

Science in Africa: Contemporary Trends in Research

Radhamany Sooryamoorthy^{1,2}

¹School of Social Sciences, University of KwaZulu-Natal, Durban, SOUTH AFRICA.

²DSI-NRF Centre of Excellence in STI Policy, Stellenbosch University, SOUTH AFRICA.

ABSTRACT

Despite numerous challenges, Africa has made notable progress in the production of science, particularly since the attainment of political independence of its countries. In the production of scientific knowledge, it has been advancing during the recent years. However, the current scenario of science on the continent is not fully known. The progress in knowledge production in science has not been empirically examined. This is crucial to the understanding of its contributions to the world of science. This paper is based on a study that traces the production of science in Africa over the past two decades with a specific focus on its research areas. Using the empirical data of 508,102 publications drawn from the Web of Science, the study examines the strengths of African science and the individual contribution of African countries to Africa and to the world. The paper also reveals disparities in science among countries on the African continent.

Keywords: Research trends, Africa, Science production, Partnership, Publications, Science, Collaboration.

Correspondence

Radhamany Sooryamoorthy

¹Faculty of Sociology, School of Social Sciences, University of KwaZulu-Natal, Durban-4041, SOUTH AFRICA.

²DSI-NRF Centre of Excellence in STI Policy, Stellenbosch University, SOUTH AFRICA.

Email id: sooryamoorthy@ukzn.ac.za

ORCID ID: orcid.org/0000-0001-6011-7807

Received: 12-05-2020

Revised: 28-03-2021

Accepted: 08-11-2021

DOI: 10.5530/jsires.10.3.54

INTRODUCTION

A lesser known and unacknowledged feature of Africa is its current status in science and its contribution to world science. Africa has excellent universities and institutions that train scientists. David Gross, a Nobel laureate in Physics, has recognised the relevance of African science to world science. When contributions of countries to world science are shifting and new players are occupying prominent places in the production of science, it is beneficial to examine the state of science in Africa. Such an examination has significance not only for the development of Africa but also for the world. Science in Africa has become an interest and concern of scholars and policymakers.^[1]

Despite the challenges that Africa has undergone, many African countries entered a period of rapid growth in the past decade.^[2] Publications in journals have been rising in Africa.^[3] Africa's share of world publications increased from 1.2% to 2.3% during 1996–2012.^[4] The rate of increase in the annual output of African authored publications has surpassed the world growth, with Africa's share of the world publication output growing from 1.5% in 2005 to 3.2% in 2016.^[5] Sub-Saharan Africa, the poorer part of the continent, doubled its contribution to world scientific research from 0.44% to 0.72% during 2003–2012.^[6] Suggesting independent and

self-reliant research in Africa, Adams *et al.*^[7] Reported that since 2000, publications within Africa that do not have any foreign author have doubled. Advances in specific research fields such as astronomy have seen the importance of science for the future of Africa.^[8] International agencies contribute by increasing their investments in science in Africa.^[9] This paper examines the current status of science in Africa and is supported by the use of empirical data. The aim of this paper is mainly to serve as a benchmark for future studies of science and its production in Africa.

The broad objective of this paper is to examine the status of science in Africa for the last two decades (2001–2018). Data on the publication output of African countries forms the basis of the paper. The analysis presented here is focused on three integral components of science, namely, publications, research areas and partners. The attempt is to identify the trends in the production of science in Africa, the strengths of Africa in specific research areas, and their relevance to both Africa and world science. The paper is divided into sections on data and methods, analysis and findings, discussion and conclusions.

DATA AND METHODS

Data for the analysis presented below was sourced from the Web of Science (WoS) database which is a preferred database widely used for mapping science and scientific development in countries. The WoS dataset of Science Citation Index Expanded (1945–present) of the Web of Science Core Collection was accessed to collect the necessary data. Publications from the database were gathered individually for each country on the continent before they were sorted according to the research areas and partners as classified in

Copyright

© The Author(s). 2021 This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

the database. All publications that were documented as articles and were published in all languages during the period of 2001–2018 were searched. Data was mined in December 2019. The WoS classification of research areas was provided under the broad subject areas of Arts and Humanities, Life Sciences, Physical Sciences, Social Sciences and Technology. Only research areas that come under the Life Sciences and the Physical Sciences were considered. Since the focus was on publications in journals, books and book chapters were excluded from the analysis.

