keeping low centrality on explicit equity and on post-implementation determinants. Collectively, an imbalance is observed: governance, operation and maintenance, monitoring, and service continuity present lower relative visibility; this supports the interpretation of "real sustainability" as partially "invisibilized".

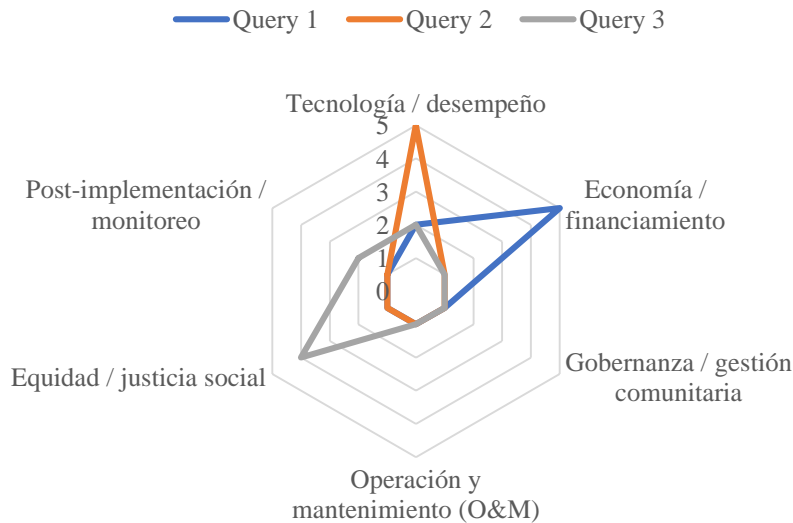


Fig. 12 Comparative profile of rural sanitation sustainability through bibliometric 'lenses' (Queries 1-3)

* Note: Qualitative scale (1-5) based on identifying emphases in bibliometric maps; represents relative intensity, not direct measurements.

The geographical distribution is also consistent with this diagnosis. The recurring leadership of Asia (particularly China and India) reflects research capacity and the centrality of the subject in national infrastructure and development agendas. This is evidenced by recent studies that systematically analyze the compatibility between the construction and operation of rural wastewater treatment facilities, emphasizing demographic, economic, and design variables as key determinants of performance [25]. In contrast, Latin America shows a low presence in the indexed records retrieved under the applied filter, which is significant given the magnitude of rural challenges in the region. Although there are recent contributions from the region regarding innovative technological solutions, such as the development of vermifiltration systems with alternative substrates for rural wastewater treatment [20], these works tend to concentrate on technical efficiency and the experimental performance of the technologies. This gap can be explained by a combination of factors: lower international indexing of regional journals, language barriers, less funding, and/or a greater weight of applied and “grey” technical literature (reports, project documents, institutional literature) that does not enter Scopus or Web of Science. In any case, the result suggests that the region does not yet represent a visible leadership in the global scientific agenda on sustainable rural sanitation, especially in social and institutional dimensions.

Overall, the analysis supports an interpretative conclusion: the global field is advancing, but it does so with an imbalance that privileges the techno-experimental and the economic-normative, while actual sustainability—understood as service continuity over time—remains partially obscured. Recent production shows significant advances in process optimization, such as pilot studies that statistically validate improvements in nitrogen removal through operational adjustments in decentralized biological systems, emphasizing efficiency and performance metrics under controlled conditions [21]. However, this type of contribution, while valuable from an engineering standpoint, does not necessarily incorporate the social, institutional, and territorial determinants that condition service continuity in rural contexts. For Latin America, this opens a strategic opportunity: to produce contextualized evidence that connects technology with governance, post-construction monitoring, institutional support, explicit equity, and territorial resilience, aligning rural sanitation with the SDG framework's principle of “leaving no one behind” [5-8].

5. Integrated Analysis and Implications

5.1. Comparative Regional Analysis

The results show a clear regional imbalance in scientific production on rural sanitation and sustainable development.

Asia, mainly China and India, leads the field, especially in studies related to sanitation technologies, wastewater treatment, and performance evaluation. North America and Europe show moderate participation, while Latin America has lower visibility, represented mainly by Brazil, Chile, and Guatemala. This limited presence is relevant because the region still faces major rural sanitation challenges associated with territorial dispersion, financing constraints, community-based management, and weak post-construction support. Therefore, the results suggest a mismatch between the practical importance of rural sanitation in Latin America and its visibility in indexed scientific production, reflecting broader patterns in which scientific knowledge production is concentrated in developed economies and leading countries in sustainability-related research fields, while emerging regions remain underrepresented [26, 27].

5.2. Thematic Evolution and Emerging Research Fronts

The thematic evolution shows that the technological and performance-oriented approach is the most consolidated research line, with strong growth after 2020 and dominant topics such as wastewater treatment, effluents, septic tanks, decentralized wastewater, and pollutant removal. This trend is consistent with studies emphasizing the technical efficiency and contaminant removal performance of decentralized and nature-based wastewater treatment systems in rural communities [28]. In contrast, the SDG 6 and sustainability approach is more recent and less developed, while the equity and inclusion approach remains intermittent. These patterns indicate that the field has advanced mainly through technical and environmental performance, whereas governance, operation and maintenance, affordability, post-implementation monitoring, gender, indigenous populations, disability, and service continuity remain emerging but underexplored research fronts, despite evidence highlighting persistent institutional, financial, and regulatory barriers affecting the long-term sustainability of decentralized wastewater systems [29].

