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One decade of institutional scientific output and impact in West Africa - The West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL)

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ABSTRACT

In the frame of climate change, Africa belongs to the regions with low capacities to cope with the negative effects. Local capacities in education and research need to be strengthened to increase the regions' social-ecological resilience and provide long-term environmental security for people. Foreign investors in this endeavour are often interested in the output and impact of their investments in order to identify the potentials for further improvements and commitments. In our study, we have focused on an international institution that is actively contributing to improve climate change research in West Africa, called WASCAL (West African Science Service Centre on Climate Change and Adapted Land Use). Taking the 10-year anniversary of WASCAL as the occasion for an assessment of the scientific output, a comprehensive systematic literature review for the time span 2012–2022 of peer-reviewed scientific publications related to WASCAL was conducted. In total, 315 high-quality papers published in 149 different peer-reviewed journals were identified. Globally, WASCAL is well connected, shown by joint publications from 58 different countries. Within West Africa, especially Burkina Faso (107 publications) and Ghana (86 publications) were represented with high levels of (co-)authorships. One of the main research areas of WASCAL is climate modelling which was reflected in the findings. Relatively underrepresented in the frame of WASCAL-related publications were studies from social sciences. In addition, more research should be conducted on the multifaceted topics of food security and urban planning. WASCAL could also contribute further to the emerging research field of tropical medicine and parasitology due to the threat to human health and food security resulting from environmental and climate change.

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1. Introduction

Climate change is causing global alterations in the cropping season, shifts in vegetation (Esquivel-Muelbert et al., 2017), increasing weather extremes and related damages (Coronese et al., 2019; Forzieri et al., 2017; IPCC, 2022a). Especially Africa is and will be confronted with increasing risks for nature and society (Trisos et al., 2022 in IPCC, 2022a). Since mid-1970, the mean annual and seasonal temperatures for West Africa have increased between 1 °C and 3 °C. Furthermore, rainfall variability increases (Trisos et al., 2022). Specific climate-related risks for Africa are losses of species, ecosystems, and, therefore, food production, a reduction in the economy, an increase in poverty, disease, damage to property, and death, an increase in insecure water and energy conditions (ibid.). In contrast, coping and adaptation strategies in Africa are low that results in high vulnerability and exposure to climate extremes (B.2.4 and C.3.1 in IPCC, 2022b). A literature review of adaptation studies between 2013 and 2021 and expert knowledge indicated that the mainly reported adaptation strategies were related to "sustainable water management (food sector), resilient infrastructure and technologies (health sector), agricultural intensification (food sector), human migration (poverty and livelihoods) and crop management (food sector)" (Williams et al., 2021 cited by Trisos et al., 2022, p. 1301 in IPCC, 2022a). Among them, no category was graded as having high feasibility of implementation, especially due to technological and institutional barriers (ibid.).

Environmental education and climate change awareness for African societies are relevant to cope with climate change. For example, a large-scale study between 2016 and 2018 in 34 African countries with 45,823 participants identified that only approx. one-third of the participants have heard and understood (mainly) the meaning of climate change (Selormey et al., 2019). In addition, approx. 67 % of the participants said that climate change is downgrading their life in their country (Selormey et al., 2019). It also has been identified that people would feel less helpless if they would get actively involved to counteract the negative consequences of climate change (e.g., Salomon et al., 2017; e.g., increase water use efficiency in the context of water shortage due to climate change). More climate change-related research and capacity development is needed to improve local livelihoods, to increase the resilience and capacities to cope with climate change. In comparison to the rest of the world, Africa faces gaps in climate change-related funding for research, local scientific participation, and publications (Trisos et al., 2022). Since 1990, only 3.8 % of the global funding for research related to climate change was spent on Africa (Overland et al., 2022). From 2016 to 2020, the United Kingdom, the EU, the USA, Germany, and Sweden were the top funding bodies for Africa. Germany spent 697 million US dollars on adaptation-related issues in Africa between 2014 and 2018 (Trisos et al., 2022). A large part of funding for climate-related research in Africa by German institutions was taken by the Federal Ministry of Education and Research (BMBF) and the German Research Foundation (DFG; North et al., 2022). For example, by October 2018, BMBF had 286 publications related to climate change in Africa (rank 5 of an international list; ibid.). BMBF has an "Africa Strategy" to find solutions for major African challenges. This strategy includes the strengthening of international networks to expand capacities for education, innovation, and implementation (BMBF, n.d.). In 2012, BMBF founded the Climate Competence Centers SASSCAL (Southern African Science Service Centre for Climate Change and Adaptive Land Management) and WASCAL (West African Science Service Centre on Climate Change and Adapted Land Use) to focus on the challenges of climate change in South and West Africa.

In view of foreign (German) investments in climate change-related research in Africa, it is time to analyze the output and impact of this research funding activity. Publishing and dissemination of scientific results and findings are an important component for outreach and especially for institutions that spend public money (e.g., Scherer et al., 2018). For example, BMBF has already invested more than 120 million Euros in WASCAL (WASCAL, 2021). Analyzing the scientific output and impact (SOI) of organizations and institutions is crucial for several reasons. First, it allows the evaluation of the effectiveness of resource allocation and to identify areas for improvement. Second, the evaluation shows knowledge and research gaps in the context of the funded institution, respectively. By tracking metrics, such as the number of publications, citations, and collaborations, institutions can gain insights into the quality and impact of their research output (e.g., Carpenter et al., 2014; Agarwal et al., 2016; Koseoglu, 2016). Knowledge of the institution's SOI might also be essential for justifying the financial resources spent on the funding measures. Finally, analyzing the SOI can be useful for decision-making processes, e.g., related to the evaluation of research reports and resource allocation. By using data-driven insights, organizations can make more informed decisions to improve their research programs.

Our study concentrates on the SOI of WASCAL, a West African large-scale research and capacity-building focused climate service center founded to strengthen the research infrastructure and capacity related to climate change (WASCAL, 2020a). WASCAL has celebrated in 2022 its 10-year anniversary. The related report mentions 273 master and doctoral theses, 700 publications and more than 1000 beneficiaries of short courses and seminars on climate change and sustainable development, among others, during the existence of WASCAL (WASCAL, 2022). In our study, we focused in more detail on the high-quality research output of WASCAL during the time frame 2012–2022 (10 years) based on internationally published peer-reviewed scientific papers. Our research questions were the following:

1) What is the research output of WASCAL regarding internationally published peer-reviewed scientific papers?
2) How visible (accessibility) is this high-quality research of WASCAL within the international scientific community?
3) Which scientific collaborations exist within WASCAL in the frame of the analysed papers?
4) Which research topics were mainly addressed in the analysed papers?

In this study, a systematic literature review of peer-reviewed scientific papers in WASCAL was conducted. Primary, this paper should provide an overview of SOI in the frame of WASCAL, but it can give also directions for other funding organizations to scientifically evaluate publications regarding their output and impact.

2. Material and method

2.1. WASCAL

The West African Service Centre for Climate Change and Adapted Land Use (WASCAL) seeks to become one of Africa's leading institutions in the provision of climate and environmental services in and for West Africa. Until today, 12 West African countries are members in WASCAL. Core buildings of WASCAL are the Headquarter in Accra (Ghana) and the Competence Center (CoC) in Ouagadougou (Burkina Faso). While the headquarter is the administrative center, the CoC is focusing on climate services, i.e., providing ground-precision data recorded by human-manned, automatic meteorological, and hydrological stationary sensors through its own WASCAL transboundary observations networks (WAS-ONs; WADIREP, 2019). In addition, the CoC serves as a provider of resources and information related to climate change that is tailored to decision-making at different societal and administrative levels. Besides research, WASCAL has a strong focus on capacity development and education by supporting young scholars in natural and social science and strengthening local universities and climate service departments. The capacity-building program of WASCAL facilitates academic education at 12 West African universities in collaboration with German research institutions through the Graduate Studies Program (GSP). Each of the 12 West African universities hosts a GSP dedicated to climate change and different climate-related issues (Table A1) to support an integrated, interdisciplinary, and multi-sectoral approach to developing and providing suitable management strategies. By the year 2020, already more than 500 students have finished their degrees (WASCAL, 2020a).

