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Scope, trends and opportunities for socio-hydrology research in Africa: A bibliometric analysis

Socio-hydrology research is concerned with the understanding of how humanity interacts with water resources. The purpose of this study was to assess the disparity between global and African trends as well as developments in the research domain of socio-hydrology. From the viewpoint of a multitude of research themes, multi-author collaborations between African and international researchers and the number of publications produced globally, the results reveal that the field of socio-hydrology is still underdeveloped and yet nascent. At a global level, the USA, China, and the Netherlands have the highest number of scientific publications, while in Africa, South Africa dominates, although these scientific publications are significantly much lower than the global output. The output of scientific publications on socio-hydrology research from Africa increased from 2016, with significant output reached in 2019. Water management and supply, hydrological modelling, flood monitoring as well as policies and decision-making, are some of the dominant themes found through keywords co-occurrence analysis. These main keywords may be considered as the foci of research in socio-hydrology. Although socio-hydrology research is still in the early stages of development in Africa, the cluster and emerging themes analysis provide opportunities for research in Africa that will underpin new frontiers of the research agenda encompassing topics such as the (1) impacts of climate change on socio-hydrology; (2) influence of socio-hydrology on water resources such as surface water and groundwater; (3) benefits of socio-hydrological models on river basins and (4) role of socio-hydrology in economic sectors such as agriculture. Overall, this study points to a need to advance socio-hydrology research in Africa in a bid to address pressing water crises that affect sustainable development as well as to understand the feedback mechanisms and linkages between water resources and different sectors of society.

Significance:

- The field of socio-hydrology is still under-researched in Africa.
- Limited research could be attributed to a lack of expertise, resources and data limitations.
- Socio-hydrology research is likely to be strengthened through collaborations between Africa and other developed countries.
- Existing gaps present opportunities to advance socio-hydrology research in Africa.

Introduction

For decades, the increased interactions between humans and the environment on a broader scale have significantly intensified impacts on societal development, particularly through the co-evolution between society and water systems.¹ Impacts of human interventions on the ecosystem are often manifested in, for example, landscape changes, accelerated mass wasting, pollution, over-abstraction of natural resources including water, and climate change. This problem is exacerbated due to the present industrial, geo-politised, religious, as well as socio-cultural activities that are highly dependent on water resources.² These interdependencies are referred to as the Water-Energy-Food-Ecosystems Nexus.³ This Nexus is mediated by policy decisions relevant to water resource management and planning for societal benefit. Such interrelated decisions are significantly influential to both water resources and society's responses, undoubtedly due to the coupling and feedback mechanisms that exist between water systems and societal behaviour.⁴ The relationship between water systems and society is described by different authors, for example, as 'system of mutual interaction',⁵ 'hydrosociology',^{6,7} 'hydro-social'⁸ and recently 'socio-hydrology',⁹ and has emerged as a research field of interest, attracting both hydrologists and social scientists.

Nowadays, the term 'socio-hydrology', which was coined by Sivapalan et al.,⁹ is considered a novel subject matter, that is duly concerned with the science of people and water, and specifically aimed at understanding the ever-changing processes and co-evolution of the coupled human-water systems.⁴ Society, in general, forms part of hydrological systems, including the water cycle. As a result, the two-way research efforts on the inherent impacts on humanity and water provide a holistic understanding of long-term progressions and can therefore lead to effective support for water resource management and planning.¹⁰ Several socio-hydrological research studies focusing on various themes have been reported in the literature. These research themes include the conceptualisation and theoretical framework of the subject matter for the benefit of water resource management, planning and sustainability,¹¹⁻¹⁵ socio-hydrological dynamics and modelling,¹ power relations and political governance.^{13,16} Despite such incredible development in socio-hydrology, as evident from the proliferation of the research publications, the socio-hydrology scholar-practitioner footprint in Africa is still nascent. Contributions that socio-hydrology research bring forth, particularly towards better water resource management and planning,

especially across developing countries, in a changing world, need to be well documented and appreciated. To achieve this, there is a need to understand the current state of research through scientific mapping of the social research patterns and trends as well as the existing gaps in this emergent discipline. The current contribution, therefore, theoretically and empirically advances, through investigating and documenting the progression of socio-hydrology (hereafter the term is also used to include hydrosocial) research in Africa, based on bibliometric analysis.

