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Towards Resolving Challenges Associated with Climate Change Modelling in Africa

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Abstract: Climate change is a significant concern impacting food security, agricultural reform, disease transmission, and disruption to human, plant, and animal ecosystems, along with a host of additional consequences, ultimately affecting the quality of life and the livelihoods of the global population. African-based research aims to better understand the impact of climate change on nature and on different aspects of humanity, as well as improve forecasting for greater economic potential. However, researchers often encounter various challenges and obstacles. Here, we conducted a bibliographic analysis and interpretation of relevant climate change peer-reviewed research articles related to the African continent. From this analysis, challenges associated with climate change modelling in Africa were identified. Primarily, the lack of an extensive observational network and technological limitations hinder modelling efforts. Additionally, an apparent pull of scientists away from African institutions to institutions further afield was observed. Novel solutions to these challenges are proffered. Finally, we highlight how the German Deutscher Akademischer Austauschdienst (DAAD) Climate Research for Alumni and Postdocs in Africa (climapAfrica) program is contributing towards resolving these challenges.

Keywords: climate change modelling; challenges; Africa; solutions; Climate Research for Alumni and Postdocs in Africa (climapAfrica)

1. Introduction

Climate variability and change are driven by internal and external factors, including natural and anthropogenic forcings dominated by greenhouse gas (GHG) emissions. The long-term continuous emissions of GHGs have contributed to the increase in global warming, which currently constitutes a serious global challenge and affects many aspects of life, including food security, disease transmission, quality of life, and all economic sectors [1,2]. The scientific evidence indicates increasing risks of serious and irreversible impacts of climate change in business-as-usual pathways associated with GHG emissions [3] Therefore, it is crucial to implement policies to increase mitigation and resilience capacities, especially where populational vulnerability to future climate change is high; for instance, the strong dependence of African countries on rain-fed agriculture is significantly linked to their economic potential and growth. The uncertainty of climate change with respect to not only rainfall distribution and magnitude, but also rising temperatures adds stress to crop production [4]. These activities also require high-energy inputs possibly hindering global goals for reducing GHG emissions. Successful adaptation requires the necessary quantification of the magnitude of impacts through targeted research objectives, for example, research that focusses on the understanding of disease transmission processes [5,6], thresholds of heat stress variability [7,8], fluctuations in economic situations [9], changes in land use practices [10], plant growth processes (i.e., food crops), among others [11]. For these purposes, modelling is usually required.

Climate change modelling and related research requires quality data with distinct spatial and temporal resolutions for setup, calibration, and validation [12–20]. The resolution required often depends on the specific objectives of the modelling task. Information at a regional scale is highly desirable, particularly across the African continent, for practical planning of local issues, such as rain-fed agriculture, water resources availability, and flood management. Often, challenges in acquiring adequate data for the modelling task at hand and the spatial distribution of the data may render certain analyses impossible; for instance, on accounting for small geographic areas with high topographical variability, see [21–29].

The objective of this paper is to identify challenges that scientists face when modelling climate change and its impacts over the African continent. We briefly discuss the distribution of researchers generating peer-reviewed publications and the contribution of African-based scientists to the literature over the last decade. The uncertainties, limits, and challenges raised in the literature survey will be investigated in detail and some solutions will be proposed to address these issues. We will also look at how initiatives, such as the German Deutscher Akademischer Austauschdienst (DAAD) Climate Research for Alumni and Postdocs in Africa (climapAfrica) program, can provide a network to encourage intra-continental collaborations and inspire international ties. The identification of these challenges will assist in delivering actions to address them in terms of better understanding the impacts of climate change on nature and thus on African countries.

2. Current Issues Facing Climate Change Modelling in Africa

Many studies, including the Intergovernmental Panel on Climate Change (IPCC) report [30], have discussed or noted the challenges of climate change modelling for past and future scenarios. Some of the major limitations—especially in Africa—are related to data quality, availability, and accessibility [31–33]. The paucity of data sources directly affects research in the assessment of climatic conditions and changes, which directly impacts livelihoods [14,34]. One of the primary sources of most climate data in Africa is a network of weather stations, which are scattered disproportionately across the landscape. The continent has a very low density of weather stations, with data not readily available [31]. In addition, the historical data gathered from this network span but a few decades and the records are typically riddled with missing information, incorrect capture, and incomplete conversion between the metric and imperial system. Moreover, most ground stations are concentrated in or near major cities or easily accessible locations, disregarding regions with rough or inhospitable terrain (e.g., mountains and deserts) [32]. Additionally, this observational network may be poorly maintained and rarely serviced, mostly due to limited investment in the respective countries' climate infrastructures [32].

In addition to a low spatial resolution of stations, the storage of data is usually undertaken by the relevant government branch or even by private groups, which introduces accessibility challenges, either by legal restrictions, lack of knowledge of the pertinent branch that hosts the data repository, and/or high access costs [32,35]. Thus, sharing of data beyond the initial user is rather limited. Furthermore, due to low financial investment, the availability of the latest products and tools is minimal, leading to a lack of dissemination of skills. Alternative options to the observation network include computational modelling, remote sensing, and geographical information systems (GISs). Over the last few decades, developments in geospatial techniques have aided researchers in visualizing the impacts of climate change. Furthermore, Woldai [36] highlighted challenges that African countries are facing with regards to the usage of earth observation data; these include poor investment in information and communication technologies along with infrastructure, a lack of capacity to process or use the available data, a lack of access to available data, and limited awareness in the private and public sectors of the mini-satellites launched by some African countries, amongst other challenges. The use of earth observation repositories for climate change modelling requires high-resolution data (i.e., spectral, temporal, spatial, and thematic resolution), which can be costly. In most cases, freely available earth observation data do not have high resolution, and this limits predictions in modelling activities.

