

Mapping Water Quality Modelling and Catchment Management Research Trends for Sustainable Development in South Africa

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Abstract

Water quality degradation in river catchments remains one of the most critical environmental and infrastructural challenges facing South Africa, which mainly involves urbanisation, industrial activities, agricultural runoff, and climate variability. This research presents a scientometric analysis of water quality modelling and catchment management research carried out in South Africa from 2005 to 2025, aiming to map knowledge trends, key contributors, and thematic developments. Using Scopus-indexed data and VOSviewer for network analysis, 50 relevant publications were identified and analysed. The results indicate a steady increase in research output, particularly after the year 2020, with dominant contributions from institutions such as Rhodes University, the University of KwaZulu-Natal, and the University of Cape Town and from funding organisations such as the Water Research Commission and the National Research Foundation. Thematic analysis reveals strong research focus areas in hydrological modelling, water pollution, nutrient dynamics, and decision-support systems, with emerging emphasis on climate change and sustainable water management. These trends strongly align with global sustainability frameworks, particularly Sustainable Development Goals 6 (SDG 6: Clean Water and Sanitation) and 13 (SDG 13: Climate Action), as well as integrated water resource management principles. Despite this progress, gaps remain in interdisciplinary integration and the translation of modelling outputs into policy and practice. This study provides a structured knowledge base to inform research, policy development, and sustainable catchment management strategies in South Africa, with broader applicability to water-stressed regions globally.

Keywords: Water quality, Catchment management, Modelling, South Africa, Scientometric review, SDG 6, SDG 13.

1. Introduction

Water quality degradation in river catchments is a critical issue that threatens environmental sustainability, public health, and economic development, particularly in water-scarce areas like South Africa. Urbanisation, agriculture, and climate variability have all increased the need for effective catchment management techniques based on scientific modelling tools. Understanding how research in this sector has progressed is critical for directing future innovation, policy development, and sustainable water management.

The role of water is critical to social and economic functions and the sustainability of ecosystems in South Africa [1], [2], [3]. The state of surface water, in particular rivers and lakes, is a critical measure of the efficiency of management and resilience to environmental changes [3], [4], [5]. Catchments play a critical role in the provision of urban and agricultural water, supporting biodiversity and the equitable distribution of water [1], [6], [7]. However, catchments are increasingly threatened by climate change, population growth, and pollution factors [8], [9]. Furthermore, land and water activities within a catchment are closely linked to surface water contamination [10],

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[11]. The impact of decreasing water quality and changes in hydrological cycles is a critical cost factor for socioeconomic factors because of increased costs related to water treatment, degradation of ecosystems, and decreasing water availability [9], [12]. Over the last ten years, academic interest in water quality modelling and catchment management has increased in most parts of the world [10], [13], [14]. This has focused mainly on developing predictive models that evaluate pollutant transport and integrated management approaches to mitigate environmental and human health risks [15], [16], [17]. As such, although interest in the subject has grown, geographic bias, methodological disparity, and fragmentation are evident in the literature, with only a limited number of studies dealing with South African catchments [18], [19].

In South Africa, there are challenges in catchment management because catchments are characterised by semi-arid to humid climates, which cause water resources to suffer from stressors [18], [20], [21]. Additionally, water resource management, including water resource governance, has an organised institutional and legal framework in which national, regional, or local institutions play important roles [22], [23], [24]. In this context, water resource governance in South Africa involves water resource allocation, monitoring, and catchment protection by the Department of Water and Sanitation, an important organ of the national government in line with water resource governance in South Africa [25], [26], [27]. Catchment management agencies, on the other hand, have been established to carry out integrated catchment water resource management at the local or regional levels in South Africa, which is in line with water resource governance in South Africa [12], [24], [26]. Although such institutions exist, water resource governance in South Africa has experienced weaknesses in terms of water resource capacity and inequitable water resource distribution, among other factors [24], [28], [29].