Based on consultations among researchers, stakeholders, and the funding organization, current research needs were met through the adaptation of the WASCAL CoC research program. Subsequently, the WASCAL Research Action Plan (WRAP 2.0) funding measure was implemented in 2021 under the framework of the BMBF's Africa strategy. WRAP 2.0 comprises the following five so-called interrelated Priority Research Themes (PRTs) of high importance for West Africa: land use and land degradation (PRT 1), risk and vulnerability to climate extremes (PRT 2), rural-urban and cross-border migration (PRT 3), sustainable agriculture and climate-smart landscapes (PRT 4), and renewable energy (PRT 5). The relevance of PRTs, and the interrelationship among them address the interest of multiple stakeholders across West Africa and ideally build on data gathered through the WAS-ONs. Furthermore, the above PRTs serve the ECOWAS' priority programs in environment and agriculture and are considered to deploy essential actions for achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 1 ('No poverty'), SDG 2 ('Zero Hunger'), SDG 13 ('Climate action'), SDG 15 ('Life on land'; UN, 2024).

2.2. The systematic literature review

A systematic literature review was used to gather information about peer-reviewed papers that were published in international journals in the name of WASCAL, i.e., mentioned in the acknowledgments, as funding source or author's affiliation. Systematic literature is a standardized scientific approach and, therefore, a more transparent and reproducible approach in comparison to other literature review processes (Snyder, 2019). The primary focus of a systematic literature review is to gather (ideally complete) empirical evidence from literature related to a specific topic. In this study, we focused on scientific peer-reviewed publications in the time frame 2012–2022 to cover a 10-years period of research output from the beginning of WASCAL.

The selection criteria for the systematic literature review were tailored to the context of WASCAL. For the specification, we consulted also WASCAL scientists of the CoC to transparently communicate and agree upon or refine selection criteria. The final list of

Table 1
Selection criteria for the publication database (corpus) of WASCAL (West African Science Service Centre on Climate Change and Adapted Land Use) based on peer-reviewed scientific journal publications and explanations of their use. Abbreviations: CoC= Competence Centre; GSP = Graduate Studies Program, BMBF= Federal Ministry of Education and Research, WASCAL-DE-Coop = Cooperation project between WASCAL and the University of Würzburg support the WASCAL GSP in identifying German cooperation partners for the GSPs, among others. WRAP 2.0 = WASCAL Research Action Plan.

#	Criterion	Explanation
1	WASCAL (co-)authorship	At least one person from the group of authors was affiliated with WASCAL. No distinction was made as to whether the abbreviation WASCAL was used or whether the full form was used. In addition, no distinction was made whether the affiliation was through the CoC or one to the GSP.
2	Funding by WASCAL	The publication explicitly referred to the funding measure and related financial support of the study by WASCAL (and/or BMBF).
3	Use of data directly related to WASCAL	The study used data directly related to WASCAL; in the presented methodology, data availability statement and/or acknowledgments in the publication, explicit reference was made to the use of data from the WASCAL observation network (e.g., meteorological parameters) and/or the WASCAL data portal.
4	Mention of "support" by WASCAL	This criterion was based on funding by WASCAL (Criterion 2) but the corresponding section does not explicitly mention the funding measure but under the headline of "Support" or "Acknowledgment". For this reason, this criterion may be seen as an extension of the criterion "Funding".
5	Mention of WASCAL project partners or WASCAL staff	Mention of persons as WASCAL experts, e.g., in the acknowledgment of the publication.
6	Affiliation/funding to/from a WRAP 2.0 project	The publications listed under this aspect explicitly mention WRAP 2.0 as a funding measure.
7	Affiliation/funding to/from WASCAL-DE-Coop project	This criterion was defined for the inclusion of research studies made directly in the context of the WASCAL-DE-Coop project.

selection criteria (Table 1) for the acquisition of peer-reviewed publications clearly allowed an assignment to WASCAL publications. Seven criteria served as a decision basis for the selection of peer-reviewed publication in the context of WASCAL. Whereas we consider Criteria 1 to 3 (Table 1) as hard criteria, rather obvious for acquiring and assigning publication to the WASCAL corpus, we had to refine and extend, respectively further criteria since first extensive literature searches showed an incomplete list of publications. Although the "hard" criteria (Criteria 1 to 3) allowed many publications to be identified in the context of WASCAL, they excluded research studies that were either a) published with the support of WASCAL experts without direct involvement by authorship, or b) published studies without explicit mentioning WASCAL but clearly related to WASCAL. For this reason, additional "soft" criteria (Criteria 4–7; Table 1) were defined and the search for relevant publications was evaluated. Several criteria can be valid for a document at the same time. The corresponding scientific work was listed as a WASCAL publication and analysed in this study if at least one of the selection criteria was met.

The WASCAL-related peer-reviewed publications were identified via the multidisciplinary bibliographic database platform Web of Science (WoS). WoS provides access to multiple publication databases and thus to extensive meta-data (e.g., reference and citation data) from scientific journals, conference proceedings, and other documents in more than 250 scientific disciplines (Clarivate, 2024). WoS is one of the most common international scientific citation search platforms (Li et al., 2018). By specific queries, WoS combines the search for corresponding publications in six indexed and further regional publication databases. The query results are listed as output and can be exported in different formats for further processing or integration into publication management systems. The search terms "WASCAL*" OR "West African Science Service Centre on Climate Change and Adapted Land Use*" OR "WRAP 2.0*" were chosen. To address any variations in the written version of the author's affiliation, the two search terms of WASCAL were tested for capitalization and spelling differences (such as "Centre" vs. "Center", and "Land Use" vs. "Land-use"). All identified publications were screened for redundancy or misinterpretation of the WoS search engine. All publications that could be clearly assigned to at least one of the selection criteria (Table 1) were entered into a literature management system; the WASCAL "corpus".

For the scientific output and impact, no standardized definitions exist, as both terms are treated differently and diversely depending on the context (e.g., see Chan et al., 2018; Scherer et al., 2018; Giorcelli et al., 2022; Sørensen et al., 2021; World Reputation Rankings by THE, 2024). The identification of the research output (RQ 1) was based on the total and annual number of peer-reviewed papers. The visibility of high-quality research of WASCAL within the scientific community (RQ 2) was analysed by the number of papers published as open access and the number of citations. The scientific collaborations within WASCAL (RQ 3) were investigated by the amount of (co-)authorship and location of author's affiliation. Here, we distinguished between the international scientific networks (with West African countries and beyond) and the regional networks within West Africa. For the overview of research topics in the frame of WASCAL (RQ 4), the number of publications in the different disciplines/research areas was in the focus. The research areas were taken from the WoS categories. The performance indicators of SOI are shown in Table A2. WASCAL publications were analysed using standardized methods of bibliometric analysis (Neves Machado et al., 2015; Wambu and Ho, 2016) with a focus on identifying (sub-)disciplines and trends in terms of collaboration and scientific output. A suitable tool for the analysis proved to be bibliometrix15, which provides a variety of tools for a complete bibliometric analysis following the science mapping workflow (Aria and Cuccurullo, 2017).

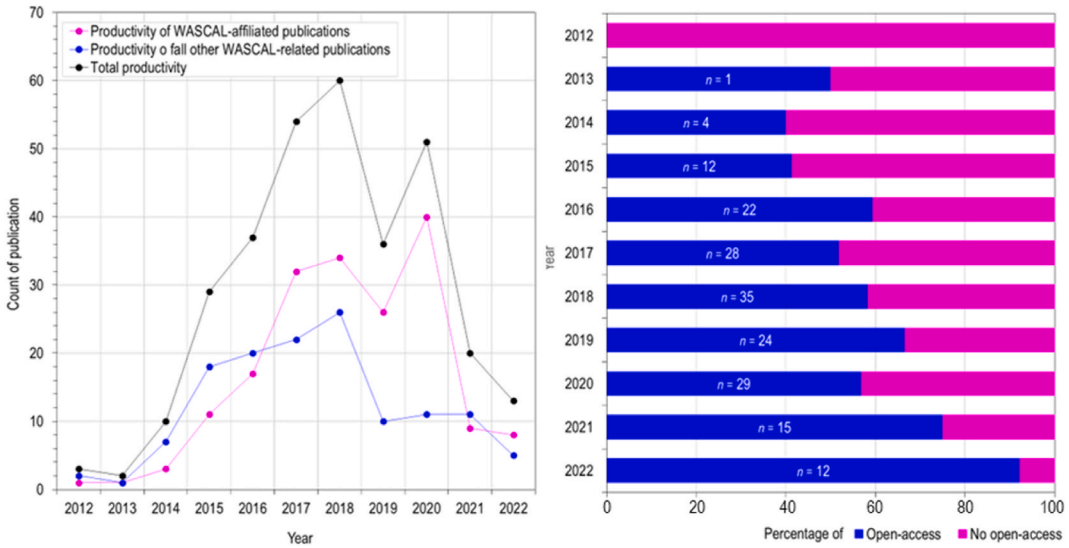

Fig. 1. Overview of the amount and access of the WASCAL-related peer-reviewed publications in the time frame between 2012 and 2022. Left figure: The total annual output and specified annual output of WASCAL-affiliated publications and all other related publications. Right figure: Open access of WASCAL-related publications per year.