In the WoS database, publications according to research areas are classified under more than 200 categories. In order to manage the data and to limit the analysis within the word limit, an appropriate strategy was adopted. For the whole set of data and for the entire period of 2001–2018, research areas with at least 50 publications were selected. If the total number of publications for a country for the chosen period was less than 500, the threshold was extended to a minimum of 20 publications. When the total number of publications was less than 100 for any country, all research areas were included. The same strategy was applied to the subsets of the data for the three distinct periods. In order to perform a trend analysis across the three sub datasets, only the top producers in Africa could be considered. This was to manage the scope of analysis. Research areas that were not part of science disciplines were excluded from analysis.

Once the publication records for the selected period against each country were gathered, data was sorted using the online options available on the WoS platform. The searched documents were then classified by research areas. Since collaboration is a pertinent factor in the production of science, data was filtered according to the online available option of countries/regions. WoS allows for the classification of publications according to the participating countries for each of the African countries. From this data collaborative partners of African countries were gathered.

Analysis and findings

Production of publications in science and trends

Africa produced 508,102 publications in science during the 19-year period between 2001 and 2018 (Figure 1). Compared to this, the world production for the same period was 6,688,920 publications. Africa thus contributed 7.6% to the world of science in the recent two decades.

Among the 54 countries on the continent, publications of the Ivory Coast, São Tomé and Príncipe, and Equatorial Guinea were not listed in the WoS database. This might be due to the absence of publications for these countries in the journals that have been indexed by the WoS. It can also be due to the lack of publications in the research areas that are part of the WoS classification. The remaining African countries on

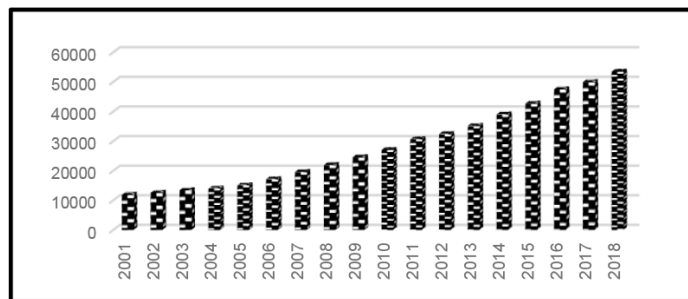


Figure 1: Science publications in Africa, 2001-2018.

average produced 9,964 papers in science in 19 years, which is 524 papers per year. Somalia is at the bottom of the list with 69 publications while South Africa is the top ranking country producing 128,435 papers. In the descending number of publications, countries that came after South Africa were Egypt (112,436 papers), Tunisia (43,883), Nigeria (31,764), Algeria (31,591), Morocco (25,981), Kenya (19,094), Ethiopia (12,314), Uganda (10,017), Tanzania (10,010), Cameroon (9,747), Ghana (8,757), Senegal (5,224), Zimbabwe (4,672), Malawi (4,671), Sudan (4,355), Burkina Faso (4,106), Zambia (3,428), Benin (3,387), Botswana (3,172), Guinea (2,854), Madagascar (2,677), Congo (2,455), Mozambique (2,386), Libya (2,382) and Mali (2,199). Namibia, The Gambia, Gabon, Rwanda, Niger and Mauritius published between 1,000 and 2,000 papers during the period. The rest of the countries on the continent had less than 1,000 publications to their credit during the period of analysis.

A single country, South Africa, contributed a quarter of the publications that Africa produced, followed closely by Egypt with 22%. Contributions from other countries fell way behind. The third largest contribution was made by Tunisia which had only 8.6% of the total output in Africa. After Tunisia were Nigeria (6.3%), Algeria (6.2%), Morocco (5.1%), Kenya (3.8%), Ethiopia (2.4%), and Tanzania and Uganda (2% each). The rest of the countries made up less than 2% of the total publications. Among the top 10 highly producing countries in science were 6 sub-Saharan countries, namely, South Africa, Nigeria, Kenya, Ethiopia, Uganda and Tanzania (Figure 2).

Over a period of 19 years publications in science in most African countries have increased substantially, varying from 2 to 20 times. The 10 highest productive countries grew at different rates. South Africa tripled its production in 2018 from that in 2001, Egypt grew by 5.4 times, Tunisia 6.4 times, Nigeria 4.7 times, Algeria 8 times, Morocco 2 times, Kenya 3.6 times, Ethiopia 9.5 times, Uganda 6.5 times and Tanzania by 5 times.