3. Materials and Methods

3.1. Data Collection: Review of Climate-Related Publications from 2011–2020

According to Harzing and Alakangas [37], Google Scholar provides greater coverage for cross-disciplinary research outputs, although they note that the user interface may not be suitable for bibliometric analyses. However, the inclusion of exclusionary notations and limiting search results by year can produce refined outputs. Thus, a systematic, year-by-year comprehensive literature survey was conducted for the period 2011–2020. Search queries were applied to publications, by year, relating to climate change modeling in Africa that mentioned encountering a "limitation" or "challenge", irrespective of discipline. The article selection criteria were as follows: "research articles on climate change modeling in Africa", "research articles published between year 2011 and 2020", the keyword "climate change", the keyword "modeling", the keyword "Africa", the keyword "challenges", and the keyword "limitations". Only peer-reviewed, original research publications based on a region within the African continent were considered, excluding conference proceedings, review articles, global perspective articles, working papers, and university theses. In all, a total of about 10,000 articles were reviewed, based on the selection criteria detailed above. (See Figure 1 for articles reviewed from the Google Scholar Database). It must be noted that this literature survey was undertaken to understand the challenges and limitations of climate research over the African continent and not as a simple systematic review of works published during the year under investigation. Although additional portals, such as Web of Science, could also have been utilized, the survey undertaken here is acceptably representative of the issues faced by researchers working in Africa.

3.2. Bibliographic Analysis

The first 1000 articles for each year, as returned by the search parameters, were individually considered to identify the challenge noted by the authors. (Comprehensive details can be found in the Supplementary Materials, Tables S1–S11. Figure 1 shows the PRISMA chart for the articles reviewed from the Google Scholar database. Figure 2 shows the number of publications per year referencing a limitation or challenge. Furthermore, beyond detailing the limitations mentioned by the authors, their affiliations were also catalogued to assess the contribution of African-based scientists to the literature (Figure 3). A comprehensive bibliographic analysis of the data collated was then performed.

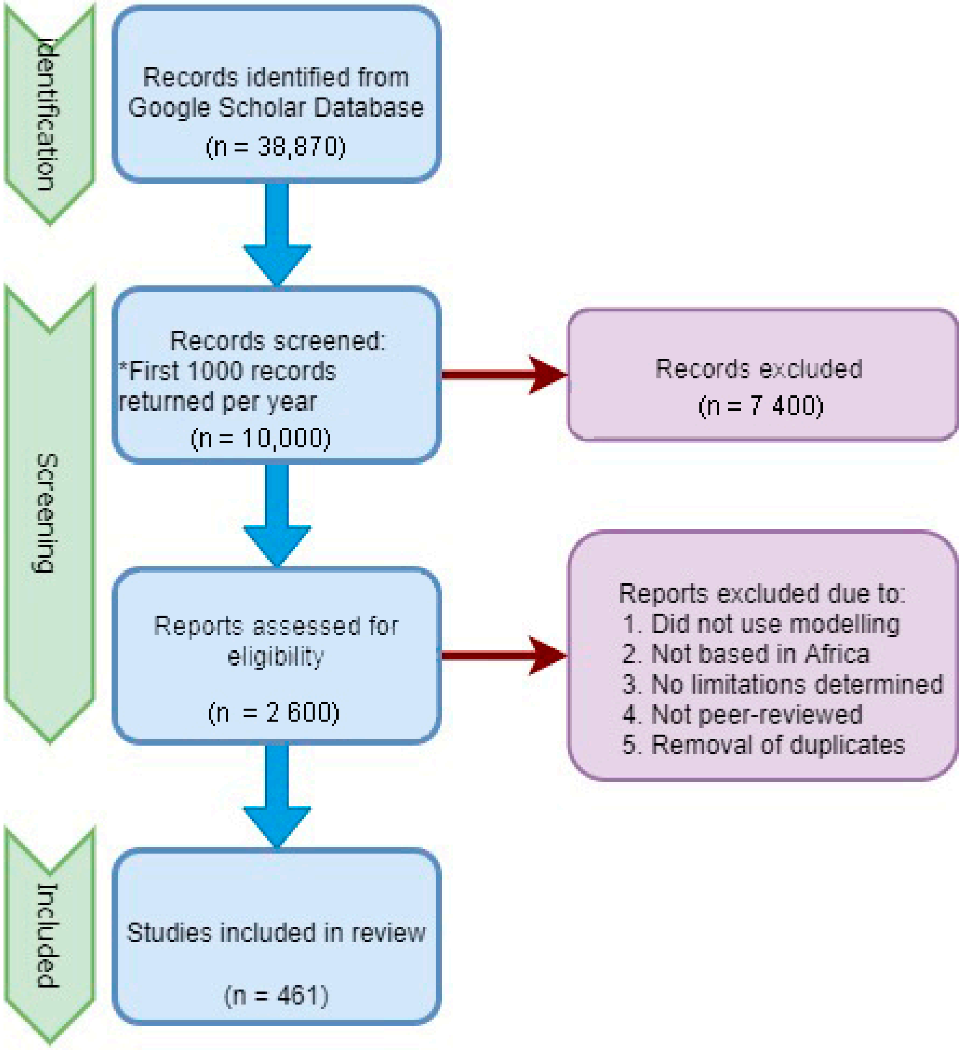

Figure 1. PRISMA chart for articles reviewed from the Google Scholar Database.

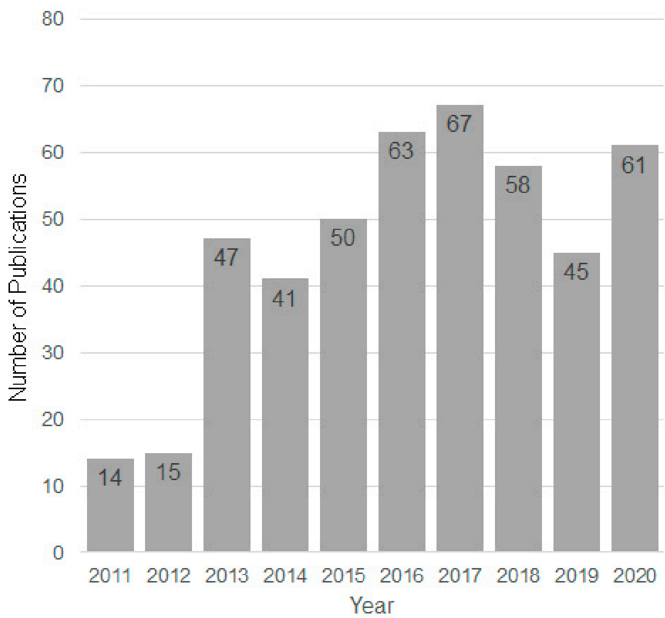

Figure 2. The number of publications per year referencing a limitation or challenge.