3. Results

Following the selection criteria (Table 1), we were able to identify a total of 315 papers. Most papers were original articles (n = 305). For 163 publications (~51.7 %), more than one criterion applies, such as WASCAL (co-)authorship (Criterion 1), WASCAL funding (Criterion 2), and use of data generated in WASCAL (Criterion 3; Table 1; Annex Figure A1). Publications fulfilling the criteria 1 or 2 and 3, respectively (Table 1, Annex Figure A.1), thus representing the core of the WASCAL corpus, are 186 (59 %) documents. For 129 (41 %) publications in the WASCAL corpus, criteria 4 to 7 are fulfilled (Annex Figure A1). For these publications no direct WASCAL associated authorship or funding, and data uptake was recorded.

In total, 891 people published within the 315 papers. On average, 6 authors published together. Only 5 publications showed a single authored paper. Almost all papers were published in English (only one publication was in French, but the abstract was provided in English). Despite five publications, a clear statement indicated the peer-reviewed processing of the paper.

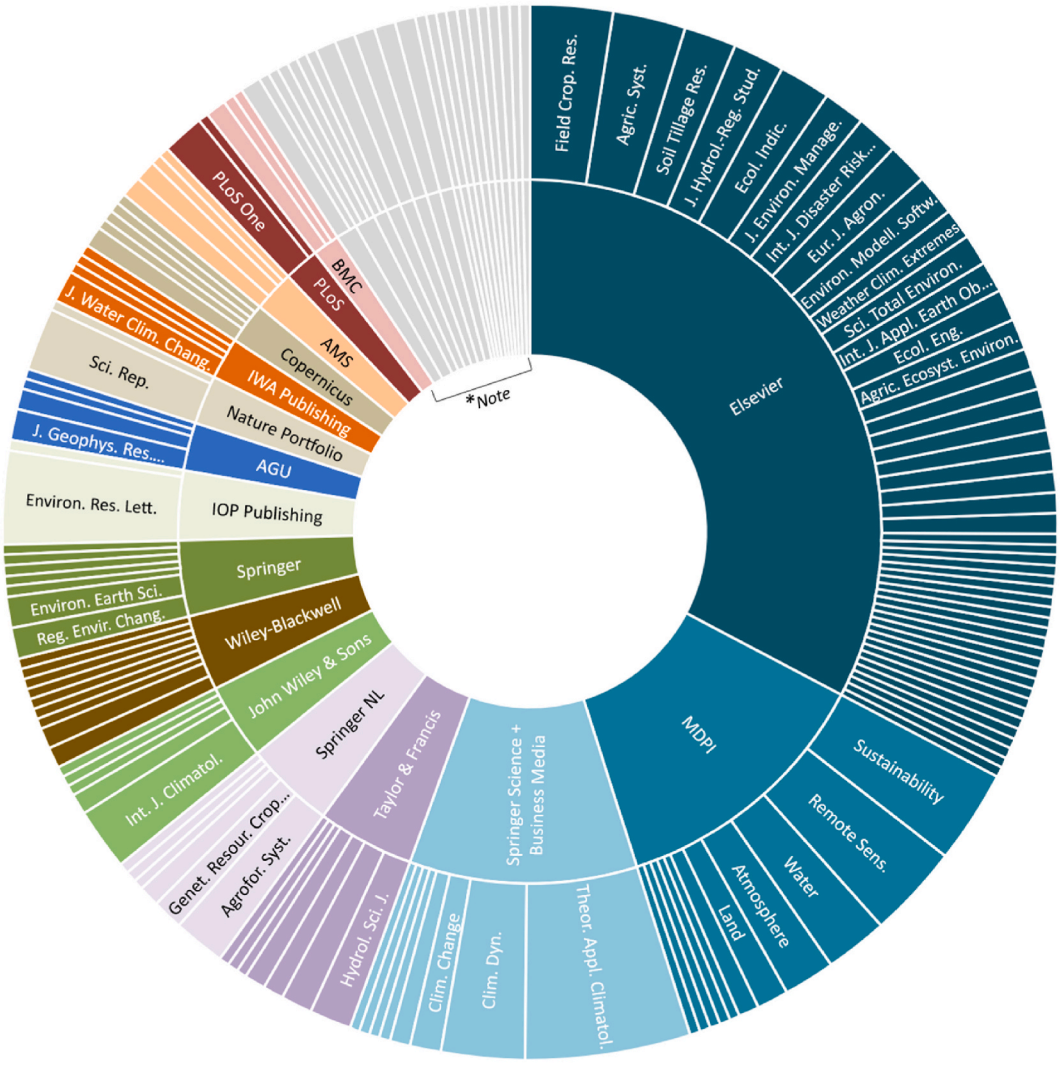

Fig. 2. Publisher (inner circle) and journals published therein (outer circle, abbreviations according to ISO4) in which WASCAL publications were published between 2015 and 2022 (as of November 22, 2022). Shown by name, only those journals are listed in which at least four WASCAL publications appeared between 2012 and 2022. *Note: Publishers from left to right: SpringerOpen, SAGE Publications, Springer Nature, Resilience Alliance, Kluwer Academic Publications, Emerald Group Publication, Cambridge University Press, Wiley-VCH, Springer New York, Inter-Research Science Center, International Union of Geological Sciences, International Society for Tropical Ecology, Hindawi, Science in China Press, American Phytopathological Society, Associazione Italiana di Telerilevamento, Frontiers Media, S.A., International Seed Testing Association. Note: The designations of the journal names shown are based on the ISO4 standard, the international standard for uniform, systematic abbreviation of scientific journals.

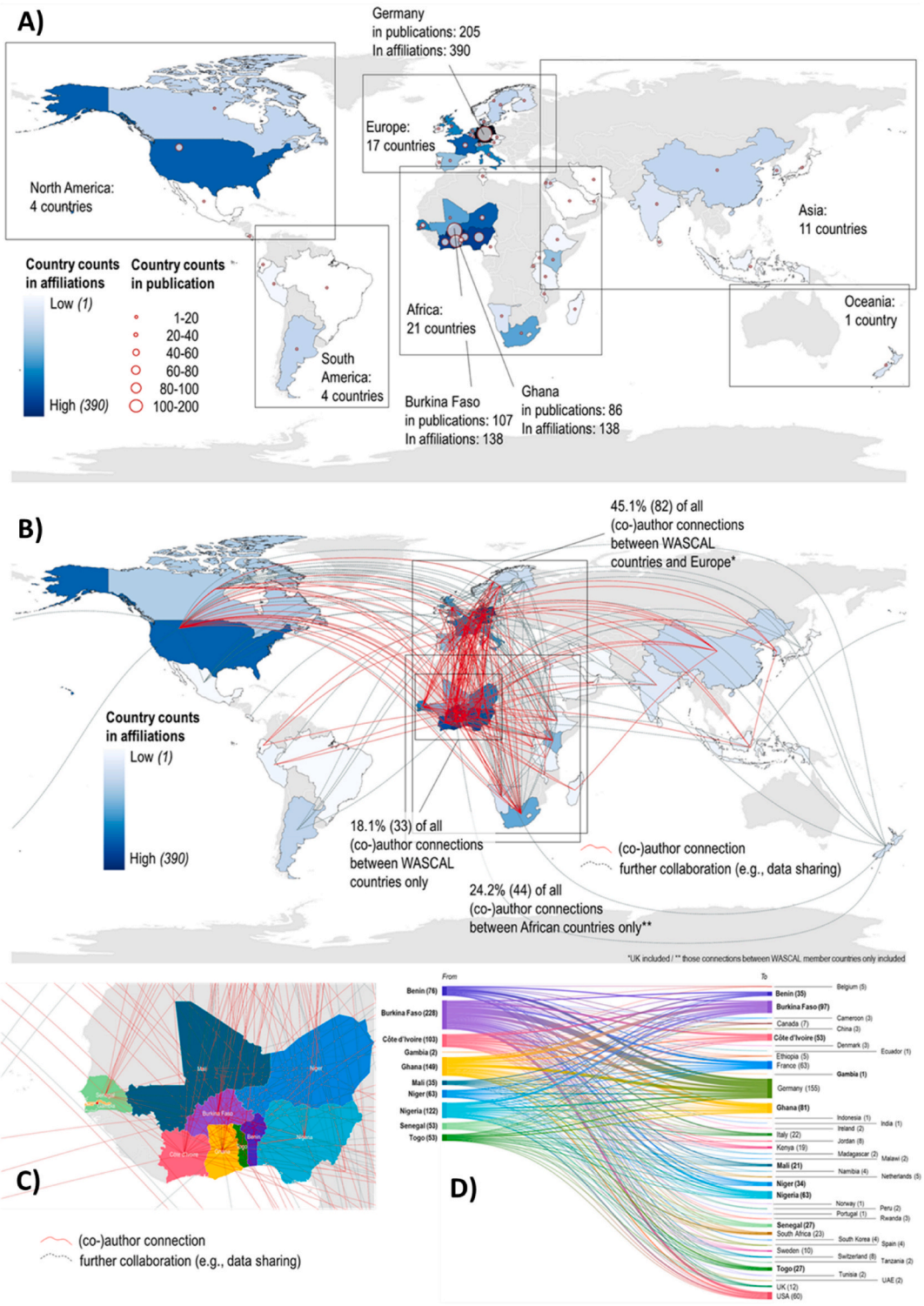

Fig. 3. A) Country counts in author's affiliation and publication of the 315 WASCAL publications in the time frame 2012–2022. Absolute frequencies of mentions in which the study areas from the publications are located. B) Co-author connections across countries. The red lines show the frequencies of co-author affiliation countries. C) (Co-)Author connections within West Africa. D) Connections of (co-) authors from West Africa. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.1. Scientific output, accessibility, and journals