Data and methods

The data analysed in this study were retrieved from the Web of Science and Scopus databases. These databases are considered to have a comprehensive archive of the scientific literature and have been widely used, particularly for the analysis of scientific publications.¹⁷ The search strings were: “socio-hydrological* research” or “studies”, “socio-hydrological* modelling” or “models”, “socio-hydrological* systems” or “dynamics”, “socio-hydrological* resilience”, “sociohydrologic* dynamics” or “models”, “hydro-socio* research” or “studies” and “human-water* interaction” or “relationships.” Each search string was placed in a separate row, with the added rows joined by the OR logical, implying that the search outcome displays documents based on the first topic [OR] the second topic, and so on. The quotation marks were included in each search so as to confine the search conditions, thereby ensuring the robustness of the search outcomes. In addition, the term “Africa”, was added in the search with an AND condition in order to search published documents that were limited to the African continent.

In the current analysis, the documents were retrieved for the period 2000–2019. Additionally, different types of documents were retrieved for the analysis, including articles, reviews, conference proceedings (or papers) and book chapters. The data – 556 and 29 documents for global and Africa, respectively (Supplementary table 1) – were used to conduct a bibliometric analysis, focusing on mapping socio-hydrological research at a global scale as well as for Africa.

The bibliometric analysis was carried out by using bibliometrix R package¹⁸ in conjunction with an open-source software program, VOSviewer¹⁹. Bibliometric analysis is one of the tools used to study/represent/display the structural and dynamic aspects of scientific research, through a scientific mapping approach.²⁰ This approach is based on analysing quantitative information of published scientific articles from the bibliographic database.²⁰ Through bibliometric analysis, general development of scientific output – including performance patterns of dominant authors, key journals, leading countries and collaborative institutions involved in the publication of scientific articles within a specific research discipline – can be identified and assessed.²¹ Other essential information that can be derived from the bibliometric analysis includes emerging research themes, research directions²²,

leading research topics and research gaps in a specific research field.²³ Bibliometric analysis methods have been applied to various studies, focusing on different fields of scientific research, for instance, in e-government,²⁴⁻²⁶ tourism,^{27,28} safety culture,²⁹ education systems,³⁰ policy,³¹ biochar,^{32,33} ecosystem services,³⁴ water resources,³⁵ and socio-hydrology.³⁶

The scientific mapping of socio-hydrology research undertaken in this study assessed the following: (1) annual publication growth and trends; (2) leading countries in the subject matter; (3) country representation and collaboration in the socio-hydrology body of knowledge; (4) keywords frequency and co-occurrence; (5) emerging themes and (6) direct citation. The authors’ keywords and keywords-plus (extracted from the titles of the cited references) were used to assess the frequency of occurrence of the keywords. According to Omerzel,²⁰ words that frequently co-occur in a cluster of documents are closely related and represent a network of themes within a field of research (in this case, socio-hydrology research).

A thematic map was used to assess the evolution of themes or topics in the socio-hydrology research field. The thematic map was sub-divided into four quadrants: the upper-right quadrant indicates the motor themes (hot topics); themes appearing in the upper-left quadrant are considered very specialised topics; and topics in the lower-right and lower-left quadrants are termed basic themes and emerging/disappearing themes, respectively.³⁷ Furthermore, direct citation network analysis was conducted to track the historical development of a scientific breakthrough in the socio-hydrology research field, including emerging research topics, technologies and trends.^{38,39} The VOSviewer software program was used to map and visualise the bibliometric network of countries’ collaboration and keywords co-occurrence.

Results

Scientific publication output and growth trend

Figure 1 depicts the annual distribution of the 29 and 556 research documents published in Africa and globally from 2000 to 2019. The results show that the number of scientific publications on socio-hydrology conducted globally remained limited between 2000 and 2008. An increase in the number of scientific publications is observed from 2009, with a significant annual increase in the number of scientific publications observed from 2014. The number of published scientific documents peaked in 2019 ($n=142$), translating to an approximately 21% average annual growth rate for that period.