For further analysis the data was segregated under three time periods of 6 years, namely, 2001–2006, 2007–2012 and 2013–2018. In order to manage the collected data, the

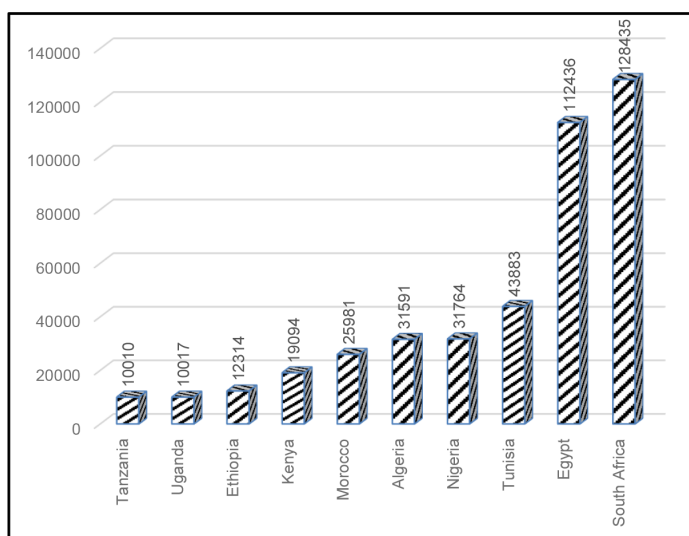


Figure 2: Top 10 highly producing countries in Africa.

analysis focussed on 10 highly productive African countries. During the first period of 6 years (2001–2006), South Africa contributed 28.3% of the total publications in Africa followed by Egypt with 20.2%. The other highest contributors were Morocco (7.4%) Tunisia (7.2%) Nigeria (6.1%) Algeria (4.8%) and Kenya (4.2%). Tanzania made 2%, Ethiopia 1.9% and Uganda 1.5%.

In the second 6-year period of 2007–2012, South Africa's share of publications in Africa decreased to 25.6% while Egypt increased its share slightly to 20.7%. Morocco lessened its production Figures from 7.4 to 5.1%. Tunisia, Nigeria and Algeria improved their production output (9.4%, 7.6% and 6.1%). While Kenya reduced its share to 3.8%, Ethiopia and Tanzania maintained their position as in the previous period. Uganda bettered its publication count by a modest 0.5%.

In the last 6-year period of 2013–2018, South Africa lost a further 1.5% of its share from the previous period. Egypt strengthened its position by raising its contribution from 20.7% in the previous period to 23.6% during the third period. During this period Morocco showed a decline of 4.4%. Tunisia lost slightly from the previous period from 9.4% to 8.6%. Nigeria reduced its share from 7.6% to 5.5%. Algeria added another 0.6% to its previous contribution while Kenya lost 0.2%. Ethiopia improved its stake by an additional 0.9%. Both Tanzania and Uganda maintained their respective shares as in the previous second period.

Research focus areas in Africa

Africa contributed its largest share of publications in the research area of chemistry with ten per cent of all publications that Africa produced during 2001–2018 being in this field. Following chemistry, in decreasing order of percentage of publications were engineering (8.7%), physics (7.6%), material

sciences (5.6%), infectious diseases (5%), environmental sciences and ecology (6.4%), agriculture (5%), science and technology (4.9%), mathematics (4.2%), public environmental and occupational health (4.1%), pharmacology (4%), plant sciences (3.2%), biochemistry and molecular biology and immunology (3% each), tropical medicine (2.9%), geology (2.7%), food science technology (2.5%), microbiology (2.5%), general internal medicine (2.3%), parasitology (2.3%), biotechnology and applied microbiology (2.1%) and veterinary sciences (1.9%). These were the strong research areas of Africa, as revealed in the count of publications.

The highest number of publications in chemistry for Africa came from Egypt (38%), followed by South Africa (20%). Egypt is the leader in Africa in the production of publications in both engineering and physics having about one-third each of Africa's total output in these two research areas. In the research area of science and technology South Africa surged ahead of other African countries making up 27% of all publications on the continent. Egypt was closely behind South Africa having produced 17% of publications in the same research area. Nigeria, Kenya, Tunisia and Algeria were the remaining major countries with percentages in the region of 4–6.