The annual output in the form of peer-reviewed scientific publications (number of publications per year; Fig. 1) showed a steady increase with the peak of output in 2018, followed by the second- and third-highest output in 2017 and 2020, regardless of the assignment of the publications in one of the two categories listed (i.e., WASCAL-affiliated publications by (co-)authoring, all other WASCAL-related publications). The lowest number of publications were indicated at the beginning and at the end of the observation period – in the time frame between 2012 ($n = 3$) and 2014 ($n = 10$) and in the year 2022 ($n = 13$; Fig. 1).

Of the total of 315 WASCAL-related publications, more than half of the papers (57.8 %) were characterized by unrestricted access (open access; $n = 182$). The remaining publications were restricted in their access (non-open-access; $n = 133$) and can only be obtained after prior article-based payment, licensing by the corresponding institution (e.g., university) or in exchange with the (co-)authors who have access to the respective publication. Over the years, a clear trend toward open-access publications has emerged. While in 2012, only 3 publications appeared as open-access, in the following years, the number of publications as open-access increased (Fig. 1). Regarding citations, the WASCAL-related papers were 8004 times cited; with 26 times on average. The maximum number of citations for one paper was 256 times.

The 315 WASCAL-related papers were published in 149 different peer-reviewed journals (Fig. 2). These can be assigned to 35

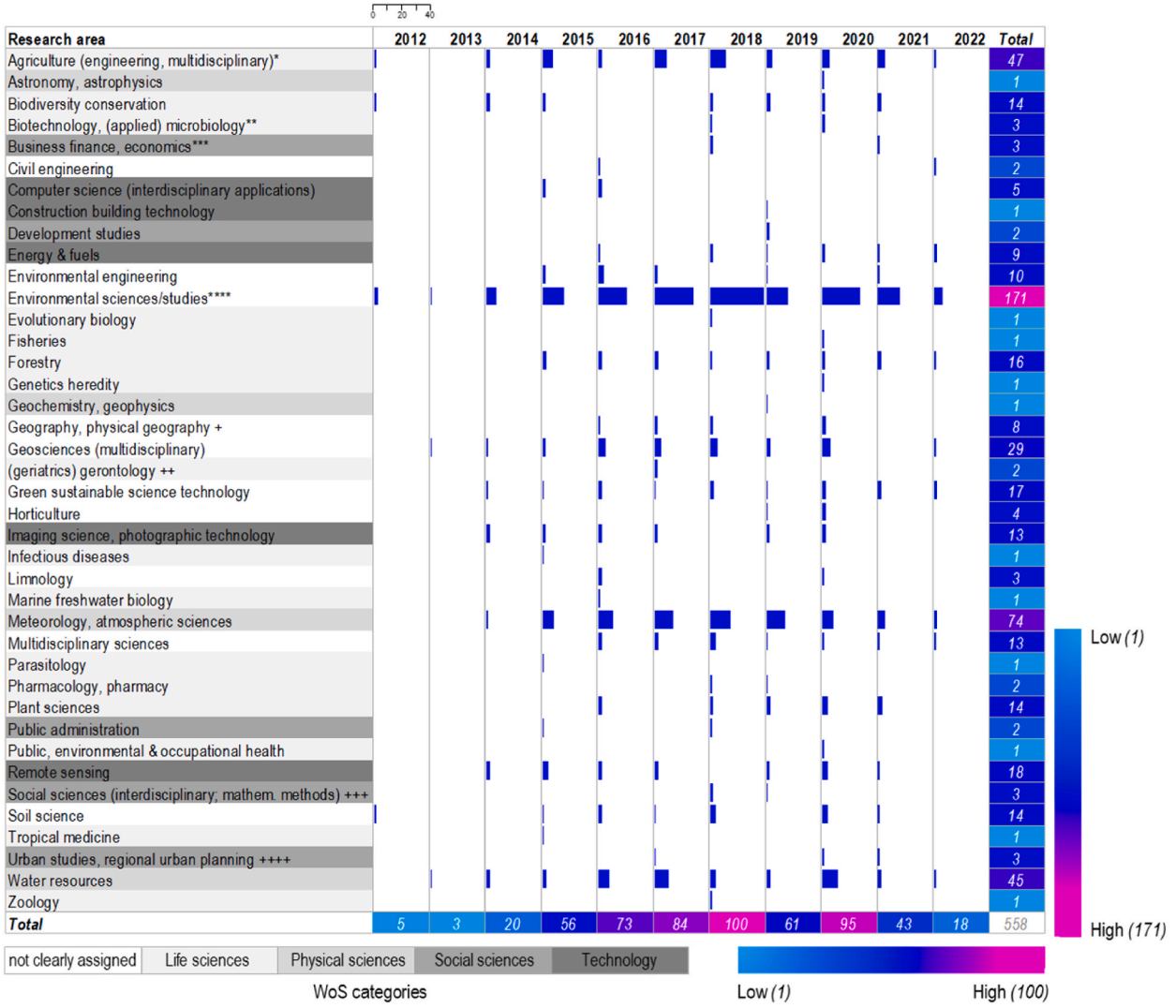

Fig. 4. Temporal evolution (2012–2022) of research areas (Web of Science categories) covered in the WASCAL publications ($n = 315$). Grouping of the categories * Agronomy, and agriculture (engineering) and agriculture (multidisciplinary), ** biotechnology, applied microbiology and microbiology, *** business finance and economics, **** Ecology, and environmental science and environmental studies, + geography and physical geography, ++ geriatrics gerontology and gerontology, +++ social sciences (interdisciplinary) and social sciences (mathematical methods), and ++++ urban studies and regional urban planning. Central panel: data bars show the counts of categories per year. The right and lower panels show the total counts in a category over the analysed period (right) and the total counts per year over all categories (upper).

publishers or their subgroups. The major publishers of scientific publications are Elsevier (32.4 %), MDPI (Multidisciplinary Digital Publishing Institute; 12.4 %), and Springer (20 %) including all sub-publisher (i.e., Springer, Springer Science + Business Media, Springer Netherlands (Springer NL), SpringerOpen, Springer Nature, Springer Science + Business Media and the New York Botanical Garden Press on behalf of the Society for Economic Botany). Even though Elsevier was the major publisher of the WASCAL-related publications, the highest amount of open-access publications within a specific journal was shown for the Springer journal "Theoretical and Applied Climatology" (Annex Fig. A2).

3.2. International and regional scientific collaboration

In the collaborations in both directions, Africa and Europe, except for Cape Verde, every WASCAL member state is represented by affiliated persons. Joint research in the context of WASCAL managed to connect scientists and stakeholders at institutions and organizations from a total of 58 different countries worldwide during the 2012–2022 observation period (Fig. 3A and B). Already joint publications by (co-)authorship (Criterion 1) applies to 182 publications and scientists collaborated internationally from 43 countries. The focus of international joint publications is on the two continents of Africa and Europe. Thus, on the one hand, there are international research publications between both continents (45 % of WASCAL-affiliated publications), but also between various African countries (~24 % of WASCAL-affiliated publications; Fig. 3C and D). Approximately 18 % of the WASCAL-affiliated publications are even based exclusively on a cooperation between WASCAL member states. The African cooperation with countries outside West Africa was mainly focused on Kenia and South Africa. In total, 20 different African countries and 13 European countries were affiliated in the publications, followed by countries in Asia (six countries) and North and South America (two countries each). Country-wise, the highest amount of (co-)authorship was shown with 205 publications and 390 affiliations for Germany. Within West Africa, especially Burkina Faso (107 publications, 138 affiliations) and Ghana (86 publications, 138 affiliations; Fig. 3A) were shown with high amounts of (co-)authorships. The highest number of different connections within Africa of (co-)authorships of West African countries came from Burkina Faso (Fig. 3D). On average, scientists from three countries (SD = 1.3) produced joint WASCAL publications. The maximum number of affiliations from different countries was reached by a study on characterizing daily West African summer monsoon precipitation using CORDEX simulations (Klutse et al., 2016). In this study, the author affiliations were from 11 different countries (Africa, Europe, and North America).