In contrast to global studies, research studies in Africa appear to be very scarce, with some of the years showing no productivity. On average, only one article was published in Africa between 2004 and 2014. This excludes the years that had no publications – 2005, 2007, 2008

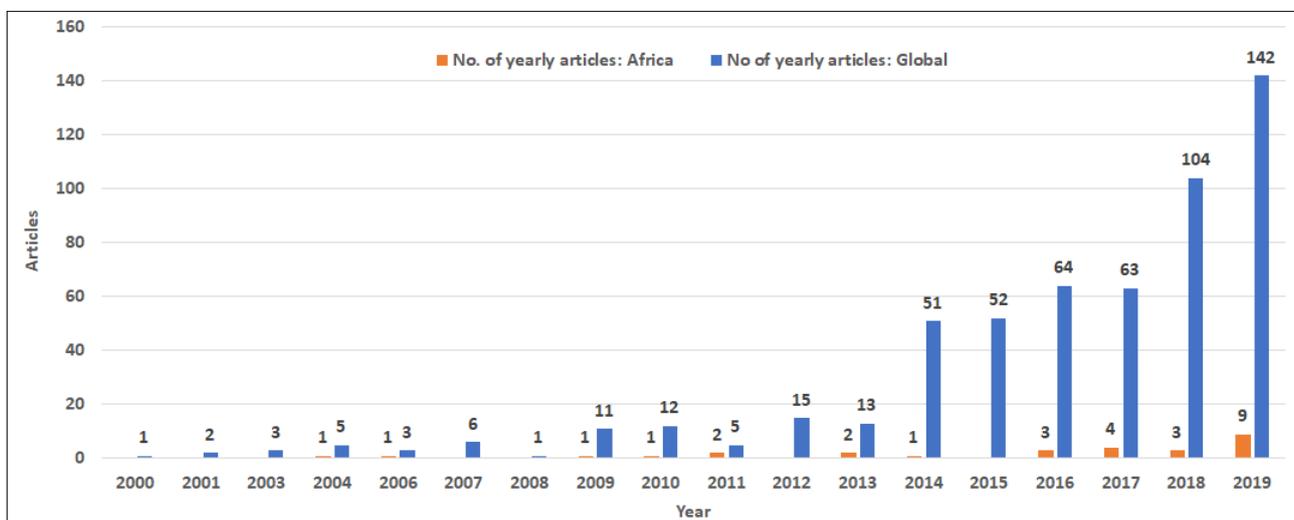


Figure 1: Annual scientific publication output, globally and from Africa.

and 2012. As shown in Figure 1, a slight increase in annual scientific publications is observed from 2016 and reached a peak in 2019 ($n=9$). Scientific publications in Africa showed an approximately 4.4% average annual growth rate.

Leading countries in scientific publications on socio-hydrology

Numerous countries have contributed to the publication of scientific articles on socio-hydrology research at a global scale (Figure 2). The published articles were either a product of multi-country publications (MCP) or single country publications (SCP). Of the 556 global documents assessed, there were 1396 and 109 authors of multi- and single-authored documents. The USA is the most productive country with 81 (16 MCP and 65 SCP) articles, followed by China (35, with 10 MCP and 25 SCP), the Netherlands (28 with 8 MCP and 20 SCP), Germany (27 with 5 MCP and 22 SCP) and the UK (26 with 5 MCP and 21 SCP). The ranking of the countries is based on the affiliation of the first author. In Africa, the 29 scientific documents were co-authored by 138 researchers under MCPs, with only 8 researchers publishing under the SCP category. The USA leads in scientific publications, with 7 articles (6 SCP and 1 MCP), followed by the Netherlands (5; 1 SCP and 4 MCP), Germany (4; 1 SCP and 3 MCP) and South Africa (4; 3 SCP and 1 MCP) and the UK (3; 2 SCP and 1 MCP). While the study focuses on Africa, the leading countries could be publishing scientific articles emanating from collaborative projects. Overall, most of the scientific papers in Africa were SCP, while only 14% of the output were MCP.