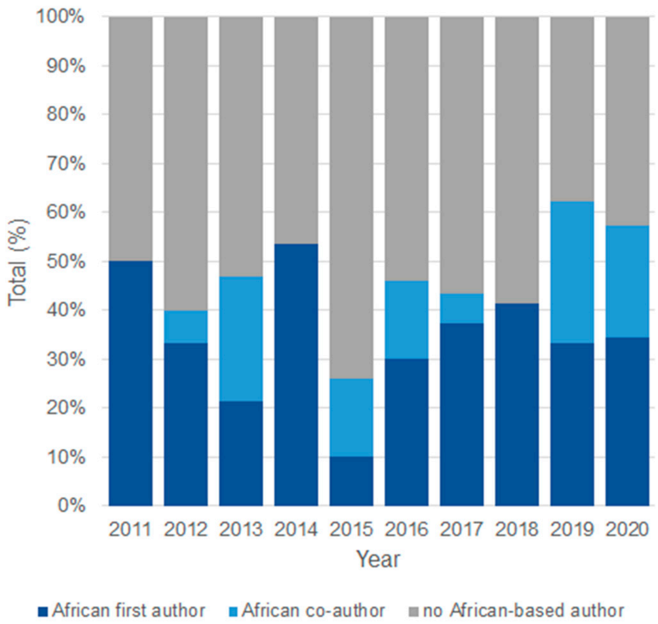

Figure 3. Author affiliations as noted from the survey, namely, articles which included African-based authors either as a first author or as a co-author and those published with no African-based affiliations.

4. Results

Publication numbers were relatively low in the initial years of the study—a mere 14 and 15 articles listing uncertainties in their research for 2011 and 2012 (Figure 2), respectively. The primary concerns for the authors were the quality and discontinuous nature of observation records (see Mango et al. [38] and Ramadan et al. [39]), with some opting to interpolate or infill missing data points, such as Mwale et al. [40]; in addition to the poor spatial resolution of the available data Notter et al. [41], noted the need to implement multiple avenues for data acquisition (see Tables S1–S11). In the following years, from 2013–2020, the average number of papers increased to 54, with a low of 41 in 2014 and a high of 67 in 2017 (Figure 2). Data limitations and observation station sparsity are still a commonly cited concern for many researchers in the years 2013–2020 (see Tables S1–S11) for a full list of relevant publications citing this limitation). The lack of a spatially extensive, high-temporal resolution observation network has limited the attempts to evaluate the impacts of climate change in several societal domains when utilizing simulation outputs from Global Climate Model (GCM), often embedded in the Coupled Model Intercomparison Project (CMIP); as well as Regional Climate Model (RCM), carried out within the framework of the COordinated Regional Climate Downscaling Experiment (CORDEX) initiative [29,33,34,42–45]. The latter authors noted that the lack of precipitation-related variables in mountainous regions may lead to interpolation errors. This was reiterated at a more regional scale by Ziervogel et al. [34], who argued that South Africa lacked a comprehensive national system to provide spatially extensive climate data, further noting the difficulty and costly nature of obtaining national data for hydrological modelling. This is one of many constraints on modelling-related research in the areas of agriculture, biodiversity, human health, amongst others, in South Africa [34].

Many authors state that some of the above issues have been partially overcome by utilizing satellite-derived data and analyses; see, for instance, the works of Golian [46] and colleagues and Tramblay et al. [17]. Although satellite-derived data come with their own challenges—for instance, low spatial and temporal resolution and the need for cloud-free imagery (see Mahmoud et al. [47])—unique research avenues can be followed, as exemplified by Busayo et al. [48], who provided insights into the emerging link between spatial planning and climate change adaptation using GIS and earth observation data in South Africa Twumasi et al. [49] used GIS and remote sensing to map flood-induced risks due to changes in weather patterns in the southern African region. Inherent uncertainties are associated with the accuracy of climate models because of data limitations Novella et al. [50] attributed the inaccuracy of their African rainfall climatology model to the unavailability of daily Global Telecommunication System (GTS) gauge reports in real time and deficiencies in the satellite estimates associated with precipitation processes over coastal and orographic areas.

The complexity of climate dynamics and diversity in processes over the African continent also raises issues in creating reliable model outputs, as noted by Stanzel et al. [51] when employing an ensemble of climate projections from CORDEX simulations over west Africa. This has led to contradictory conclusions for the same region [52]. Additionally, the computational power and time investment required to run these models is a global issue [53–57] (e.g., CMIP and CORDEX), and can be beyond the reach of many researchers, leading to the necessity of collaboration with international partners. Bias correction [17,58,59] is an additional factor required in validating models; however, the reliability of the output is dependent on the approach employed and the extent of the calibration time, which factors may lead to questionable results, particularly for arid to semi-arid regions. As stated by Beck et al. [32], the foremost prerequisite should be to " ... produce reliable estimates of the net climate forcing over the African continent and the surrounding oceans" that are of the same standard as other continents—a target that remains difficult to achieve.

5. Discussion

5.1. Insights Obtained from the Bibliography Analysis

The lack of capacity-building and development initiatives (human and infrastructural) in African institutions, both in the private and public sectors, is a major challenge. Fewer research facilities have been established on the continent when it comes to climate change research or large-scale climate change modelling research [60,61], except for South Africa. South African researchers contribute significantly to the percentage representation of African-based authors; for instance, 60% of African-based research published in 2013 had a South African researcher as the first author, while the same figure for 2019 was 33% (see Supplementary Materials, 2013, 2019, spreadsheets). The quality of research conducted and published, the high impact of the journals targeted, and the caliber of the methodologies adopted and data generated are considerably linked to South Africa's research capacity. In the later years of the review, more inter- and intra-continental collaborations were observed; many locally based authors are included alongside their international counterparts. In 2019 and 2020, 23% and 29% of articles included African-based researchers, respectively, as compared to an average of 8% for the preceding years considered in this study (see Supplementary Materials, 2019 and 2020, spreadsheets). The significance of quality collaborations amongst African researchers and between African and foreign researchers/institutions cannot be overemphasized; such collaborations have yielded—and are still yielding—quality research results and outputs [62–64].