3.3. Overarching themes of research

The overarching themes of the 315 WASCAL-related publications came from different scientific disciplines (Fig. 4). Many publications could be assigned to physical sciences. Highest amounts were shown for the topic of environmental/ecological studies that were shown 171 times as research areas according to the WoS categories in the time frame 2012–2022. The amount of environmental studies was followed by a) meteorology and atmospheric sciences (74 times), b) agronomy, and agriculture (engineering) and agriculture (multidisciplinary; 47 times), and c) water resources (45 times). Especially the year 2018 was a peak year of different research areas, which was followed by the year 2020. Lowest levels with only one time referred as research area according to the WoS categories was identified for astronomy/astrophysics, construction building technologies, evolutionary biology, fisheries, genetics heredity, geochemistry/geophysics, infectious diseases, marine freshwater biology, parasitology, public, environmental and occupational health, tropical medicine, and zoology. Relatively underrepresented were studies from social sciences. In addition, only three publications related to urban planning were identified.

One of the main research areas of WASCAL is climate modelling (e.g., Sylla et al., 2015; Dieng et al., 2018; Nikiema et al., 2017; Diallo et al., 2016; Kebe et al., 2020; Saley et al., 2019). WASCAL has developed regional climate models that provide projections of future climate change in West Africa at a high resolution (Heinzeller et al., 2018). These and other climate models have been used to assess the impacts of climate change on various sectors, including agriculture, water resources, and energy (Dimobe et al., 2018; Hipt et al., 2019; Ferner et al., 2018; Larbi et al., 2021; Obahoundje et al., 2017). In addition, researchers in WASCAL have assessed the local perceptions of climate change on the environment and ecosystem services (Agwu et al., 2018; Sanogo et al., 2017). WASCAL has also conducted research on land use change and its impacts on the environment and society. This research has focused on the drivers of land use change, the effects on biodiversity and ecosystem services, and the social and economic implications for local communities (e.g., Belem and Saqalli, 2017; Kleemann et al., 2017b; Koo et al., 2019). In addition to these areas of research, WASCAL has also produced scientific output related to renewable energy (e.g., Odou et al., 2020; Sawadogo et al., 2020; Danso et al., 2021; Ballo et al., 2022), water resources management (e.g., Yira et al., 2016; Badjana et al., 2017; Naabil et al., 2017; Hounkpe and Diekkrueger, 2018; Alhassan and Jin, 2020; Ascott et al., 2020; Salack et al., 2022), and disaster risk mapping and reduction (e.g., Asare-Kyei et al., 2017; Ntajal et al., 2017; Almoradie et al., 2020). WASCAL has developed software tools and data sets that are partly freely available to researchers and policymakers, including a crop simulation model, a hydrological model and observatory (Bliefernicht et al., 2018), and a climate data portal (WASCAL-hydromet-net.org).

4. Discussion

WASCAL has produced over the 10-year-time period a considerable amount of peer-reviewed scientific papers. In total, 315 papers were published – already besides the huge amount of policy papers, conference papers, dissertations, master theses and bachelor theses (see WASCAL, 2022) that were not counted in the frame of this paper. Especially the year 2018 was a peak year regarding the total amount of peer-reviewed scientific publication in the context of WASCAL and regarding the spectrum of different research areas of the

publications. The collaboration between Germany and West Africa showed a strong scientific network. The author connections within West Africa and other African countries showed many and diverse links that could serve also in future for a profound scientific basis to ensure a continuation of WASCAL. Most African authors came from Burkina Faso, followed by Ghana and Nigeria. Interestingly, Overland et al. (2022) identified in a search of the largest database of research funding that, between 1990 and 2020 and within West Africa, the highest climate change research funding was provided for Ghana while funding for other West African countries along the coastline was rather lower. Pasgaard et al. (2015) also identified that locally based authors of climate change studies in West Africa were mainly from Nigeria while no studies were found for Togo, Guinea, among others. Furthermore, in relation to the number of scientific papers about climate change adaptation between 1988 and 2020, Ghana and Nigeria showed the highest amounts among West African countries (Sietsma et al., 2021). In our study, Ghana and Nigeria were strongly represented, too. Collaborations could be also related to the historical past, cultural ties and language (Nature, 2014). The majority of our analysed papers were published in English where English-speaking West African countries might have an advantage. However, Burkina Faso was also a strong player in our study which could be related to the location of the WASCAL CoC in Ouagadougou. Furthermore, Dano, located in southwestern Burkina Faso, belongs to the main research sites in WASCAL (WASCAL, 2020b). In addition, it can be confirmed by our study that other West African countries such as Gambia and Mali are comparably less represented in published research. It also means that future scientific collaborations in publications could focus more on the underrepresented West African countries.

The accessibility of the publications during the analysed time frame was partially limited due to the fact that, in total, only 57.8 % of the publications were freely accessible even though BMBF promotes the open access of data and results (BMBF, 2021). However, the share of open access publications has improved over the time period. In 2022, more than 90 % of the papers were published as open access. Open-access research is important because it allows an improved sharing of information and knowledge, which can help in the advancement of science, technology, and innovation. Especially people of the Global South have often not sufficient resources to access subscription-based journals (Powell et al., 2020; Tai and Robinson, 2018). Since the expansion of the international research network and cooperation should belong to the primary goals (not only of WASCAL), it is important to provide greater access and visibility of research, which can help to increase the impact and reach of research also locally and across socio-economic boundaries. The finding regarding the limited open access during the total period of investigation could be also related to the fact that a relatively high share of the papers was released with publishers such as Elsevier, Springer, and Taylor & Francis that rather cover hybrid journals. The open access costs of hybrid journals are partially very high, and it might not be possible to cover these costs by project or university money. Another factor could have been that the DEAL negotiations (DEAL, 2022) to enable open access for publications from German institutions (also as co-author of African studies) were only initiated in 2013 and suspended in 2017 (Mittermeier, 2023a). In 2018, the negotiations were resumed and open access conditions could have been improved (Mittermeier, 2023b).

Taking a look at the research topics, the majority of publications were based in environmental/ecological science which could hint towards an interdisciplinary research field. Meteorology and atmospheric sciences were the 2nd rank which represents well the focus of climate and atmospheric studies of WASCAL – not least because "climate change" is part of WASCAL's name. As 3rd rank, the multidisciplinary context of agriculture was identified. However, "food security" was less pronounced in the findings. The analysis of food systems goes beyond agriculture, e.g., topics related to food storage, logistics, stock markets, alternative food sources, livelihood diversification, etc. Food security is and will continue to be a very important topic in the frame of climate change. Trisos et al. (2022) identified that the main funding sectors in the global funding scheme for research in Africa related to climate change were food systems, ecosystems, and freshwater.

As expected, pure studies from social sciences were less represented in the publication output. This fact was already existing during a long time of WASCAL due to major focus on environmental, land use change, and climate change analyses and author's collaborations within meteorology, agriculture, and other physical sciences. However, many interdisciplinary studies within WASCAL confirm the use of a combination between approaches and methods from social and natural sciences (e.g., Kleemann et al., 2017a, b; Koo et al., 2019). Furthermore, studies of diseases (i.e., infectious diseases, tropical medicine, parasitology) were relatively underrepresented. Besides the need to strengthening studies in social sciences, the research field of diseases could be an interesting future research area due to the importance of human health and food security in the frame of environmental change and climate change (e.g., Lake et al., 2012; Myers and Patz, 2009; Sweileh, 2020).

In addition, only three papers in our analysis were directly related to urban studies and regional urban planning. Links between urbanization and climate change clearly exist. For example, so called "heat islands" (hotspots of high temperatures) in cities might increase with climate change (Busby et al., 2014; Li et al., 2021) and coastal and flood-prone cities might be more at risk in future due to rising sea levels and more extreme weather events (Douglas et al., 2008; Hinkel et al., 2012). According to the IPCC, more investment of research in Africa is especially needed in cities and for the restoration of ecosystems (IPCC, 2022a,b). The fast process of urbanization in many African cities lacks a clear spatial planning and supervision of uncontrolled urban development (Jiang et al., 2021). Even though more than three WASCAL peer-reviewed publications of spatial analysis of urban spaces in West Africa exist (e.g., Mahmoud et al., 2016), there should be potentially a stronger focus on urban planning issues in future WASCAL-related research. First steps have been taken already by changing the scope of the WASCAL GSP in Minna from "Climate Change and Adapted Land Use" to „Climate Change and Human Habitats". It shows that the need to focus more on urban issues in research and capacity building has been recognized.