Countries' collaboration networks

The collaboration mapping of 66 countries resulted in six clusters (Figure 3). Approximately 1216 lines connected the countries; for better visualisation, only 400 lines representing the strongest links between

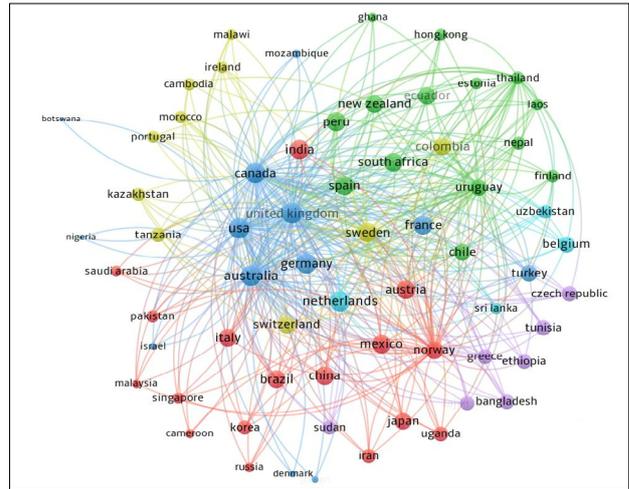


Figure 3: Countries' network collaboration at the global scale.

countries are displayed. The USA (63), Australia (63), Canada (62) and the UK (62) and Germany (62) had the most country collaborations in the dark blue cluster. The most collaborative countries in the red cluster were India (57), Austria (55), Mexico (54), China (54), Italy and Brazil (both with 52 links). Spain (57), Peru (56), South Africa (54), and New Zealand (52) showed significant collaborations in the green cluster. The main collaborative countries in the yellow cluster were Sweden (57), Colombia (51), Switzerland (48), Tanzania (34), Morocco (24), and Malawi (21). The pink and light blue clusters contain few countries with dominant collaborations by Czech Republic (39) and Ethiopia (37) as well as the Netherlands (64) and Belgium (44), respectively. While the network of African countries is not exhaustive, South Africa, Uganda, Tanzania, Morocco, Senegal, Cameroon, Nigeria, Botswana, Ghana, Mozambique, Sudan, are some of the countries publishing socio-hydrology research in the region.

Keywords co-occurrence analysis

The keywords (approximately 100 for global scale) were grouped into four clusters and are represented by circle shapes in different colours and sizes (Figure 4a). The red cluster reflects on different themes that address important issues within socio-hydrology research. These themes include maintenance of water reservoirs (e.g. surface water, groundwater, and aquifers) and the impacts of climate variability and change on water resources (climate change, drought, anthropogenic effect, irrigation systems, water availability/demand/allocation and seasonal variation). In addition, the red cluster highlights issues relating to governance and stakeholder participation, climate research (through modelling), sustainable development, resilience, and decision-making. Keywords appearing in the yellow cluster are related to water resource management/supply/quality. The green cluster covers planning and innovation concepts such as hydrological modelling/simulation, water planning, conceptual framework, interdisciplinary approach, floodplain, nature–society relations, resource allocation, and uncertainty analysis. The blue cluster consists of policy and environmental management related words. These themes include environmental policy, risk assessment, land use, ecosystems, agriculture, streamflow, rivers and urbanisations.

Keywords co-occurrence analysis for Africa resulted in three clusters (Figure 4b). Hydrological modelling and climate change themes dominated in the green cluster. The red cluster brings to the fore water resource and management issues, with keywords such as hydrology, catchment modelling, integrated approach, and runoff. Agriculture is the central theme in the yellow cluster, connecting with water, food supply and irrigation systems. Rivers dominate in the blue cluster, connecting with river basin, and households within the same cluster as well as with other keywords in the green and red clusters.