Furthermore, the most prominent foreign countries (i.e., those outside the African continent) conducting and publishing on climate change modeling can be ascertained. The United States of America is the highest contributor, producing a fifth (20.3%) of the research publications on climate change modelling between the years 2011–2020. The contributions of the United Kingdom are marginally lower, with a percentage of 19.2%, and they are ranked second amongst the foreign countries. German-based authors rank third, being responsible for 12.2% of publications (see Table S12). Overall, thirty-eight (38) foreign countries ((USA, UK, Germany, China, Portugal, Italy, The Netherlands, France, Spain, Greece, Brazil, Estonia, Fiji, Belgium, Australia, Sweden, Hongkong, India, Hungary, Canada, Costa Rica, Austria, Singapore, Norway, Turkey, Lithuania, Denmark, Mexico, Switzerland, Colombia, Ireland, Thailand, Laos, Sri Lanka, Saudi Arabia, Finland, Japan, and Peru)) collaborated with researchers and research institutions from different African countries. Notably, between the years 2011–2020, the United States of America, the United Kingdom, and Germany primarily engaged in collaborations with South Africa over any other African country. South African researchers accounted for 22%, 36.4%, and 13.8% of their collaborations, respectively. Other foreign countries, such as France, Norway, Italy, Spain, Greece, The Netherlands, Hongkong, India, Hungary, Canada, Denmark, Sri Lanka and Laos, also have higher percentages of collaborations with South African institutions and researchers (see Table S13). Germany, Brazil, Estonia, Austria, Turkey, Lithuania, and Peru have the highest or high number of collaborations with Nigerian institutions and researchers. Japan, Finland, Thailand, Colombia, Switzerland, Mexico, Sweden, Australia, Belgium, Brazil, Greece, The Netherlands, China, and the UK, have the highest or a high number of collaborations with Kenyan institutions and researchers. Out of the thirty-eight (38) collaborating foreign countries, South African institutions and researchers had the highest collaborations with sixteen (16) of them. On the other hand, China had limited cooperative engagement with local African institutions and climate change modeling researchers, with collaborations with institutions in only six (6) African countries, namely, Mali, Ghana, Zimbabwe, Botswana, Kenya, and Uganda, each with a collaborative percentage of 16.667%.

The prominence of international collaborations may be due to a plethora of reasons. Many African scientists travel overseas to conduct research and establish research collaborations. This can be partly explained and substantiated by the brain-drain syndrome currently plaguing the African continent [65–73]. Many arguments have been identified for this trend and some mentioned here as being revealed by the literature survey. The employment opportunities, strong economies, and societal stability of developed countries strongly influence the migration of African scientists and directly contribute to the brain drain of the continent [65–73].

5.2. Overcoming the Challenges

Many practices can be employed to overcome the challenges detailed above. The implementation and increase in the number of open access data repositories (for instance, PANGAEA [74], NOAA [75], FAO [76], WorldClim [77], etc.) may be an underlying mechanism responsible for the upward trend in locally authored publication numbers. Particularly noteworthy would be the online availability and the open data policy of such archives as that associated with Landsat imagery [78] coupled with the later improvement in internet bandwidth in Africa, which may have been a fundamental cause of the exponential increase in the number of downloads of Landsat imagery from 2013 onwards [79].

However, the dissemination of the scientific repositories within the community would accelerate the adoption of and expand contributions to their inventories. The CORDEX-Africa initiative [45], hosted by the University of Cape in South Africa, is central to African-based modelling endeavors, hosting training workshops since 2011 and encouraging inter- and intra-regional research objectives. The development of the Coupled Model Intercomparison Project (CMIP) and subsequent phases provides an additional avenue for data acquisition through a standardized organization, with the curation and dissemination of model outputs for similar simulations [80]. Advances have been made with the innovation of open-source software, online platforms, and virtual training courses. The advent of open-access software such as that provided by Python, R and its associated packages, and Google Earth Engine [81], coupled with online tutorials to make coding easier to learn, read, and debug, has lifted the financial constraints that restrict access to licensed software—a hurdle many researchers experience in developing countries. To take GEE as an example, the cloud-based platform hosts a wide range of geospatial datasets which are updated almost daily [82]. Therefore, a primary goal for African countries to become more self-reliant in their research would be to enhance capacity-building, both human and infrastructural, in disciplines that can contribute to addressing climate change through modelling.

5.3. Beyond the Science

Two of the greatest challenges confronting the African scientific community are the long-standing brain drain and the lack of capacity development. Moving forward, local government and relevant stakeholder investment in education, research, and development need to be prioritized. This would provide the needed computational resources, skills, and infrastructure for researchers involved in climate change modelling and encourage the retainment of scientists in African institutions. For example, investing in improving the density and maintenance of the observational network in developing countries, especially sub-Saharan African (SSA) countries, would provide a valuable data source in years to come, resulting in more accurate observational historical climate data. This would ease and increase the emergence of impact studies, such as assessments of modelled heat stress, modelling of diseases, economic modelling, crop modelling, etc., in such a way as to account for small geographic units. The local availability of resources would assist in expanding research in climate change modeling in various sectors of human society, including infrastructural developments in the areas of ICT and the installation of advanced satellite technologies. These developments would provide direct access to quality real-time, high-resolution, climate-related data; thus, the spatial resolution of RCMs, for example, can be increased to yield data for finer geographic units or provide a greater understanding of physical processes. Accordingly, climate data are of paramount importance in capturing the specificities of the various topographically diverse geographic units. However, an increase in the spatial resolution of climate models is not to be achieved at the expense of superior simulations and should be accompanied by improved data-assimilation methods. Furthermore, global, regional, and local initiatives that provide a collaborative and transparent environment can foster research and innovation across the continent; for instance, SEACRIFOG [83] has developed an integrative network for long-term and sustainable cooperation among African and European environmental research infrastructures. Additionally, the Climate Research for Alumni and Postdocs in Africa (climapAfrica) is a research initiative established by the German government and implemented by the Deutscher Akademischer Austauschdienst (DAAD) in cooperation with the climate competence centers Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) and West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), with the aim of fostering application-oriented research to tackle climate change in southern and western Africa. A priority for climapAfrica is the establishment of an African network for collaboration and information exchange amongst African researchers working on climate change and modelling-related projects. This has been achieved through various means. Capacity-building is a high priority; the initiative has hosted climate change-related online seminars with experts, training sessions, workshops, conferences, and exchange programs, with the aim of expanding the skillsets of African early-career scientists (ECSs), as related by the alumni and postdocs. The platform encourages independent collaboration within the network, fostering interdisciplinary and cross-disciplinary research. Notably, most of these existing regional and local initiatives, i.e., SASSCAL, WASCAL, SEACRIFOG and climapAfrica, are mostly funded by non-African organizations; therefore, there is an urgent need for African governments to invest in local scientific talent themselves.