In recent years, there has been an evident rise in scientific interest in water quality modelling, catchment, or water quality measure modelling [30], [31], [32]. Various studies have been conducted to develop predictive water quality, transport modelling, or predictive water quality methods, using different methods to strengthen water catchment strategies [27], [33], [34], [35]. Although this scientific interest has increased, there

have been some imbalances in geographical studies, including in water quality catchments, scientific publications, and the need for more studies on South Africa water catchments [19], [27], [36]. In fact, only a few scientometric studies related to South Africa exist. Scientometric analyses for the mapping of the relevant body of literature and its key contributors and themes over time, within the context of catchments and water quality studies in the context of South Africa, have yet to receive sufficient focus for the purpose of informing future research directions and for the better promotion of interdisciplinary collaboration.

Consequently, this study applies a bibliometric review methodology covering the period of 2005-2025 to explore the development of scientific research on the modelling of water quality and the management of catchments in South Africa. The year 2005 was chosen as the beginning point to capture two decades of research advancement and to correspond with the postimplementation phase of important national water policies, such as the National Water Resource Strategy. Using knowledge mapping techniques, this review reveals the following: (a) trends in South Africa's publication output on water quality and catchment management during the last 20 years and (b) publication trends, document types, key research keywords, publication sources, affiliation analyses, and funding sponsors that establish discourse in the region. Through an integration of the learning trajectory and framework of research in this field, this study offers insight for researchers, water institutions, and policymakers, providing a systematic reference point for future research, planning, and sustainable catchment management in South Africa. The methodology and conclusions of this study are applicable to other water-stressed areas with comparable environmental and governance issues, despite the study's focus on South Africa.

2. Methodology

In this study, a systematic scientometric review was undertaken with adherence to the PRISMA to facilitate a high level of transparency and rigor in data acquisition [37]. The literature available in prominent scientific databases that falls under the study of water quality modelling and management in South African catchments for the period of 2005-2025 was identified and assessed

for scientometric study. Network analyses were further carried out to explore the structure and dynamics of the research landscape. These involved the coupling of sources and countries, as well as keyword co-occurrence, and were used for determining research clusters and themes and for studying knowledge links within the landscapes as well as the affiliation and funding sources related to the study area [38]. The scientometric mapping method aided the analysis of thematic developments and collaborative research efforts related to water quality research and catchment management research carried out in South Africa.

2.1. Data retrieval

Scopus was chosen as the primary source, as it is a comprehensive source of peer-reviewed publications, offering adequate metadata for reliable scientometric analysis [39], [40]. A keyword-based search using a structured approach was performed on December 24, 2025, for documents published on water quality modelling and catchment management in South Africa. The following keywords were applied in the title, abstract, and keyword fields as search strategies: "water quality" OR "water pollution" OR "catchment management" OR "watershed management" AND "modelling" OR "simulation" OR "monitoring" OR "assessment" AND "South Africa". An initial search resulted in 93 documents. To ensure the relevance and quality of the dataset, a set of clearly defined inclusion and exclusion criteria was adopted, as shown in Table 1, which restricted the analysis to peer-reviewed articles, conference papers, and reviews directly related to water quality and catchment management in South Africa.

Table 1. Data screening criteria for inclusion and exclusion.

Criteria	Inclusion	Exclusion
Geographical scope	South Africa	Studies not related to South Africa
Language	English	Non-English
Publication range	2005-2025	Published before 2005
Subject area	Environmental Science and Engineering	Studies outside Environmental Science and Engineering
Type of document	Journal, review, conference, and books	Editorial, retracted, and concept paper.
Publication status	Published	Article in press

After this filtering process, 50 documents were selected for scientometric analysis. Figure 1 shows the general research technique used in this study.