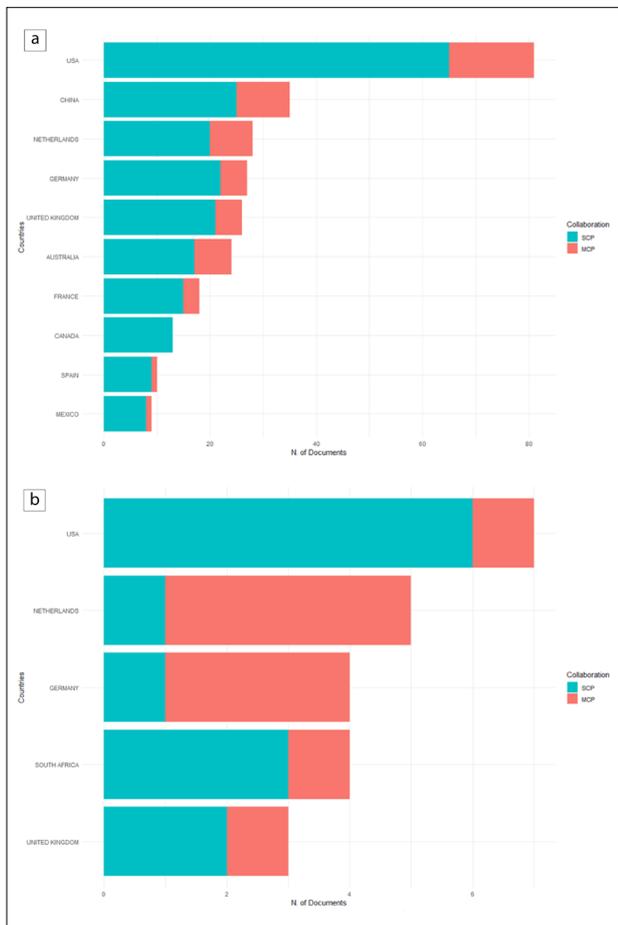


Figure 2: Most productive countries in regard to socio-hydrology research output, (a) globally and (b) in Africa.

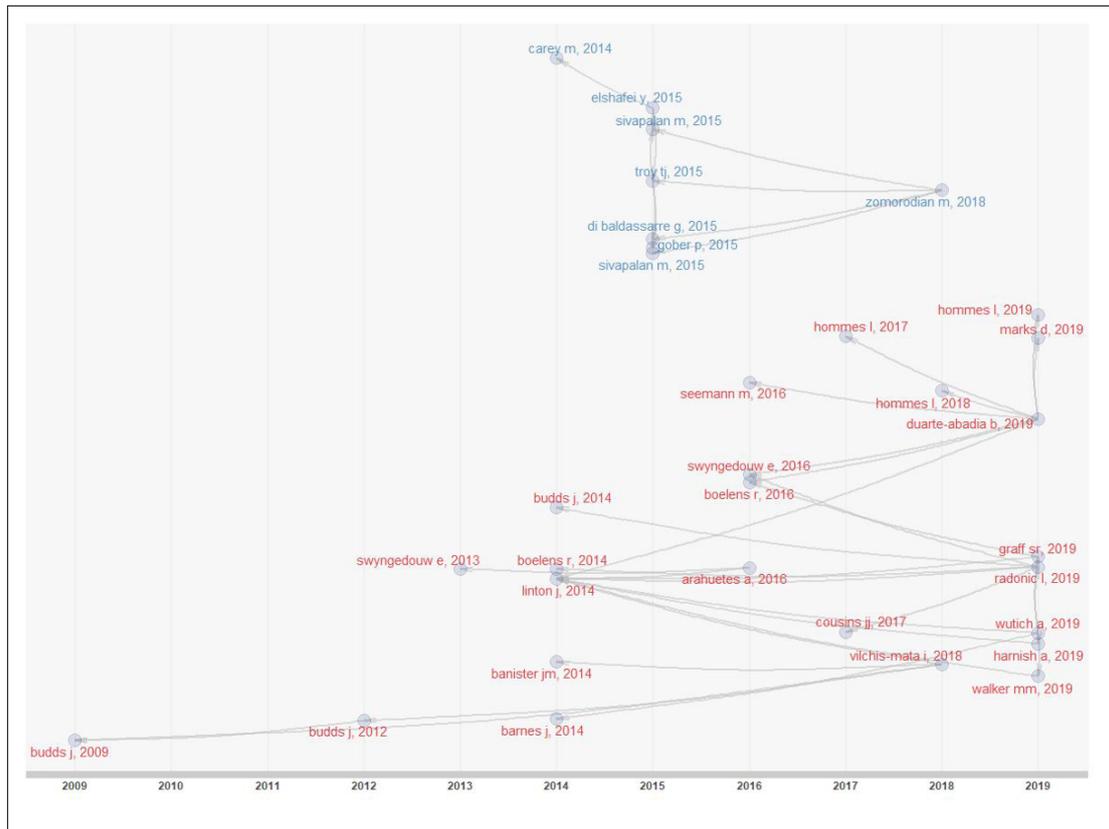


Figure 6: Historical direct citation network of hydrosocial research.