In conducting research in mathematics, South Africa (26%), Egypt (22%), Morocco (13%) and Algeria (13%) were the key countries. These four countries jointly produced three-fourths of all Africa's publications in mathematics. In areas such as public, environmental and occupational health, pharmacology, plant sciences, and biochemistry and molecular biology, either South Africa or Egypt were the frontrunners. South Africa produced the highest percentage of Africa's publications in infectious diseases (20%), followed by Kenya (9.8%) and Uganda (8%). In immunology the major contributors in Africa were South Africa (23%), Kenya (10%), Egypt (8.7%) and Uganda (7.8%). All are in sub-Saharan Africa.

Compared to world Figures, Africa's largest contribution to the world of science was in tropical medicine. Africa's share was one-third of all publications the world had produced in this research area during 2001–2018. The continent a leader in parasitological research as well with Africa producing 15% of the world production. Related to the research areas of tropical medicine and parasitology is the area of infectious diseases in which 13% of the publications for the world originated in Africa. In agriculture and plant sciences Africa contributed 5% each to the total world publications. In immunological research Africa made up 4.8% of the total world output.

The recent research focus of Africa is evident from the segregated dataset for 2013–2018. Algeria's strength is shown in engineering research, producing about a quarter of all its publications. Physics (17%) and chemistry (15%) are the

two other research areas that Algeria currently prioritises. Egypt relied on chemistry (17%), engineering (14%), physics and materials science (9% each) and pharmacology (8%) as their key research areas. Ethiopia produced mostly in public, environmental and occupational health (12%), environmental sciences and ecology, and agriculture (10% each) and infectious diseases (8%). Kenya produced mainly in infectious diseases (14%), followed by environmental sciences and ecology (12%), science and technology (11%) and tropical medicine (7%). Morocco's largest share of publications was in physics (19%), followed by chemistry and engineering (12% each), and mathematics (10%). Nigeria demonstrated its strengths in engineering, and environmental sciences and ecology (9% each), and chemistry and general internal medicine (7% each). South Africa's highest number of publications were in chemistry, and environmental sciences and ecology (9% each), engineering (8%), and science and technology (7%). Tanzania paid more attention to research in infectious diseases (15%), public environmental and occupational health, and tropical medicine (11% each). Publishing 15% each, Tunisia's strength is visible in chemistry and engineering. Physics and materials science (11% each) were also obvious. Uganda's preferred research foci were on infectious diseases (21%), immunology, and public environmental and occupational health (12% each) and in science and technology (11%).

Research partners of Africa

Africa has research partners from all over the world. During the period of analysis African countries collaborated with 151 other countries, both within and outside the continent. Of most of the partners (not publications which might involve more than one author and one partner) with whom African scholars associated, 10.5% were US researchers. This is the highest percentage of African partners for the period. The other top international collaborators with Africa were France (8.4%), the UK (7.2%), Germany (4.3%), Saudi Arabia (3.7%), Australia (2.9%), Canada (2.5%), Spain and Italy (2.4% each), the Netherlands (2.3%), China and Belgium (2.1% each), Japan and India (1.8% each), Switzerland (1.54%), Brazil (1.3%), Denmark (1.2%), Austria and Sweden (1% each), The rest of the partners had less than 1% of the total number of collaborators of Africa (Figure 3).

The above partners of Africa were collaborating with only some specific African countries. In other words, their involvement with Africa in the production of science was not equal or uniform in all 54 countries on the continent. For instance, being the top research collaborator of Africa, the US produced more publications with South Africa than any other country on the continent. About 30% of the total US collaborators worked with South African partners. The second biggest in Africa was Egypt with 15% of US collaborators.

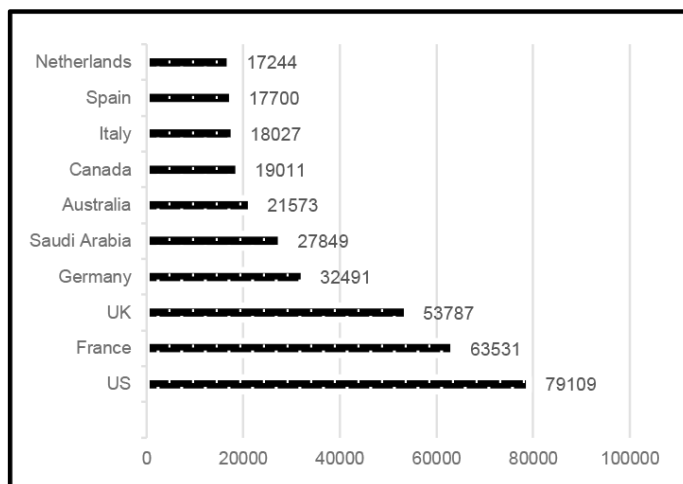


Figure 3: Top African partners.