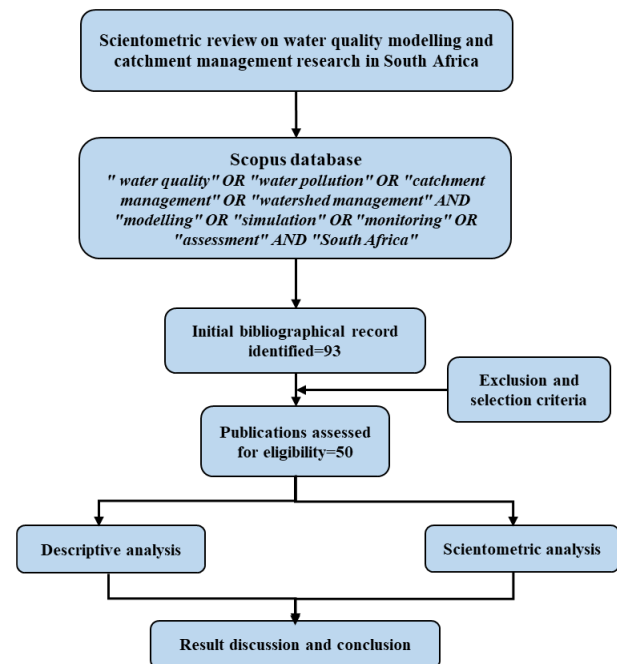


Figure 1. Study flow diagram.

2.2. Data analysis

In this study, scientometric mapping and network analyses of trends of research contributions and themes in South African water quality and catchment research were performed, and a scientometric network analysis software program named VOSviewer (version 1.6.18) was utilised together with a Microsoft Excel package. These tools are effective for data evaluation on the basis of publication trends and author-keyword themes [40], [41]. In the VOSviewer software, cut-off points for co-citation, number of publications, source, and keyword occurrence were used for the production of network visualisations [42], [43]. The thickness of the links denotes the strength of the connection, and the color of the clusters denotes different research or collaborative efforts. By adopting this integrated bibliometric and scientometric analysis, an insightful understanding of the publication trends, contributing authors, and subject matters for future references for further studies and evidence-based management in the catchment in South Africa was gained.

3. Results and Discussion

This section illustrates and discusses the findings of the scientometric analysis, which include publishing patterns, document types, keyword co-occurrence, and institutional contributions. The findings are interpreted to highlight emergent research issues, patterns of collaboration, and consequences for South African water resource management.

3.1. Yearly publication trend

The data were subjected to statistical analysis to determine the trends of research contributions to water quality modelling and catchment management for the period between 2005 and 2025, as shown in Figure 2.

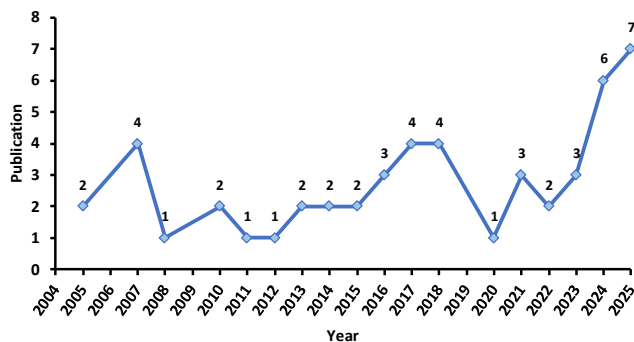


Figure 2. Research annual publication distribution from 2005-2025.

The initial publications in terms of scholarly output in 2005 comprised two publications, and it rose to four in 2007, which signifies that it was an unfolding body of knowledge with dispersed efforts. The phase between 2008 and 2012 signifies a low level of engagement, with one to two publications per annum, which signifies development and awareness of water quality. Between 2013 and 2016, there was some degree of consolidation, where the number of publications was standardised to be either two or three annually. This was when interest in pollution, modelling, and water resource management at the catchment scale was becoming more pronounced at the local and global levels. There was some acceleration in the pace of publication productivity between 2017 and 2018, where there was an average of four publications yearly. The post-2020 period showed a distinct rising pattern, despite a decrease in 2020, which was likely caused by disturbances to research efforts more generally, which may be linked to disruptions induced by the

COVID-19 pandemic. Publications rose steadily from three in 2021 to six in 2024, peaking at seven in 2025. This recent surge underlines renewed and hardening scholarly interest impelled by rising concerns related to climate variability and water pollution, coupled with the need for data-driven catchment management strategies.