6. Conclusions

Research in Africa comes with many challenges; here, we have identified and addressed the uncertainties that revolve around climate change modelling and publishing within the continent. Some challenges associated with climate change modelling research in Africa were identified, among which were:

(i) The lack of seamless access to available data;
(ii) The low financial investment for climate change research in Africa;
(iii) The use of climate model (GCM and RCM) instrumentations, with their numerous limitations;
(iv) The challenges related to poor quality/missing data, often associated with the long-term measurement of climatic parameters (precipitation, temperature, etc.).

We have proposed some solutions to address these challenges, emphasizing the potential contribution of initiatives such as climapAfrica to help address the data issues related to climate change modelling in under-studied regions, such as the African continent. The results of this study could therefore be an important input for the elaboration of policies that would enable the establishment in Africa of a continuous, dense, and good-quality observation network, improving access to quality data from publicly available online databases, which would immensely contribute towards increasing the adaptation and mitigation capacities of African populations in relation to the harmful effects of climate change.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app12147107/s1, Table S1: 2011 Climate change modeling articles included for review from the Google Scholar Database; Table S2: 2012 Climate change modeling articles included for review from the Google Scholar Database; Table S3: 2013 Climate change modeling articles included for review from the Google Scholar Database; Table S4: 2014 Climate change modeling articles included for review from the Google Scholar Database; Table S5: 2015 Climate change modeling articles included for review from the Google Scholar Database; Table S6: 2016 Climate change modeling articles included for review from the Google Scholar Database; Table S7: 2017 Climate change modeling articles included for review from the Google Scholar Database; Table S8: 2018 Climate change modeling articles included for review from the Google Scholar Database; Table S9: 2019 Climate change modeling articles included for review from the Google Scholar Database; Table S10: 2020 Climate change modeling articles included for review from the Google Scholar Database; Table S11: Summary and Table Containing the Statistics and Analysis of the contents of Tables S1–S10 for All Selected Climate change modeling articles included for review from the Google Scholar Database; Table S12: Percentage and number of publication numbers published on climate change modeling by foreign countries (i.e., outside the African continent); Table S13: Percentage (%) rate of collaborative climate change modeling research between African and foreign countries ((USA, UK, Germany, China, Portugal, Italy, The Netherlands, France, Spain, Greece, Brazil, Estonia, Fiji, Belgium, Australia, Sweden, Hong kong, India, Hungary, Canada, Costa Rica, Austria, Singapore, Norway, Turkey, Lithuania, Denmark, Mexico, Switzerland, Colombia, Ireland, Thailand, Laos, Sri Lanka, Saudi Arabia, Finland, Japan, and Peru) countries.