The US also associated with African scholars in Kenya (9%), Uganda (5.1%), Nigeria (4.4%), Tanzania (3.8%), Ethiopia (2.9%), Morocco and Ghana (2.8% each), Malawi (2.4%) and Cameroon (1.8%).

France, the second biggest partner of Africa, collaborated mostly with Tunisia (22% of all its collaborators), Algeria (18%), Morocco (14%), South Africa (13%), Egypt (4.5%), Cameroon (4.2%), Senegal (3.8%) and Madagascar (1.7%).

The UK worked with South Africa (32%), Egypt (10.6%), Kenya (8%), Nigeria (5%), Tanzania (4.7%), Uganda (4.5%), Ghana and Malawi (3.2% each), Morocco (2.9%) and Ethiopia (2.7%). Germany preferred South Africa (31%), Egypt (21%), Morocco (5.8%), Kenya (5.2%) and Nigeria (3.7%) to other African partners. Saudi Arabia's collaborators within Africa worked largely with Egypt (73%) and then Tunisia (8.4%). Forty per cent of Australia's African collaborators associated with South Africa, followed by Benin (16%). Canada's major African partners included South Africa (31%), Egypt (17%), Morocco (8.4%), Kenya (6%) and Tunisia (5.3%).

In regional collaboration between African countries, South Africa is the key partner of other African countries with 2.4%. It is followed by Ethiopia (2.1%), Kenya (1.3%), Nigeria (1%), Uganda (0.8%) and Tanzania (0.7%).

DISCUSSION

The analysis of publications that Africa produced during 2001-2018, and over three different periods showed trends of science production in Africa. The analysis was centred around three key aspects of science production, namely, the number of publications, research areas and partners involved in the production of publications. The above analysis and findings suggest that for the past two decades science in Africa has been showing progressive trends towards growth. These trends are obvious in terms of the number and share of

publications within Africa and in relation to world science. A steady growth in the number of publications was evident in the data for the period of analysis. However, contributions of countries varied widely and only a few countries made the largest contributions to the total production count.

Some prominent research areas and their strengths in certain areas have been revealed in the analysis. The substantial contribution Africa has made to research areas such as tropical medicine, parasitology, infectious diseases and immunology is seemingly quite significant for world science. These are crucial research areas for Africa in general and some African countries in particular. Given the presence of diseases and sporadic outbreak of epidemics that are common in several African countries investment in these research areas is important for them to address such problems. Only two countries, South Africa in sub-Saharan Africa and Egypt in North Africa, lead the continent in science by producing about half of the total publications in Africa. This has been shown in several other studies of African science.^[10-11] Other countries have lessons to learn from the priorities, knowledge generation, allocation of resources for scientific research, and the national science, technology and innovation policies of these two countries that made them the top producers of science in Africa.

A glaring finding of the analysis is that in the production of science in Africa there were only 10 countries that contributed 2% or more to the total output during 2001–2018. More significantly, nearly half of all publications in Africa came from only two countries, South Africa and Egypt, leaving the remaining half to be shared by 52 other countries. This is a great disparity amongst the countries on the continent. Disparities between north and sub-Saharan African countries are obvious. About three quarters of the publications originated from six countries, namely, South Africa, Egypt, Tunisia, Algeria, Nigeria and Morocco, of which only two are sub-Saharan countries. In other words, 11% of the countries produced 74% of the total number of publications in science in Africa, and 89% of the countries made up only 26% of the total. It is relevant to note, as Mouton (2008)^[35] observed, scientific institutions in several African countries are still under-resourced, fragile and susceptible to political instability.

Among the 10 major countries with scientific output in Africa, half of them were in sub-Saharan Africa. Apart from South Africa, three other sub-Saharan countries made considerable progress in the production of publications in science. They were Ethiopia, Uganda and Tanzania, which also reported a growth rate of 10–14 per annum in their publication outputs. Among these three countries, Ethiopia had a higher publication output than the other two or any other sub-Saharan countries. In recent years, as the trend analysis indicated, some of the output from high producing countries decreased from the

previous two periods of analysis. At the same time, other countries such as Ethiopia and Uganda continued to improve their production figures. This will have an effect on the distribution of publications produced by countries in Africa and it will go a long way in minimising the disparities that have been observed in the data. With the production of other African countries that have made only a single digit percentage towards Africa's total contribution the increasing production in some of these countries is encouraging. Again, this will also have an impact on weakening the divide between north and sub-Saharan Africa in the production of science.