5.3. Policy and Practice Implications

The findings suggest that rural sanitation policies should not be evaluated only through coverage or infrastructure indicators. Although technological performance is important, sustainable rural sanitation also requires operation and maintenance, financial viability, institutional support, community participation, post-construction monitoring, and equity. This perspective is consistent with studies emphasizing the importance of monitoring systems, data-driven decision-making, and integrated WASH management approaches for improving sustainable sanitation outcomes. This is especially important for Latin America, where many rural systems depend on community organizations with limited technical and financial support. Similar evidence from developing-country contexts shows that financial constraints, sociocultural factors, and weak monitoring processes continue to affect sanitation adoption and long-term sustainability [30].

Therefore, bibliometric evidence can help policymakers identify whether scientific research is addressing the real barriers that affect SDG 6 progress in rural areas.

5.4. Collaboration and Network Analysis

The bibliometric analysis revealed that scientific production is led by a few countries: China, India, and the US. In contrast, countries of the Latin American region are less prominent; the cause of that is attributed to lower collaboration networks, language barriers, and a low rate of publication in indexed journals. Consequently, the documents are neither captured by Scopus nor Web of Science. Increasing collaboration between Latin American institutions and productive regions can improve the methodology and visibility; the incorporation of local community-management systems and territorial inequalities into a global perspective will be beneficial. The presented challenges are aligned with SDG 6, which refers to improving developing contexts that are affected by institutional limitations, financial constraints, and insufficient technical capacities [31].

5.5. Gaps and Future Research Agenda

The identified research gaps include, in particular, the poor level of visibility of the topics related to governance, O&M, post-implementation monitoring, affordability, acceptance, equity, and service sustainability. Similar gaps were detected in the case of weak links between environmental governance and territorial planning approaches concerning rural sanitation [32]. For future investigations, the development of Latin American scientific production, carrying out comparative regional studies, integrating technology performance evaluation with institutional and sociological indices, and incorporating gender, indigenous, disabilities, and other disadvantaged groups into rural sanitation studies can be proposed. The rationale for this recommendation is provided by the existence of scientific evidence pointing to the importance of community participation, proper maintenance arrangements, financing, and institutional mechanisms in sustainable rural sanitation provision [3]. Finally, it is recommended and continuous update the bibliometric analysis.

6. Conclusion

Scientific output about rural sanitation associated with sustainable development has experienced recent growth. Nonetheless, the field demonstrates an uneven structure: although technological-environmental literature displays increased volume and consolidation, the explicit emphasis on sustainability and SDG 6, along with the aspects of equity and inclusion, remains less prominent and more sporadic, indicating a still incomplete integration of sustainability in its multifaceted context.

Asia is consistently at the forefront of scientific production, with China and India as the primary contributors across the three examined methodologies. In contrast, Latin

America has only a few nations that actively contribute, which evidences the literature gap in sustainable rural sanitation in the region.

The general approach is based on the SDGs, economic viability, a technological focus, effluents, pollutant removal, and a social dimension linked to the implementation of WASH programs. Other important factors for sustainability—such as governance, maintenance, post-implementation monitoring, and clear equity—are not as prominent as the general approach, reflecting an imbalance.

Latin America's top priorities are improving indexed scientific production, linking technological performance to real-world use, and moving toward more integrated ways that balance technical efficiency and institutional sustainability. This practice can solve fundamental problems related to mere technology acquisition and ensuring continuous service through efficient governance, financial stability, and social fairness.

The main novelty of this study is that it demonstrates, through a three-lens bibliometric approach, that rural sanitation sustainability has been unevenly represented in the scientific literature, with limited integration of governance, O&M, equity, and service continuity, especially in relation to Latin America.

As the main novelty of the conducted review, a three-perspective bibliometric approach was presented. It is concluded that sanitation sustainability in Latin America has been unevenly represented in the scientific literature, evidencing limited integration of governance and long-term operation and maintenance.

Recommendations

Based on the findings, it is important to improve Latin American scientific production on sustainable rural sanitation by getting more articles published in high-impact indexed journals and promoting the globalization of regional research. The low level of engagement makes it harder for the region to be seen in comparison to others and makes it harder for it to have an impact on the global debate over SDG 6.

It is also a good idea to encourage networks of collaboration between nations in Asia that are leaders in scientific production and countries in Europe and North America that are already established. Strengthening strategic co-authorships and joint projects could enhance technical capabilities, improve access to funding, and solidify research trajectories with increased breadth and significance.

In terms of themes, it is proposed to balance the technology approach with more focus on the service's institutional and social sustainability. Evidence indicates that

aspects such as governance, operation and maintenance, post-implementation monitoring, and financial sustainability are still not very visible in the dominant clusters, even though they are very important for service continuity in rural areas. Bringing these variables together may contribute to a closer and more comprehensive understanding of sustainability. In the same way, it is seen to be important to make the equity aspect of rural sanitation research clearer. While research pertaining to gender, indigenous populations, and disability exists, these categories do not constitute predominant axes. Their explicit inclusion in titles, abstracts, and keywords

would enhance their visibility and retrievability in forthcoming bibliometric evaluations, thereby reinforcing adherence to the principle of "leaving no one behind."

Lastly, it is suggested to keep an eye on the field's bibliometrics on a regular basis and publish the results based on different analytical methods. This follow-up would allow the evolution of the field to be examined over time in terms of thematic and geographical shifts, emerging research lines to be identified, and the likelihood of the previously identified gaps being addressed in the near future to be assessed.

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