The general trend of publications seems to be moving from exploratory studies toward a mature and sustained research field, with increasing output in recent years underlining the growing importance of water quality modelling and catchment management for addressing environmental and water security challenges in South Africa, which are maintained in a sustainable way.

3.2. Document type

The dataset was also queried to investigate the types of documents that have been published concerning the modelling of water quality and catchment management in South Africa during the period 2000-2025, as depicted in Figure 3. It is evident that peer-reviewed articles form the bulk of the literature on the topic since they contribute 41 articles (82%) of the total document, which suggests that the topic is informed by scientific results whose validity has been verified. Conference papers account for five (5) publications, accounting for 10% of the total documents and provide significant outlets for the initial dissemination of novel methods and preliminary results.

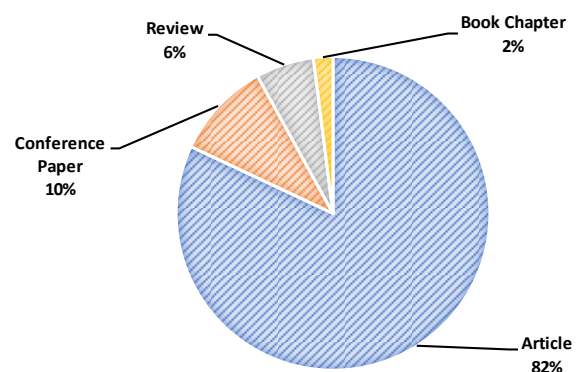


Figure 3. Type of published document and its distribution.

These publications can act as stepping stones for the publication of full papers in the form of journal publications in fields such as hydrological simulation research and decision support systems. Review articles, accounting for three (3) publications, accounting for (6%) of the overall publishing output, are relatively few, which

indicates, in turn, that despite the body of research having grown, there is much work to be done in terms of theoretical integration.

Finally, book chapters contributed to one (1) publication (2%), representing the selective use of synthesised knowledge in academic scholarship, mainly for pedagogical intentions. The dominance of journal articles with a high percentage of 82%, coupled with contributions from conference proceedings, reviews, and book chapters, tends to suggest a well-established yet still maturing body of research with sound empirical bases and potential for higher-level synthesis work towards a more sustainable water quality and catchment management system in South Africa.

3.3. Keyword cooccurrences

The keyword search analysis enables a thorough insight into the thematic arrangement, research focus, and connectivity of studies in the South African field of water

quality models and catchment management. Table 2 shows the top 42 most researched keywords showing topics of interest in the study field between 2005 and 2025, and Figure 4 shows the searched keyword network visualisation with macro-clusters whose constituents portray study themes of interest. Keywords that frequently appear in the search and have a relatively high total link strength are thematic hubs that organise the field of study around them. The most prominent keyword was "water quality" (Occ. = 34; TLS = 286), thereby emphasising its importance as the focal thematic area in the body of knowledge. The close association with other words suggests that it is essentially the key area that dominates the understanding or planning apropos to modelling, assessment of pollution, and planning on how to manage them. Closely associated words such as "catchments" (Occ. = 26; TLS = 254), "South Africa" (Occ. = 26; TLS = 230), and "rivers" (Occ. = 22; TLS = 200) suggest relevance at the catchment scale and contextually at the geographical level.

Table 1. Study area with the most searched keywords.