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References

1. Parham, P.E.; Michael, E. Modeling the effects of weather and climate change on malaria transmission. *Environ. Health Perspect.* **2010**, *118*, 620–626. [CrossRef] [PubMed]
2. Pradhan, B.K.; Ghosh, J. Climate policy vs. agricultural productivity shocks in a dynamic computable general equilibrium (CGE) modeling framework: The case of a developing economy. *Econ. Model.* **2019**, *77*, 55–69. [CrossRef]
3. Stern, N.; Stern, N.H. *The Economics of Climate Change: The Stern Review*; Cambridge University Press: London, UK, 2007.
4. Challinor, A.; Wheeler, T.; Garforth, C.; Craufurd, P.; Kassam, A. Assessing the vulnerability of food crop systems in Africa to climate change. *Clim. Chang.* **2007**, *83*, 381–399. [CrossRef]
5. Mellor, J.E.; Levy, K.; Zimmerman, J.; Elliott, M.; Bartram, J.; Carlton, E.; Clasen, T.; Dillingham, R.; Eisenberg, J.; Guerrant, R.; et al. Planning for climate change: The need for mechanistic systems-based approaches to study climate change impacts on diarrheal diseases. *Sci. Total Environ.* **2016**, *548*, 82–90. [CrossRef] [PubMed]
6. Tjaden, N.B.; Caminade, C.; Beierkuhnlein, C.; Thomas, S.M. Mosquito-borne diseases: Advances in modelling climate-change impacts. *Trends Parasitol.* **2018**, *34*, 227–245. [CrossRef]
7. Teixeira, E.I.; Fischer, G.; van Velthuizen, H.; Walter, C.; Ewert, F. Global hot-spots of heat stress on agricultural crops due to climate change. *Agric. For. Meteorol.* **2013**, *170*, 206–215. [CrossRef]
8. Jagarnath, M.; Thambiran, T.; Gebreslasie, M. Heat stress risk and vulnerability under climate change in Durban metropolitan, South Africa—identifying urban planning priorities for adaptation. *Clim Chang.* **2020**, *163*, 807–829. [CrossRef]
9. Wei, Z.; Fang, X.; Su, Y. A preliminary analysis of economic fluctuations and climate changes in China from BC 220 to AD 1910. *Reg. Environ. Chang.* **2015**, *15*, 1773–1785. [CrossRef]
10. Bühne, H.S.; Tobias, J.A.; Durant, S.M.; Pettorelli, N. Improving Predictions of Climate Change–Land Use Change Interactions. *Trends Ecol. Evol.* **2021**, *36*, 29–38. [CrossRef]
11. Hassan, R.M. Implications of climate change for agricultural sector performance in Africa: Policy challenges and research agenda. *J. Afr. Econ.* **2010**, *19*, 77–105. [CrossRef]
12. Chang, H.; Jung, I.-W. Spatial and temporal changes in runoff caused by climate change in a complex large river basin in Oregon. *J. Hydrol.* **2010**, *388*, 186–207. [CrossRef]
13. Shrestha, R.R.; Schnorbus, M.A.; Werner, A.T.; Berland, A.J. Modelling spatial and temporal variability of hydrologic impacts of climate change in the Fraser River basin, British Columbia, Canada. *Hydrol. Process.* **2012**, *26*, 1840–1860. [CrossRef]
14. Chien, H.; Yeh, P.J.-F.; Knouft, J.H. Modeling the potential impacts of climate change on streamflow in agricultural watersheds of the Midwestern United States. *J. Hydrol.* **2013**, *491*, 73–88. [CrossRef]
15. Oluwagbemi, O.O.; Fornadel, C.M.; Adebiyi, E.F.; Norris, D.E.; Rasgon, J.L. ANOSPEX: A stochastic, spatially explicit model for studying Anopheles metapopulation dynamics. *PLoS ONE* **2013**, *8*, e68040. [CrossRef] [PubMed]
16. Oluwagbemi, O.O. Climate Change and the spread of some deadly diseases: A ticking time bomb. In Proceedings of the a Workshop Policy Brief Paper from the ClimapAfrica-DAAD Sponsored Workshop Training on Advocacy for Research Output, Accra, Ghana, 23 November–18 December 2020; Volume 15. [CrossRef]
17. Tramblay, Y.; Ruelland, D.; Somot, S.; Bouaicha, R.; Servat, E. High-resolution Med-CORDEX regional climate model simulations for hydrological impact studies: A first evaluation of the ALADIN-Climate5 model in Morocco. *Hydrol. Earth Syst. Sci.* **2013**, *17*, 3721–3739. [CrossRef]
18. Vansteenkiste, T.; Tavakoli, M.; Ntegeka, V.; Willems, P. Climate change impact on river flows and catchment hydrology: A comparison of two spatially distributed models. *Hydrol. Process.* **2013**, *27*, 3649–3662. [CrossRef]
19. Oubeidillah, A.A.; Kao, S.-C.; Ashfaq, M.; Naz, B.S.; Tootle, G. A large-scale, high-resolution hydrological model parameter data set for climate change impact assessment for the conterminous US. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 67–84. [CrossRef]
20. Shelia, V.; Hansen, J.; Sharda, V.; Porter, C.; Aggarwal, P.; Wilkerson, C.J.; Hoogenboom, G. A multi-scale and multi-model gridded framework for forecasting crop production, risk analysis, and climate change impact studies. *Environ. Model. Softw.* **2019**, *115*, 144–154. [CrossRef]
21. Alberti, M.; Marzluff, J.M.; Shulenberger, E.; Bradley, G.; Ryan, C.; Zumbrunnen, C. Forecasting regional to global plant migration in response to climate change. *Bioscience* **2005**, *55*, 749–759. [CrossRef]
22. Xu, C.; Widén, E.; Halldin, S. Modelling hydrological consequences of climate change—progress and challenges. *Adv. Atmos. Sci.* **2005**, *22*, 789–797. [CrossRef]
23. Oluwagbemi, O.O.; Ogeh, D.N.; Adewumi, A.; Fatumo, S.A. Computational and mathematical modelling: Applicability to Infectious Disease Control in Africa. *Asian J. Sci. Res.* **2016**, *9*, 88–105. [CrossRef]
24. Zhang, F.; Chen, J.M.; Pan, Y.; Birdsey, R.A.; Shen, S.; Ju, W.; Dugan, A.J. Impacts of inadequate historical disturbance data in the early twentieth century on modeling recent carbon dynamics (1951–2010) in conterminous US forests. *J. Geophys. Res. Biogeosci.* **2015**, *120*, 549–569. [CrossRef]
25. Fox, S.; Wilbach, J.; Oluwagbemi, O.; Mketpsa, M.; Ujeneza, E.L.; Hargrove, J. Modeling mortality rate in immature Tsetse fly. In Proceedings of the a Technical Report for the (ICI3D) of the International Clinic on the Meaningful Modeling of Epidemiological Data (ICI3D) 2015 Workshop, @African Institute of Mathematical Sciences (AIMS), Capetown, South Africa, 31 May–14 June 2015.