5. Conclusion

A comprehensive systematic literature review for the time frame 2012–2022 of peer-reviewed scientific publications in the context of WASCAL was conducted. This format of a standardized assessment of research can be also used by other scientific institutions to

track and assess their scientific output and impact. The 315 high-quality scientific publications, the 8004 citations, the 891 individual authors, and the joint research from 58 different countries, among others, reflect the high representativeness of WASCAL's research and its role as science funder in Africa and abroad. Other West African countries than Ghana, Nigeria, and Burkina Faso should be more actively involved in future. WASCAL's primary research mission of climate-related analyses has been fulfilled by showing mainly environmental studies, meteorology and atmospheric sciences as research areas. Future and stronger research focus of WASCAL could be laid on food security, health and diseases, urban planning and social sciences to better link the multifaceted and complex layers of social-ecological systems in the frame of climate change research. By this approach, WASCAL will contribute even stronger to reach the Sustainable Development Goals.

CRediT authorship contribution statement

Sarah Schönbrodt-Stitt: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Janina Kleemann:** Conceptualization, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Christine Fürst:** Conceptualization, Supervision, Writing – review & editing. **Paul Vlek:** Conceptualization, Writing – review & editing. **Daouda Koné:** Writing – review & editing. **Kehinde Ogunjobi:** Writing – review & editing. **Michael Thiel:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Writing – review & editing.

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Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envdev.2025.101283.

Data availability

All papers and their metadata respectively are available through the Web of Science Core Database. For non-open-access research papers, special licenses might be necessary for retrieving them.

References

Agarwal, A., Durairajanayagam, D., Tatagari, S., Esteves, S.C., Harlev, A., Henkel, R., Roychoudhury, S., Homa, S., Puchalt, N.G., Ramasamy, R., Ahmad Majzoub, A., Ly, K.D., Tvrda, E., Assidi, M., Kesari, K., Sharma, R., Banihani, S., Ko, E., Abu-Elmagd, M., Gosalvez, J., Bashiri, A., 2016. Bibliometrics: tracking research impact by selecting the appropriate metrics. Asian J. Androl. 18 (2), 296–309.

Agwu, O.P., Bakayoko, A., Jimoh, S.O., Porembski, S., 2018. Farmers' perceptions on cultivation and the impacts of climate change on goods and services provided by Garcinia kola in Nigeria. Ecol. Process. 7, 36. https://doi.org/10.1186/s13717-018-0147-3.

Alhassan, A., Jin, M., 2020. Evapotranspiration in the Tono reservoir catchment in Upper East Region of Ghana estimated by a novel TSEB approach from ASTER imagery. Remote Sens. 12 (3), 569. https://doi.org/10.3390/rs12030569.

Almoradie, A., Brito, M. M. de, Evers, M., Bossa, A., Lumor, M., Norman, C., Yacouba, Y., Hounkpe, J., 2020. Current flood risk management practices in Ghana: gaps and opportunities for improving resilience. J. Flood Risk Manag. 13 (4), e12664. https://doi.org/10.1111/jfr3.12664.

Aria, M., Cuccurullo, C., 2017. bibliometrix: an R-tool for comprehensive science mapping analysis. J. Informetr. 11 (4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007.

Asare-Kyei, D., Renaud, F.G., Kloos, J., Walz, Y., Rhyner, J., 2017. Development and validation of risk profiles of West African rural communities facing multiple natural hazards. PLoS One 12 (3), e0171921. https://doi.org/10.1371/journal.pone.0171921.

Ascott, M.J., Macdonald, D.M.J., Black, E., Verhoef, A., Nakohoun, P., Tirogo, J., Sandwidi, W.J.P., Bliefernicht, J., Sorensen, J.P.R., Bossa, A.Y., 2020. In situ observations and lumped parameter model reconstructions reveal intra-annual to multidecadal variability in groundwater levels in sub-Saharan Africa. Water Resour. Res. 56 (12), e2020WR028056.

Badjana, H.M., Fink, M., Helmschrot, J., Diekkrueger, B., Kralisch, S., Afouda, A.A., Wala, K., 2017. Hydrological system analysis and modelling of the Kara River basin (West Africa) using a lumped metric conceptual model. Hydrol. Sci. J.-J. Sci. Hydrol. 62 (7), 1094–1113. https://doi.org/10.1080/02626667.2017.1307571.

Ballo, A., Koffi, K.V., Korgo, B., Ogunjobi, K.O., Agbo, S.N., Kone, D., Savadogo, M., 2022. Law and policy review on green hydrogen potential in ECOWAS countries. Energies 15 (7), 2304. https://doi.org/10.3390/en15072304.

Belem, M., Saqalli, M., 2017. Development of an integrated generic model for multi-scale assessment of the impacts of agro-ecosystems on major ecosystem services in West Africa. J. Environ. Manag. 202, 117–125.

Bliefernicht, J., Berger, S., Salack, S., Guug, S., Hingerl, L., Heinzeller, D., Mauder, M., Steinbrecher, R., Steup, G., Bossa, A.Y., Waongo, M., 2018. The WASCAL hydrometeorological observatory in the Sudan Savanna of Burkina Faso and Ghana. Vadose Zone J. 17 (1), 1–20. https://doi.org/10.2136/vzj2018.03.0065.

BMBF, 2021. Open access website of BMBF. German Federal Ministry of Education and Research (BMBF). https://www.bildung-forschung.digital/digitalezukunft/de/wissen/open-access/open-access_node.html. (Accessed 19 July 2023).

BMBF, n.d.: International affairs The Africa Strategy of the BMBF. German Federal Ministry of Education and Research (BMBF). Available at: https://www.bmbf.de/bmbf/en/international-affairs/worldwide-networking/middle-east-and-africa/the-africa-strategy-of-the-bmbf.html (accessed 12 July 2023).

Busby, J.W., Cook, K.H., Vizy, E.K., Smith, T.G., Bekalo, M., 2014. Identifying hot spots of security vulnerability associated with climate change in Africa. Clim. Change 124, 717–731.

Carpenter, C.R., Cone, D.C., Sarli, C.C., 2014. Using publication metrics to highlight academic productivity and research impact. Acad. Emerg. Med. 21 (10), 1160–1172. https://doi.org/10.1111/acem.12482.

Chan, S., Falkner, Robert, Goldberg, Matthew, van Asselt, Harro, 2018. Effective and geographically balanced? An output-based assessment of non-state climate actions. Clim. Policy 18 (1), 24–35. https://doi.org/10.1080/14693062.2016.1248343.

Clarivate, 2024. Web of science platform. https://clarivate.com/products/scientific-and-academic-research/research-discovery-and-workflow-solutions/webofscience-platform/. (Accessed 29 August 2024).

Coronese, M., Lamperti, F., Keller, K., Chiaromonte, F., Roventini, A., 2019. Evidence for sharp increase in the economic damages of extreme natural disasters. Proc. Natl. Acad. Sci. 116 (43), 21450–21455. https://doi.org/10.1073/pnas.1907826116.

Danso, D.K., François, B., Hingray, B., Diedhiou, A., 2021. Assessing hydropower flexibility for integrating solar and wind energy in West Africa using dynamic programming and sensitivity analysis. Illustration with the Akosombo reservoir, Ghana. J. Clean. Prod. 287, 125559. https://doi.org/10.1016/j.jclepro.2020.125559.

DEAL, 2022. Project DEAL – transformative agreements. https://deal-konsortium.de/en/about-deal/rationale-and-objectives. (Accessed 27 June 2024).

Diallo, I., Giorgi, F., Deme, A., Tall, M., Mariotti, L., Gaye, A.T., 2016. Projected changes of summer monsoon extremes and hydroclimatic regimes over West Africa for the twenty-first century. Clim. Dyn. 47 (12), 3931–3954. https://doi.org/10.1007/s00382-016-3052-4.

Dieng, D., Laux, P., Smiatek, G., Heinzeller, D., Bliefernicht, J., Sarr, A., Gaye, A.T., Kunstmann, H., 2018. Performance analysis and projected changes of agroclimatological indices across West Africa based on high-resolution regional climate model simulations. J. Geophys. Res. Atmos. 123 (15), 7950–7973. https://doi.org/10.1029/2018JD028536.