S/N	Keyword	Occ.	TLS	S/N	Keyword	Occ.	TLS
1	Water quality	34	286	22	River pollution	5	63
2	South Africa	26	230	23	Nonhuman	5	60
3	Catchments	26	254	24	Land cover	5	44
4	Rivers	22	200	25	Western cape	4	37
5	Runoff	20	205	26	Sustainable development	4	22
6	Water management	18	172	27	Sub-Saharan Africa	4	45
7	Water resource	12	124	28	Simulation	4	35
8	Hydrological modelling	11	86	29	River	4	49
9	Climate change	11	81	30	Rain	4	54
10	Water resources	9	72	31	Pollution	4	33
11	Water pollution	8	75	32	Ph	4	66
12	Water conservation	8	82	33	Land use change	4	23
13	River water	8	84	34	Information management	4	41
14	Human	7	77	35	Hydrology	4	36
15	Environmental monitoring	7	87	36	Hydrological response	4	31
16	Southern Africa	6	66	37	Geographic distribution	4	56
17	Nutrients	6	58	38	Eutrophication	4	36
18	Modelling	6	64	39	Decision making	4	40
19	Land use	6	51	40	Controlled study	4	53
20	Africa	6	70	41	Computer simulation	4	35
21	Surface water	5	48	42	Catchment area (hydrology)	4	52

3.4. Publication sources

The publication sources analysis provides an overview of the disciplinary orientation, level of influence, and distribution of water quality modelling and catchment management literature in South Africa. The criterion set was a minimum of two (2) documents, and only nine (9) out of 29 documents met the criterion. Table 3 shows the publication source with a minimum of two (2) documents, and Figure 5(a) depicts the network visualization for the publication source. The findings show the concentration of outputs in highly cited peer-reviewed journals related to the discipline and thus the level of maturity in the field of study. Water SA stands out among these sources in that five (5) publications originated from this outlet, thereby affirming its crucial role in being a prominent outlet for disseminating water research publications that are directly applicable to South Africa. Although its citation number is relatively low, its familiarity is a result of its aptness in relation to local applications. The high-impact international journals, such as Hydrological Processes (two papers; 111 citations) and Physics and Chemistry of the Earth (3 papers; 71 citations), have a high citation density, meaning that even though there is less research being published through such channels, their impact on the research community is quite pronounced. Thus, the research conducted by South Africa on hydrological dynamics and processes, as well as Earth's processes, resonates well with the global research community. Journals such as the Journal of Environmental Management, Science of the Total Environment, and South African Journal of Science are only a few that have submitted three publications, which reflects the emphasis on environmental management and interdisciplinary research studies on this subject area. The journals make it easy to combine research related to water quality modelling studies and other research studies concerning ecosystem health, pollution management, and resource management. Specialised journals such as Water (Switzerland) and Water Resources Management emphasise the emphasis of the literature in terms of methodologies/methods, specifically regarding hydrological simulation modelling, decision support systems, and comprehensive water resource management.

On the other hand, modelling Earth systems and the environment has increased resort to modelling in South

African catchments. In conclusion, the trend of sources of publications shows a balanced publication pattern that combines local journals, which aid in the formulation of policies, with prominent international journals that boost citation impact. This trend indicates that the research environment has matured to a stage where South African research related to the quality of water and management of catchments has contributed at the local and international levels.

In addition, Figure 5(b) provides a density map where the concentrated research efforts and collaborations for water quality modelling and catchment management research in South Africa for the period 2005-2025 are visually presented. The density variations indicate areas of high and low research activity, with darker regions representing concentrated publication output and collaboration intensity, whereas lighter regions indicate comparatively underexplored areas. The density map is created via VOS viewer software based on co-occurrence and publication information. The darker areas show the concentrated research efforts and levels of cooperation in the research, and the brighter yellow areas denote the portions where the largest number of research papers have been published or produced. The areas where fewer research papers have been produced and where levels of cooperation among research authors appear as light areas.

Table 3. Publication sources with a minimum of two (2) documents.