26. Campiglio, E.; Dafermos, Y.; Monnin, P.; Ryan-Collins, J.; Schotten, G.; Tanaka, M. Climate change challenges for central banks and financial regulators. *Nat. Clim. Chang.* **2018**, *8*, 462–468. [CrossRef]
27. Magagula, V.; Odhiambo, J.; Oluwagbemi, O.; Pandey, S.; Rerolle, F.; Van Ness, S. Modeling the impact of clinical Immunity on Malaria Infection: Insight from the Garki Project. In Proceedings of the Technical Report for the (ICI3D) of the International Clinic on the Meaningful Modeling of Epidemiological Data (ICI3D) 2015 Workshop, @African Institute of Mathematical Sciences (AIMS), Capetown, South Africa, 28 May–9 June 2018.
28. Oluwagbemi, O. *A Stochastic Computational Model for Anopheles Metapopulation Dynamics: Towards Malaria Control and Insight for Possible Eradication*; Germany, 2013; p. 184. ISBN 978-3-659-41990-4. Available online: https://www.amazon.com.au/Stochastic-Computational-Anopheles-metapopulation-dynamics/dp/3659419907 (accessed on 5 June 2022).
29. Mboka, J.M.; Kouna, S.B.; Chouto, S.; Djuidje, F.K.; Nguy, E.B.; Fotso-Kamga, G.; Matsaguim, C.N.; Fotso-Nguemo, T.C.; Nghonda, J.P.; Vondou, D.A.; et al. Simulated impact of global warming on extreme rainfall events over Cameroon during the 21st century. *Weather* **2020**, *76*, 347–353. [CrossRef]
30. IPCC. Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Masson-Delmotte, V.P., Zhai, A., Pirani, S.L., Connors, C., Péan, S., Berger, N., Caud, Y., Chen, L., Goldfarb, M.I., Gomis, M., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2021; pp. 3–32. [CrossRef]
31. Dinku, T. Challenges with availability and quality of climate data in Africa. In *Extreme Hydrology and Climate Variability*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 71–80.
32. Beck, J.; López-Ballesteros, A.; Hugo, W.; Scholes, R.; Saunders, M.; Helmschrot, J. Development of a climate forcing observation system for Africa: Data-related considerations. *Data Sci. J.* **2019**, *18*, 42. [CrossRef]
33. Oluwagbemi, O.; Adeoye, E.T.; Fatumo, S. Building a Computer-Based Expert System for Malaria Environmental Diagnosis: An Alternative Malaria Control Strategy. *Egypt. Comput. Sci. J.* **2009**, *33*, 55–69.
34. Ziervogel, G.; New, M.; van Garderen, E.A.; Midgley, G.; Taylor, A.; Hamann, R.; Stuart-Hill, S.; Myers, J.; Warburton, M. Climate change impacts and adaptation in South Africa. *WIREs Clim. Chang.* **2014**, *5*, 605–620. [CrossRef]
35. Dinku, T.; Thomson, M.C.; Cousin, R.; del Corral, J.; Ceccato, P.; Hansen, J.; Connor, S.J. Enhancing national climate services (ENACTS) for development in Africa. *Clim. Dev.* **2018**, *10*, 664–672. [CrossRef]
36. Woldai, T. The status of Earth Observation (EO) & Geo-Information Sciences in Africa–trends and challenges. *Geo-Spat. Inf. Sci.* **2020**, *23*, 107–123. [CrossRef]
37. Harzing, A.-W.; Alakangas, S. Google Scholar, Scopus and the Web of Science: A longitudinal and cross-disciplinary comparison. *Scientometrics* **2015**, *106*, 787–804. [CrossRef]
38. Mango, L.M.; Melesse, A.M.; McClain, M.E.; Gann, D.; Setegn, S.G. Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: Results of a modeling study to support better resource management. *Hydrol. Earth Syst. Sci.* **2011**, *15*, 2245–2258. [CrossRef]
39. Ramadan, H.H.; Beighley, R.E.; Ramamurthy, A.S. Modelling streamflow trends for a watershed with limited data: Case of the Litani basin, Lebanon. *Hydrol. Sci. J.* **2012**, *57*, 1516–1529. [CrossRef]
40. Mwale, F.D.; Adeloye, A.J.; Rustum, R. Infilling of missing rainfall and streamflow data in the Shire River basin, Malawi–A self organizing map approach. *Phys. Chem. Earth Parts A/B/C* **2012**, *50*, 34–43. [CrossRef]
41. Notter, B.; Hurni, H.; Wiesmann, U.; Abbaspour, K.C. Modelling water provision as an ecosystem service in a large East African river basin. *Hydrol. Earth Syst. Sci.* **2012**, *16*, 69–86. [CrossRef]
42. Tabor, K.; Williams, J.W. Globally downscaled climate projections for assessing the conservation impacts of climate change. *Ecol. Appl.* **2010**, *20*, 554–565. [CrossRef]
43. Fotso-Nguemo, T.C.; Chamani, R.; Yepdo, Z.D. Projected trends of extreme rainfall events from CMIP5 models over Central Africa. *Atmos. Sci. Lett.* **2018**, *19*, e803. [CrossRef]
44. Fotso-Nguemo, T.C.; Diallo, I.; Diakhaté, M.; Vondou, D.A.; Mbaye, M.L.; Haensler, A.; Gaye, A.T.; Tchawoua, C. Projected changes in the seasonal cycle of extreme rainfall events from CORDEX simulations over Central Africa. *Clim. Chang.* **2019**, *155*, 339–357. [CrossRef]
45. CSAG. Climate System Analysis Group. Available online: https://www.csag.uct.ac.za/cordex-africa/ (accessed on 20 April 2022).
46. Golian, S.; Moazami, S.; Kirstetter, P.-E.; Hong, Y. Evaluating the performance of merged multi-satellite precipitation products over a complex terrain. *Water Resour. Manag.* **2015**, *29*, 4885–4901. [CrossRef]
47. Mahmoud, I.M.; Duker, A.; Conrad, C.; Thiel, M.; Shaba Ahmad, H. Analysis of settlement expansion and urban growth modelling using geoinformation for assessing potential impacts of urbanization on climate in Abuja City, Nigeria. *Remote Sens.* **2016**, *8*, 220. [CrossRef]
48. Busayo, E.T.; Kalumba, A.M.; Orimoloye, I.R. Spatial planning and climate change adaptation assessment: Perspectives from Mdantsane Township dwellers in South Africa. *Habitat Int.* **2019**, *90*, 101978. [CrossRef]