Discussion

Salient features of socio-hydrology research in Africa

Socio-hydrology has become a prominent field of science aimed at understanding the dynamics and co-evolution of human–water interactions.⁹ This field of research has evolved over the years, seemingly, under synonyms such as hydrosociology⁶, hydro-social⁸ and ecohydrosolidarity,⁴⁹ among others. In this study, we investigated the current body of knowledge and the nature of socio-hydrology research at the global scale as well as in Africa. Socio-hydrology research slowly emerged in 2000, with only one scientific article reported globally. On average, only 13% of articles were released between 2000 and 2011, taking into account the years that had no published output (i.e. 2002 and 2005). Socio-hydrology research gained momentum from 2014, resulting in approximately 79% of the published scientific articles being produced between 2015 and 2019. This great progression suggests that the scientific community globally are paying greater attention to and are advancing socio-hydrology research. In Africa, socio-hydrology research progressed at a minimal rate between 2004 and 2014. However, there is evidence of growing interest in the socio-hydrology research domain among researchers. This assertion is corroborated by the significant growing trend in research publications from Africa between 2016 and 2019.

The current study illustrates that socio-hydrology research has established social structures. In this regard, there is an overwhelming collaboration among countries at the global scale, as evidenced by about 1396 authors involved in multi-country authorship of published scientific documents. However, collaboration between countries in Africa is still lacking. The observed extent of collaboration patterns in the African domain is mostly between developed countries with the necessary expertise, resources, and funding measures. This is also evident from the topmost countries contributing to socio-hydrology research output both globally and in Africa. For instance, the USA is the topmost leading country in published scientific articles at both global and African scales. None of the African countries appears in the list of top ten most

productive countries at a global scale. South Africa is the only country appearing in the top five list at a regional scale. There is, therefore, a need for African countries to expand collaboration between developing countries so that the benefit of socio-hydrology research can be attained in the region. The most significant benefits of such collaborations would include knowledge sharing, and access to advanced technologies such as socio-hydrological models to support the management and planning of water resources, including transboundary resources in the context of a changing climate.

The scope of topics and methods used in socio-hydrology is also still very limited. The results reported in this study indicate that research in socio-hydrology has expanded over the years, with two main emerging areas of research practices: the development of a conceptual framework that also highlighted limitations of hydrological modelling and integrative studies that guide policy and practice in water resource planning and management. The latter have taken a holistic approach to study the coupled human and hydrological systems on human and environmental factors (e.g. increased population growth, water governance, environmental management, and climate).⁵⁰ Overall, through direct citation analysis, we posit that the hydrosocial research theme considered by researchers along the two clusters emerged as a concept, and then transitioned into a theoretical framework and tool with practical policy applications in water resources planning and management.

Thematic analysis indicated that research on topics such as water security and hydropower are well established at a global scale. This is especially true in countries such as Colombia and Mexico. There is, however, a need for more research on important cross-cutting topics such as drought, resilience to environmental stressors (associated with, for example, climate change), water governance and hydro-social territories. Emerging topics on water resource management, climate change and health have been undertaken mostly in China. The present analysis also points to global research that has been conducted on specialised topics such as water resource management, politics, flood system dynamics and energy. Meanwhile, the focus in Africa has been on the application of socio-hydrology research to river basins, households

and food supply. Consequently, there is a need to expand this work to further support other nexus sectors such as biodiversity and energy.