S/N	Source	Documents	Citations	TLS
1	Water SA	5	12	28
2	Water (Switzerland)	3	34	26
3	South African Journal of Science	3	41	25
4	Science of the Total Environment	3	45	23
5	Physics And Chemistry of The Earth	3	71	19
6	Journal Of Environmental Management	3	42	12
7	Water Resources Management	2	25	27
8	Modelling Earth Systems and Environment	2	48	18
9	Hydrological Processes	2	111	8



Figure 5(a). Network visualisation for the publication source.

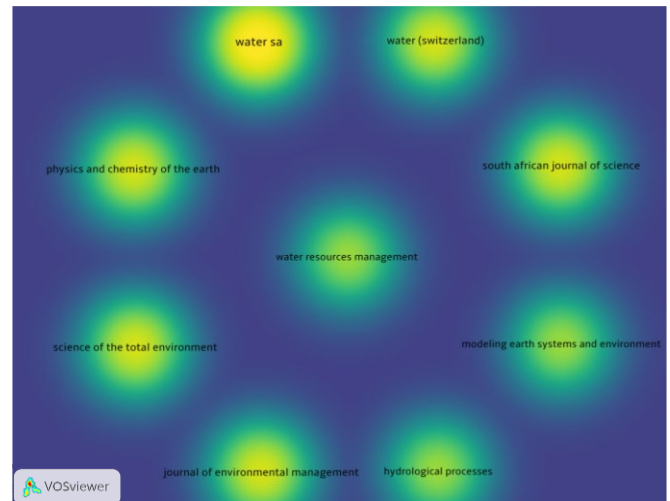


Figure 5(b). Density map for the publication source.

The number of publications in these journals highlights the ever-increasing academic interest in water quality and catchment studies in South Africa. Scholars are increasingly using these platforms to share information and networks to respond to one of the most pressing challenges in water resources in southern Africa because of climatic variability and environmental impacts.

3.5. Affiliation analysis

Affiliation analysis was used to establish the major institutions that have contributed to water quality models and catchment management studies in South Africa. The top 15 affiliations related to the study between the years 2005 and 2025 are shown in Figure 6.

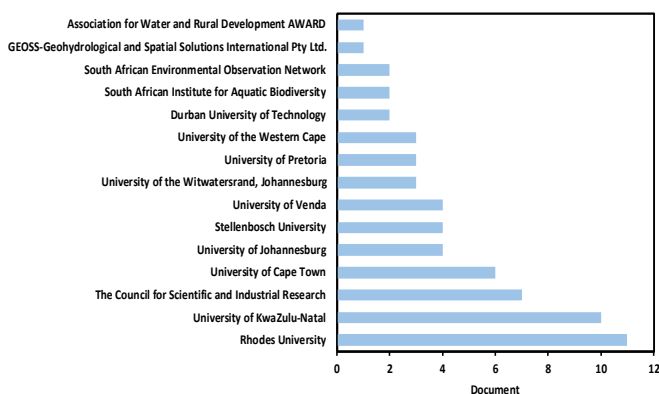


Figure 6. Affiliation analysis related to the study area.

The focus of the research has been on national universities and research institutions. Rhodes University

has the top position, with 11 papers on the list, and reflects a clear research priority concerning the evaluation of catchments, modelling of water quality, and integrated management strategies. The University of KwaZulu-Natal, with 10 papers, and the Council for Scientific and Industrial Research (CSIR), with seven (7) papers, are the next highest in the list, which clearly indicates a good level of involvement with applications of water resource management practices. The University of Cape Town, with 6 papers, and the University of Johannesburg, with four (4) papers, also indicate well-developed capabilities with hydrological modelling practices. The middle-level contributors include Stellenbosch University, University of Venda, University of the Witwatersrand, University of Pretoria, University of the Western Cape, and Durban University of Technology. Notably, the fact that publications are made by research-based entities such as the South African Institute for Aquatic Biodiversity, South African Environmental Observation Network, and others (including private research organisations such as GEOSS-Geohydrological & Spatial Solutions International Pty Ltd.) signifies a level of collaboration between research entities in their respective fields. The affiliation network has a core-periphery pattern whereby flagship institutions are pacemakers for the advancement of concepts and models, whereas applied institutions and networks are responsible for the implementation of monitoring, exploratory, and intervention programs within the realm of water quality improvement and catchment management within the Republic of South Africa. While this concentration highlights the presence

of established centers of excellence, it also raises the possibility of restricted research diversity and uneven capacity development among institutions.