49. Twumasi, Y.A.; Merem, E.C.; Ayala-Silva, T.; Osei, A.; Petja, B.M.; Alexander, K. Techniques of remote sensing and GIS as tools for visualizing impact of climate change-induced flood in the Southern African region. *Am. J. Clim. Chang.* **2017**, *6*, 306–327. [CrossRef]
50. Novella, N.S.; Thiaw, W.M. African rainfall climatology version 2 for famine early warning systems. *J. Appl. Meteorol. Climatol.* **2013**, *52*, 588–606. [CrossRef]
51. Stanzel, P.; Kling, H.; Bauer, H. Climate change impact on West African rivers under an ensemble of CORDEX climate projections. *Clim. Serv.* **2018**, *11*, 36–48. [CrossRef]
52. Laprise, R.; Hernández-Díaz, L.; Tete, K.; Sushama, L.; Šeparović, L.; Martynov, A.; Winger, K.; Valin, M. Climate projections over CORDEX Africa domain using the fifth-generation Canadian Regional Climate Model (CRCM5). *Clim. Dyn.* **2013**, *41*, 3219–3246. [CrossRef]
53. Jacob, D.; Teichmann, C.; Sobolowski, S.; Katragkou, E.; Anders, I.; Belda, M.; Benestad, R.; Boberg, F.; Buonomo, E.; Cardoso, R.M.; et al. Regional climate downscaling over Europe: Perspectives from the EURO-CORDEX community. *Reg. Environ. Chang.* **2020**, *20*, 1–20. [CrossRef]
54. Giorgi, F.; Gutowski, W.J., Jr. Regional dynamical downscaling and the CORDEX initiative. *Annu. Rev. Environ. Resour.* **2015**, *40*, 467–490. [CrossRef]
55. Sawadogo, W.; Reboita, M.S.; Faye, A.; Da Rocha, R.P.; Odoulami, R.C.; Olusegun, C.F.; Adeniyi, M.O.; Abiodun, B.J.; Sylla, M.B.; Diallo, I.; et al. Current and future potential of solar and wind energy over Africa using the RegCM4 CORDEX-CORE ensemble. *Clim. Dyn.* **2021**, *57*, 1647–1672. [CrossRef]
56. Fotso-Nguemo, T.C.; Vondou, D.A.; Diallo, I.; Diedhiou, A.; Weber, T.; Tanessong, R.S.; Nghonda, J.P.; Yepdo, Z.D. Potential impact of 1.5, 2 and 3 °C global warming levels on heat and discomfort indices changes over Central Africa. *Sci. Total Environ.* **2021**, *804*, 1–11. [CrossRef]
57. Sørland, S.L.; Brogli, R.; Pothapakula, P.K.; Russo, E.; Van de Walle, J.; Ahrens, B.; Anders, I.; Bucchignani, E.; Davin, E.L.; Demory, M.-E.; et al. COSMO-CLM regional climate simulations in the Coordinated Regional Climate Downscaling Experiment (CORDEX) framework: A review. *Geosci. Model. Dev.* **2021**, *14*, 5125–5154. [CrossRef]
58. Mbaye, M.L.; Diatta, S.; Gaye, A.T. Climate change signals over senegal river basin using regional climate models of the CORDEX Africa simulations. In *International Conference on Innovations and Interdisciplinary Solutions for Underserved Areas*; Springer: Cham, Switzerland, 2018; pp. 123–132.
59. Kim, J.; Waliser, D.E.; Mattmann, C.A.; Goodale, C.E.; Hart, A.F.; Zimdars, P.A.; Crichton, D.J.; Jones, C.; Nikulin, G.; Hewitson, B.; et al. Evaluation of the CORDEX-Africa multi-RCM hindcast: Systematic model errors. *Clim. Dyn.* **2014**, *42*, 1189–1202. [CrossRef]
60. Ziervogel, G.; Zermoglio, F. Climate change scenarios and the development of adaptation strategies in Africa: Challenges and opportunities. *Clim. Res.* **2009**, *40*, 133–146. [CrossRef]
61. Conway, D. Adapting climate research for development in Africa. *WIREs Clim. Chang.* **2011**, *2*, 428–450. [CrossRef]
62. Abramo, G.; D'Angelo, C.A.; Solazzi, M. The relationship between scientists' research performance and the degree of internationalization of their research. *Scientometrics* **2011**, *86*, 629–643. [CrossRef]
63. Rensburg, I.; Motala, S.; David, S.A. Opportunities and challenges for research collaboration among the BRICS nations. *Comp. A J. Comp. Int. Educ.* **2015**, *45*, 814–818. [CrossRef]
64. Medhi, B.; Bansal, S.; Mahendiratta, S.; Kumar, S.; Sarma, P.; Prakash, A. Collaborative research in modern era: Need and challenges. *Indian J. Pharmacol.* **2019**, *51*, 137. [CrossRef]
65. Dovlo, D. The brain drain in Africa: An emerging challenge to health professionals' education. *J. High Educ. Afr.* **2004**, *2*, 1–18.
66. Capuano, S.; Marfouk, A. African Brain Drain and Its Impact on Source Countries: What Do We Know and What Do We Need to Know? *J. Comp. Policy Anal. Res. Pract.* **2013**, *15*, 297–314. [CrossRef]
67. El-Khawas, M.A. Brain drain: Putting Africa between a rock and a hard place. *Mediterr. Q.* **2004**, *15*, 37–56. [CrossRef]
68. Carr, S.C.; Inkson, K.; Thorn, K. From global careers to talent flow: Reinterpreting 'brain drain'. *J. World Bus.* **2005**, *40*, 386–398. [CrossRef]
69. Dodani, S.; LaPorte, R.E. Brain drain from developing countries: How can brain drain be converted into wisdom gain? *J. R. Soc. Med.* **2005**, *98*, 487–491. [CrossRef]
70. Eyal, N.; Hurst, S.A. Physician brain drain: Can nothing be done? *Public Health Ethics* **2008**, *1*, 180–192. [CrossRef]
71. Kana, M.A. From brain drain to brain circulation. *Jos J. Med.* **2009**, *4*, 8–10. [CrossRef]
72. Serour, G.I. Healthcare workers and the brain drain. *Int. J. Gynecol. Obstet.* **2009**, *106*, 175–178. [CrossRef] [PubMed]
73. Salami, B.; Dada, F.O.; Adelakun, F.E. Human resources for health challenges in Nigeria and nurse migration. Policy. *Polit Nurs. Pr.* **2016**, *17*, 76–84. [CrossRef]
74. PANGAEA. Data Publisher for Earth and Environmental Science. Available online: https://www.pangaea.de (accessed on 20 May 2022).
75. NOAA. National Oceanic and Atmospheric Administration Data Discovery Portal. Available online: https://data.noaa.gov/datasetsearch/ (accessed on 20 May 2022).
76. FAO. Food and Agriculture Organization of the United Nations. Available online: http://www.fao.org/home/en/ (accessed on 20 May 2022).

77. WorldClim. Global Climate and Weather Data Website. Available online: https://worldclim.org/ (accessed on 20 May 2022).
78. Woodcock, C.E.; Allen, R.; Anderson, M.; Belward, A.; Bindschadler, R.; Cohen, W.; Gao, F.; Goward, S.N.; Helder, D.; Helmer, E.; et al. Free access to Landsat imagery. *Science* **2008**, *320*, 1011. [CrossRef] [PubMed]
79. Zhou, Y.; Dong, J.; Liu, J.; Metternicht, G.; Shen, W.; You, N.; Zhao, G.; Xiao, X. Are there sufficient Landsat observations for retrospective and continuous monitoring of land cover changes in China? *Remote Sens.* **2019**, *11*, 1808. [CrossRef]
80. ESGF. Earth System Grid Federation. Available online: https://esgf-node.llnl.gov/projects/cmip6/ (accessed on 19 April 2022).
81. GEE. Google Earth Engine. Available online: https://earthengine.google.com/ (accessed on 20 April 2022).
82. Gorelick, N.; Hancher, M.; Dixon, M.; Ilyushchenko, S.; Thau, D.; Moore, R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sens. Environ.* **2017**, *202*, 18–27. [CrossRef]
83. SEACRIFOG. Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations. Available online: www.seacrifog.eu (accessed on 30 April 2022).