Dimobe, K., Kouakou, J.L.N., Tondoh, J.E., Zoungrana, B.J.-B., Forkuor, G., Ouédraogo, K., 2018. Predicting the potential impact of climate change on carbon stock in semi-arid West African savannas. Land 7 (4), 124. https://doi.org/10.3390/land7040124.

Douglas, I., Alam, K., Maghenda, M., Mcdonnell, Y., McLean, L., Campbell, J., 2008. Unjust waters: climate change, flooding and the urban poor in Africa. Environ. Urbanization 20 (1), 187–205.

Esquivel-Muelbert, A., Baker, T.R., Dexter, K.G., Lewis, S.L., ter Steege, H., Lopez-Gonzalez, G., Phillips, O.L., 2017. Seasonal drought limits tree species across the Neotropics. Ecography 40, 618–629. https://doi.org/10.1111/ecog.01904.

Ferner, J., Schmidtlein, S., Guuroh, R.T., Lopatin, J., Linstädter, A., 2018. Disentangling effects of climate and land-use change on West African drylands' forage supply. Glob. Environ. Change 53, 24–38.

Forzieri, G., Cescatti, A., e Silva, F.B., Feyen, L., 2017. Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study. Lancet Planet. Health 1 (5), e200–e208. https://doi.org/10.1016/S2542-5196(17)30082-7.

Giorcelli, M., Lacetera, N., Marinoni, A., 2022. How does scientific progress affect cultural changes? A digital text analysis. J. Econ. Growth 27 (3), 415–452. https://dx.doi.org/10.1007/s10887-022-09204-6.

Heinzeller, D., Dieng, D., Smiatek, G., Olusegun, C., Klein, C., Hamann, I., Salack, S., Bliefernicht, J., Kunstmann, H., 2018. The WASCAL high-resolution regional climate simulation ensemble for West Africa: concept, dissemination and assessment. Earth Syst. Sci. Data 10 (2), 815–835. https://doi.org/10.5194/essd-10-815-2018.

Hinkel, J., Brown, S., Exner, L., Nicholls, R.J., Vafeidis, A.T., Kebede, A.S., 2012. Sea-level rise impacts on Africa and the effects of mitigation and adaptation: an application of DIVA. Reg. Environ. Change 12, 207–224.

Hipt, F. op de, Diekkrueger, Bernd, Steup, G., Yira, Y., Hoffmann, T., Rode, M., Naeschen, K., 2019. Modeling the effect of land use and climate change on water resources and soil erosion in a tropical West African catch-ment (Dano, Burkina Faso) using SHETRAN. Sci. Total Environ. 653, 431–445. https://doi.org/10.1016/j.scitotenv.2018.10.351.

Hounkpe, J., Diekkrueger, B., 2018. Challenges in calibrating hydrological models to simultaneously evaluate water resources and flood hazard: a case study of Zou basin, Benin. Episodes 41 (2), 104–113. https://doi.org/10.18814/epiiugs/2018/018010.

IPCC, 2022a. In: Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., Rama, B. (Eds.), Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, p. 3056. https://doi.org/10.1017/9781009325844.

IPCC, 2022b: Summary for Policymakers [H.-O. Portner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegria, M. Craig, S. Langsdorf, S. Loschke, V. Moller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Portner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegria, M. Craig, S. Langsdorf, S. Loschke, V. Moller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-33, https://doi.org/10.1017/9781009325844.001.

Jiang, S., Zhang, Z., Ren, H., Wei, G., Xu, M., Liu, B., 2021. Spatiotemporal characteristics of urban land expansion and population growth in Africa from 2001 to 2019: evidence from population density data. ISPRS Int. J. GeoInf. 10 (9), 584. https://doi.org/10.3390/ijgi10090584.

Kebe, I., Diallo, I., Sylla, M.B., Sales, F. de, Diedhiou, A., 2020. Late 21st century projected changes in the relationship between precipitation, African easterly jet, and African easterly waves. Atmosphere 11 (4), 353. https://doi.org/10.3390/atmos11040353.

Kleemann, J., Baysal, G., Bulley, H.N.N., Fürst, C., 2017a. Assessing driving forces of land use and land cover change by a mixed-method approach in north-eastern Ghana, West Africa. J. Environ. Manag. 196, 411–442. https://doi.org/10.1016/j.jenvman.2017.01.053.

Kleemann, J., Celio, E., Nyarko, B.K., Jimenez-Martinez, M., Fürst, C., 2017b. Assessing the risk of seasonal food insecurity with an expert-based Bayesian Belief Network approach in northern Ghana, West Africa. Ecol. Complex. 32, 53–73. https://doi.org/10.1016/j.ecocom.2017.09.002.

Klutse, N.A.B., Sylla, M.B., Diallo, I., Sarr, A., Dosio, A., Diedhiou, A., Kamga, A., Lamptey, B., Ali, A., Gbobaniyi, E.O., Owusu, K., 2016. Daily characteristics of West African summer monsoon precipitation in CORDEX simulations. Theor. Appl. Climatol. 123, 369–386.

Koo, H., Kleemann, J., Fürst, C., 2019. Impact assessment of land use changes using local knowledge for the provision of ecosystem services in northern Ghana, West Africa. Ecol. Indic. 103, 156–172. https://doi.org/10.1016/j.ecolind.2019.04.002.

Koseoglu, M.A., 2016. Mapping the institutional collaboration network of strategic management research: 1980–2014. Scientometrics 109 (1), 203–226. https://doi.org/10.1007/s11192-016-1894-5.

Lake, I.R., Hooper, L., Abdelhamid, A., Bentham, G., Boxall, A.B.A., Draper, A., Fairweather-Tait, S., Hulme, M., Hunter, P.R., Nichols, G., Waldron, K.W., 2012. Climate change and food security: health impacts in developed countries. Environ. Health Perspect. 120 (11), 1520–1526.