3.6. Funding sponsor analysis

A critical discussion of funding sources has identified key institutions that fund research in water quality modelling and catchment management in South Africa, as shown in Figure 7.

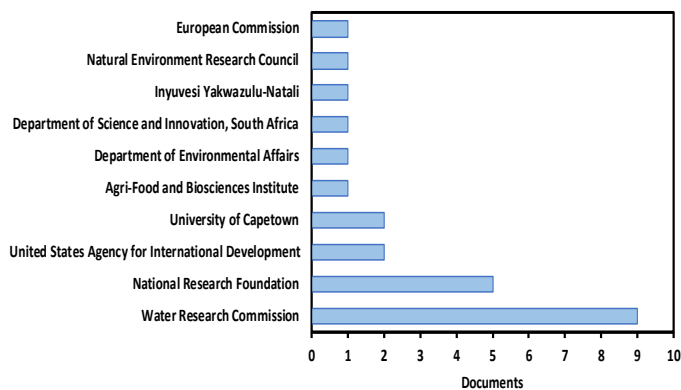


Figure 7. Top funding sources related to the study area.

According to the Scopus database, the funding institution with the highest number of publications is the WRC, with a total of nine (9) publications. The thrust of WRC management in advancing water research includes its focus on catchment management, water quality, and climate change research. The National Research Foundation (NRF) is second with five (5) publications, indicating its focus on promoting scientific capability and excellence in research by South African tertiary institutions. The international funding bodies that supported scientific publications with at least one paper included USAID and the European Commission, with a total of two (2) and one (1) publications, respectively. These findings indicate that water resource challenges are of international interest. Other supporters, including the University of Cape Town, Agri-Food and Biosciences Institute, Department of Environmental Affairs, Department of Science and Innovation (South Africa), Inyuvesi YakwaZulu-Natali, and Natural Environment Research Council (UK), jointly supported 1-2 publications. This highlights a diversified portfolio that includes support from the national and international sectors in addition to the institution. This shows how there is a mix of local and international funding that promotes

both investigative and practical work. The role of various types of nationwide funding, such as the WRC and NRF, in this network clearly shows that there is much dedication to solving water quality and catchment management issues in South Africa, and international funding in this platform allows for the sharing of ideas from across the globe. The modest contribution of international funding bodies provides an opportunity to improve global research collaboration and financing diversity.

3.7. Implications for Sustainable Water Resource Management

The findings of this study demonstrate a strong correlation between South Africa's current research trends and global sustainability targets, especially SDG 6 and SDG13. The increasing importance of scientific methods in promoting sustainable and climate-resilient water resource management is shown in the popularity of topics such as hydrological modelling, climate change, and water quality monitoring. Improving watershed planning, pollution management, and water allocation all depend on the water quality models and decision-support systems found in this study. In response to mounting environmental challenges, these technologies allow stakeholders to evaluate risks, model future scenarios, and put proactive management measures into action.

Nevertheless, despite these developments, there is still little integration of modelling results into operational and policy decision-making. The efficient use of these techniques in practical settings is nevertheless hampered by issues such as data scarcity, insufficient technical capability, and institutional fragmentation. This emphasises the necessity of improving the integration of research, policy, and practice, especially through cooperation between local stakeholders, governmental organisations, and academic institutions.