The keywords co-occurrence analysis on research done to date on the African continent brought forth topical issues such as catchments, water resources, runoff, rivers and river basins. From a global perspective, co-occurrence analysis brought to the fore water management, water supply, water resources, water conservation, groundwater and irrigation as hot topics. Additionally, the thematic analysis shows that climate change research is an emerging topic that is still nascent in the context of socio-hydrology research at both the global and African scales. However, given the vulnerability of Africa to current and future changes in climate perpetuated by social, economic, and political factors, there is a need to augment this research to enhance the resilience of socio-ecological systems in the region.⁵¹

Opportunities and gaps in socio-hydrology research in Africa

From a global perspective, socio-hydrology research points to some gaps and opportunities for future research. Wesselink et al.¹⁹ highlighted the benefits of combining both social and hydrological science approaches so as to strengthen both research domains rather than antagonistically question their fundamental assumptions. Their study suggests that the siloed and water-centric approaches cannot adequately capture the everyday realities of water. These realities manifest as complex systems and therefore require integrative approaches to ensure that water users at the community level also contribute to water governance. Nevertheless, governance of hydro-social systems is complex, hence there is a need to establish more effective communication pathways to navigate through conflicting stakeholder priorities and interests. Water demand and environmental management mechanisms such as payment for environmental services can lead to further marginalisation of poor communities' livelihood strategies.⁵² Similarly, there is an opportunity to address social and environmental injustice when responding to projected changes in climate. However, initiatives would require that governance actors have a good understanding of how to incorporate the coupled nature of various location- and context-specific human-water interactions and embrace the uncertainties that are part of the process.⁵³⁻⁵⁵

More so, Page et al.⁵⁶ illustrated that there is a need to develop an integrative water research methodology to appreciate the impacts and necessity of desalination within complex hydro-socio-technical systems in countries, especially those currently faced with water scarcity. Furthermore, studies on the multidimensional change in watershed processes resulting from the change in forest cover in tropical regions of Africa illustrate that there are still knowledge gaps on how different types of forest transitions affect low flows and the socio-hydrological links. Therefore, research is required to provide a better understanding of the subject matter and guide policy development within the different tropical regions to integrate concepts and methods as informed by the most recent research.⁵⁷

The bibliometric assessment in this study has demonstrated the diversity of research themes that are linked to socio-hydrology as shown in global studies. It has also highlighted opportunities for Africa to also explore relevant established and emerging concepts to ensure that the knowledge generated can guide policy and yet also transition it to practice in order to achieve sustainable development within the African context.^{58,59} The identified emerging research topics in Africa have the potential to contribute to the sustainability of socio-ecological systems and improved human well-being. Such topics include socio-hydrology and its links to energy, health, politics, land governance in communal areas, transboundary water resources as well as climate change related extreme weather events such as floods and droughts.

Conclusion

A bibliometric analysis was conducted to evaluate the nature of socio-hydrology research as well as salient features, such as developmental patterns, research collaborations, keywords co-occurrence and emerging

themes within the subject matter, at a global scale and, specifically, across the African continent. While socio-hydrology research at a global scale began to show an increasing trend two decades ago, gaining momentum in 2014, the scientific publications on socio-hydrology in the African continent only emerged in 2016. The sparing extent of social networks of socio-hydrology research point to the need to collaboratively expand and enhance the research domain in the region. Notwithstanding the apparent developed conceptual structures inherent in the socio-hydrology research domain, developed countries continue to harbour the intellectual structures. This is, undoubtedly, duly supported by the inherent well-established social structures: the collaborative networks. From this perspective, socio-hydrology scholarship on the African continent is, sadly, in its infancy, yet growing. Recognising the inherent pathways of socio-hydrology scholarship, several emerging research topics were identified, and if pursued, we argue, will immensely expand socio-hydrology research on the African continent. Some of these research themes, we opine, include (1) the impacts of climate change on socio-hydrology systems; and (2) the influence of socio-hydrology interactions on the Water-Energy-Food Nexus; and (3) the applications of system dynamic modelling for advancing the understanding of the complex coupled socio-hydrology dynamics.

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Competing interests

We have no competing interests to declare.

Authors' contributions

C.M.B.: Conceptualised the study, analysed data, crafted the original draft, and finalised the manuscript. J.O.B.: Conceptualised the study, wrote the scripts, discussed the results, and edited and approved the manuscript. M.M.: Crafted the introduction, discussed the results and edited the manuscript. N.N.Z.: Acquired data, discussed the results and edited the manuscript. A.M.A.: Discussed the results and edited the manuscript. J.Pd.W.: Prepared the study area map and discussed the results. O.M.A.: Discussed the results and edited the manuscript. All authors read the final manuscript and approved the submission.

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