Larbi, I., Hountondji, F.C., Dotse, S.Q., Mama, D., Nyamekye, C., Adeyeri, O.E., Djan'na Koubodana, H., Odoom, P.R.E., Asare, Y.M., 2021. Local climate change projections and impact on the surface hydrology in the Vea catchment, West Africa. Nord. Hydrol 52 (6), 1200–1215. https://doi.org/10.2166/nh.2021.096.
Li, K., Rollins, J., Yan, E., 2018. Web of Science use in published research and review papers 1997–2017: a selective, dynamic, cross-domain, content-based analysis. Scientometrics 115, 1–20. https://doi.org/10.1007/s11192-017-2622-5.
Li, X., Stringer, L.C., Dallimer, M., 2021. The spatial and temporal characteristics of urban heat island intensity: implications for East Africa's urban development. Climate 9 (4), 51.
Mahmoud, I.M., Duker, A., Conrad, C., Thiel, M., Ahmad, S.H., 2016. Analysis of settlement expansion and urban growth modelling using geoinformation for assessing potential impacts of urbanization on climate in Abuja City, Nigeria. Remote Sens. 8 (3), 220.
Mittermeier, B., 2023a. DEAL: Wo stehen wir nach 10 Jahren? (Teil 1). https://www.b-i-t-online.de/heft/2023-02-fachbeitrag-mittermaier.pdf. (Accessed 27 June 2024).
Mittermeier, B., 2023b. DEAL: Wo stehen wir nach 10 Jahren? (Teil 2). https://www.b-i-t-online.de/heft/2023-03-fachbeitrag-mittermaier.pdf. (Accessed 27 June 2024).
Myers, S.S., Patz, J.A., 2009. Emerging threats to human health from global environmental change. Annu. Rev. Environ. Resour. 34, 223–252.
Naabil, E., Lamptey, B.L., Arnault, J., Olufayo, A., Kunstmann, H., 2017. Water resources management using the WRF-Hydro modelling system: case-study of the Tono dam in West Africa. J. Hydrol.-Reg. Stud. 12, 196–209. https://doi.org/10.1016/j.ejrh.2017.05.010.
Neves Machado, R., Vargas-Quesada, B., Leta, J., 2015. Intellectual structure in stem cell research: exploring Brazilian scientific articles from 2001 to 2010. Scientometrics 106 (2), 525–537. https://doi.org/10.1007/s11192-015-1793-1.
Nikiema, P.M., Sylla, M.B., Ogunjobi, K., Kebe, I., Gibba, P., Giorgi, F., 2017. Multi-model CMIP5 and CORDEX simulations of historical summer temperature and precipitation variabilities over West Africa. Int. J. Climatol. 37 (5), 2438–2450. https://doi.org/10.1002/joc.4856.
North, M.A., Hastie, W.W., Craig, M.H., Slotow, R., 2022. Tracing primary sources of funding for, and patterns of authorship in, climate change research in Africa. Environ. Sci. Pol. 127, 196–208. https://doi.org/10.1016/j.envsci.2021.10.023.
Ntajal, J., Lamptey, B.L., Mahamadou, I.B., Nyarko, B.K., 2017. Flood disaster risk mapping in the lower mono river basin in Togo, West Africa. Int. J. Disaster Risk Reduct. 23, 93–103. https://doi.org/10.1016/j.ijdrr.2017.03.015.
Obahoundje, S., Ofosu, E.A., Akpoti, K., Kabobah, A.T., 2017. Land use and land cover changes under climate uncertainty: modelling the impacts on hydropower production in Western Africa. Hydrology 4 (1), 2. https://doi.org/10.3390/hydrology4010002.
Odou, O.D.T., Bhandari, R., Adamou, R., 2020. Hybrid off-grid renewable power system for sustainable rural electrification in Benin. Renew. Energy 145, 1266–1279. https://doi.org/10.1016/j.renene.2019.06.032.
Overland, I., Sagbakken, H.F., Isataeva, A., Kolodzinskaia, G., Simpson, N.P., Trisos, C., Vakulchuk, R., 2022. Funding flows for climate change research on Africa: where do they come from and where do they go? Clim. Dev. 14 (8), 705–724. https://doi.org/10.1080/17565529.2021.1976609.
Pasgaard, M., Dalsgaard, B., Maruyama, P.K., Sandel, B., Strange, N., 2015. Geographical imbalances and divides in the scientific production of climate change knowledge. Glob. Environ. Change 35, 279–288. https://doi.org/10.1016/j.gloenvcha.2015.09.018.
Powell, A., Johnson, R., Herbert, R., 2020. Achieving an equitable transition to open access for researchers in lower and middle-income countries. ICSR Perspectives. https://doi.org/10.2139/ssrn.3624782.
Salack, S., Sanfo, S., Sidibe, M., Daku, E.K., Camara, I., Dieng, M.D.B., Hien, K., Torou, B.M., Ogunjobi, K.O., Sangare, S.A.K.S.B., Kouame, K.R., Koffi, Y.B., Liersch, S., Savadogo, M., Giannini, A., 2022. Low-cost adaptation options to support green growth in agriculture, water resources, and coastal zones. Sci. Rep. 12 (1), 17898. https://doi.org/10.1038/s41598-022-22331-9.
Saley, I.A., Salack, S., Sanda, I.S., Moussa, M.S., Bonkaney, A.L., Ly, M., Fode, M., 2019. The possible role of the Sahel Greenbelt on the occurrence of climate extremes over the West African Sahel. Atmos. Sci. Lett. 20 (8), e927. https://doi.org/10.1002/asl.927.
Salomon, E., Preston, J.L., Tannenbaum, M.B., 2017. Climate change helplessness and the (de)moralization of individual energy behavior. J. Exp. Psychol. Appl. 23 (1), 15–28. https://doi.org/10.1037/xap000010528.
Sanogo, K., Binam, J., Bayala, J., Villamor, G.B., Kalinganire, A., Dodiomon, S., 2017. Farmers' perceptions of climate change impacts on ecosystem services delivery of parklands in southern Mali. Agrofor. Syst. 91, 345–361. https://doi.org/10.1007/s10457-016-9933-z.
Sawadogo, W., Abiodun, B.J., Okogbue, E.C., 2020. Impacts of global warming on photovoltaic power generation over West Africa. Renew. Energy 151, 263–277. https://doi.org/10.1016/j.renene.2019.11.032.
Scherer, J., Weber, S., Azofra, M., Ruete, A., Sweeney, E., Weiler, N., Sagias, I., Haardt, J., Cravetto, R., Spichtlinger, D., Ala-Mutka, K., 2018. Making the Most of Your H2020 Project – Boosting the Impact of Your Project through Effective Communication, Dissemination and Exploitation. European IPR Helpdesk in cooperation with the European Commission, p. 21, 2018. https://op.europa.eu/en/publication-detail/-/publication/3bb7278e-ebf3-11e9-9c4e-01aa75ed71a1. (Accessed 12 December 2020).
Selormey, E.E., Dome, M.Z., Essima, L.O., Logan, C., 2019. Change ahead: experience and awareness of climate change in Africa. Pan African Profiles: Afrobarometer Policy Paper, 60. Afrobarometer, Accra, Ghana, pp. 1–30. Available at: https://afrobarometer.org/sites/default/files/publications/Policy%20papers/ab_r7_policypaperno60_experience_and_awareness_of_climate_change_in_africa.pdf. (Accessed 30 June 2023).
Sietsma, A.J., Ford, J.D., Callaghan, M.W., Minx, J.C., 2021. Progress in climate change adaptation research. Environ. Res. Lett. 16 (5), 054038. https://doi.org/10.1088/1748-9326/abf7f3.
Snyder, H., 2019. Literature review as a research methodology: an overview and guidelines. J. Bus. Res. 104, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039.
Sørensen, O.H., Bjørner, J., Holtermann, A., Dyreborg, J., Sørli, J.B., Kristiansen, J., Nielsen, S.B., 2021. Measuring societal impact of research - developing and validating an impact instrument for occupational health and safety. Res. Eval. 31 (1), 118–131. https://doi.org/10.1093/reseval/rvab036.
Sweileh, W.M., 2020. Bibliometric analysis of peer-reviewed literature on climate change and human health with an emphasis on infectious diseases. Glob. Health 16 (1), 1–17.
Sylla, M.B., Giorgi, F., Pal, J.S., Gibba, P., Kebe, I., Nikiema, M., 2015. Projected changes in the annual cycle of high-intensity precipitation events over West Africa for the late twenty-first century. J. Clim. 28 (16), 6475–6488. https://doi.org/10.1175/JCLI-D-14-00854.1.
Tai, T.C., Robinson, J.P.W., 2018. Enhancing climate change research with open science. Front. Environ. Sci. 6. https://doi.org/10.3389/fenvs.2018.00115.
THE, 2024. World reputation Rankings 2023. THE: times higher education, United Kingdom. https://www.timeshighereducation.com/world-university-rankings/2023/reputation-ranking. (Accessed 27 June 2024).
Trisos, C.H., Adelekan, I.O., Totin, E., Ayanlade, A., Efitre, J., Gemeda, A., Kalaba, K., Lennard, C., Masao, C., Mgaya, Y., Ngaruiya, G., Olago, D., Simpson, N.P., Zakieldeen, S., 2022. Africa. In: Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., Rama, B. (Eds.), Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455. https://doi.org/10.1017/9781009325844.011.
UN, 2024. The 17 Goals. United Nations (UN). Department of Economic and Social Affairs. https://sdgs.un.org/goals. (Accessed 27 June 2024).
WADIREP, 2019. WASCAL scientific research data catalog. West African science service Centre on climate change and adapted land use (WASCAL). https://wascal-dataportal.org/. (Accessed 28 June 2024).
Wambu, E.W., Ho, Y.S., 2016. A bibliometric analysis of drinking water research in Africa. WaterSA 42 (4), 612–620. https://doi.org/10.2166/wh.2023.293.
WASCAL, 2020a. WASCAL homepage. West African science service Centre on climate change and adapted land use (WASCAL). https://wascal.org/. (Accessed 12 July 2023).
WASCAL, 2020b. Description of the Dano basin in WASCAL. West African science service Centre on climate change and adapted land use (WASCAL). https://wascal.org/dano-basin/. (Accessed 2 June 2025).
WASCAL, 2021. BMBF has invested €120 million in WASCAL for climate change and renewable energy in West Africa. https://wascal.org/bmbf-has-invested-e120-million-in-wascal-for-climate-change-and-renewable-energy-in-west-africa/. (Accessed 12 July 2023).

WASCAL, 2022. A decade of providing climate solutions to West Africa. West African science service Centre on climate change and adapted land use (WASCAL). https://wascal.org/wp-content/uploads/2022/10/WASCAL-A-DECADE-REPORT_FINAL.pdf. (Accessed 27 June 2024).

Williams, P.A., Simpson, N.P., Totin, E., North, M.A., Trisos, C.H., 2021. Feasibility assessment of climate change adaptation options across Africa: an evidence-based review. Environ. Res. Lett. 16 (7), 073004. https://doi.org/10.1088/1748-9326/ac092d.

Yira, Y., Diekkrueger, B., Steup, G., Bossa, A.Y., 2016. Modeling land use change impacts on water resources in a tropical West African catchment (Dano, Burkina Faso). J. Hydrol. 537, 187–199. https://doi.org/10.1016/j.jhydrol.2016.03.052.