3.8. Research Gaps and Future Directions

Even with the reported increase in research output, several gaps still exist. First, the very modest number of publications indicates that the discipline is still in its infancy, making it difficult to adequately capture patterns at the national level. Second, there is a significant concentration of research in a few top universities, which

may limit the sector's ability to build its capacity and disseminate knowledge more widely even though it is a sign of centres of excellence.

Additionally, the data show that interdisciplinary approaches are not well integrated, especially in regard to connecting hydrological modelling with socioeconomic and governance aspects. Additionally, more attention must be given to underrepresented areas, including rural catchments, real-time monitoring systems, and the integration of local and indigenous knowledge into frameworks for water management.

Future research should prioritise the development of integrated, data-driven, and policy-relevant modelling approaches, as well as strengthening international collaboration to enhance knowledge and innovation.

3.9. Limitations of the Study

There are various limitations to this study. First, using only the Scopus database may result in database bias because pertinent research that was indexed in other databases or grey literature sources was excluded. Second, the robustness of the trend analysis and the generalisability of the results may be limited by the comparatively small sample size of 50 documents. Furthermore, studies concentrating on regions, rivers, or catchments that did not specifically identify the nation in their metadata would have been overlooked by the keyword search technique, which included general phrases such as "South Africa".

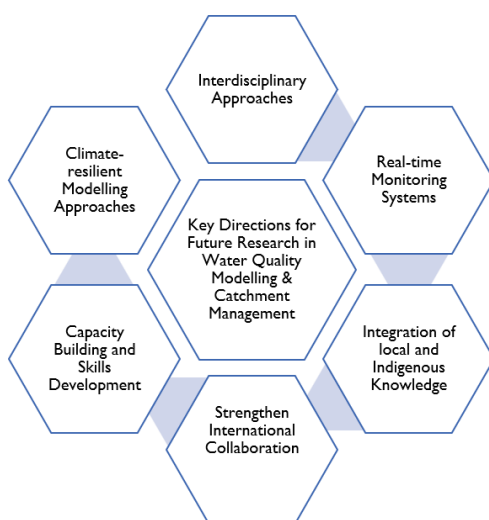


Figure 8. Key directions for future research in water quality modelling and catchment management.

To provide a more thorough picture of the research environment, future studies should use multi-database techniques and expanded search strategies. These limitations should be considered when interpreting the results. Figure 8 depicts significant areas for future research in water quality modelling and catchment management. While these priorities are based on the South African context, they are broadly applicable to other water-stressed regions worldwide.

4. Conclusion

The scientometric analysis conducted in this review also extensively maps the body of literature existing in water quality modelling and catchment management in South Africa from 2005-2025, revealing an area of studies that has evolved. Keywords co-occurrence and network-centric studies have also focused on research foci that have emerged over time, including climate-driven hydrological effects, vulnerability to floods, sustainable intervention for catchments, and model-driven decision-making assistance, which thereby show the industry's responsiveness to simple environmental issues.

The study highlights water SA, water (Switzerland), and hydrological processes as the top publication channels, and institutional analysis reveals the critical contributions of Rhodes University, the University of KwaZulu-Natal, and CSIR as the key drivers for conceptual and applied research. The funding analysis confirms the critical support provided by national and international organisations, the Water Research Commission, and the National Research Foundation as crucial drivers for building research capability and knowledge translation.

These findings cumulatively indicate a sound, integrated, and multidisciplinary research landscape that is well placed to inspire solutions to South Africa's high-priority water resource challenges. By pinpointing emerging themes, influential institutions, and key funding sources, this study offers a strategic path for future research in support of evidence-based catchment management, climate-resilient water governance, and sustainable water resource planning. The study outcome also indicates a vibrant, interlinked, and interdisciplinary research environment that is well equipped to address the pressing issues concerning the use of water resources in

South Africa. Through the identification of thematic practices, core research organisations, and key research funders, this research presents a particular roadmap for future research efforts and supports informed catchment and water resource management practices.

Competing Interest Statement

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data Availability Statement

All data generated or analysed during this study are included in this article.

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