Some of the findings of this study resonate with that of other pertinent studies of African science. Earlier Gruhn^[13] reported that scientific development in Africa was unevenly distributed. This was also shown in this research. This unequal contribution to science in Africa can be explained in terms of other indicators such as GDP and the percentage of GDP allocated to R&D called GERD, and the science, technology and innovation policies of countries. Studies have also illustrated the relationship between GDP and research publications.^[5,12] Jonathan *et al.*^[13] observed a relationship between GDP and publications in some sub-Saharan countries.

Similar findings about the research focus areas of Africa were obtained in other research. As Confraria and Godinho^[14] reported, there has been an increased level of specialisation in science in Africa since 2004. Africa is represented significantly in certain areas such as clinical medicine, biology, biomedical research, chemistry, engineering, physics, astronomy and agriculture.^[15] Pouris^[16] focus areas of research in Africa included immunology, environment and ecology, plant and animal sciences and agriculture. The prominence of South Africa in astronomy, geology, clinical medicine and mining technology has also been reported.^[17,18] Hassan^[19] noted that Africa has pockets of internal strengths in immunology, meteorology and biotechnology. This has implications for the future of science in Africa and the world at large. Globally, Africa is a force to be reckoned with in tropical medicine, parasitology and infectious diseases. In agricultural research, Africa's contribution to the world has been significant. The committed focus of African these research areas has immediate relevance and applications to its current problems. Rigorous research in these areas is essential for Africa as it is often attacked by outbreaks of epidemics.

Scientific collaboration is a symbiotic process, benefitting both African scholars and their international partners. A growing volume of literature discusses the benefits of international collaboration in science^[20] as a means of enhancing both productivity, visibility and impact. An increase in student enrolment in science and technology subjects also contributed to this.^[22] Collaboration with their preferred partners is advantageous to African countries, some of which had

historical links with each other. The major partner of Africa is the US, followed by some European countries. Partnership with these countries has been identified in similar other studies.^[23-25] Apart from North American and European countries, the presence of Brazil, China and India in Africa is inconsiderable in the data. Clearly, this is a recent trend to be acknowledged in African collaboration. The interest of these countries in Africa has been growing over the past few years, but is not limited to collaboration in science alone. Typical collaboration patterns (Egypt and Saudi Arabia, for instance) were also evident in the data, as reported upon earlier.^[21] As shown in the data, collaboration is largely influenced and inspired by a combination of factors that include historical legacy, language, culture, scientific standing of African countries, research areas of mutual interest, funding and science policies. Unfortunately, the powerful forces in science in Africa do not collaborate with other countries on the continent as much as they associate with international partners. Note that collaboration dominance has been reported as a deterrent for science in Africa.^[26] This is an area of concern for Africa. Regional and intra-continental collaboration, in comparison to international collaboration, has not been very active in Africa. As pointed out earlier, there is a great disparity among African countries in the quantity of publications. A great majority of them have not been able to make their presence felt in science production. Regional collaboration can be an option for scientifically weak countries in Africa to work with their stronger neighbours to improve not only their production profile but also their skills and capacity in science. Stronger countries should also take the initiative by working with their weaker counterparts on the continent. This is a responsibility that scientifically able countries in Africa should shoulder for mutual benefits and for Africa as a whole. As there is proven evidence^[27-29,36] that suggests a positive relationship between collaboration and productivity, regional collaboration will have a desirable effect on the production of science by poorer African countries in the near future. It is also a fact that many of the scientifically poor performing countries have strengths in certain research areas can encourage their stronger neighbours on the continent to collaborate and co-publish research findings.

Since the 1970s there have been advancements in higher education, with the increased enrolment of students in science, technology and engineering.³⁰ In the following decades further changes were to be seen in the expansion of institutions' scientific research, and development of science policies.³¹ Beaudry *et al.*,³² in their extensive study of young African scientists, have noted the improving conditions for productive scientific research. The shortage of researchers and research leaders remains another major issue.³³ Collaboration dominance has also been flagged as a deterrent for science in Africa.³⁴

CONCLUSION

Science is no more in its infancy in Africa, at least for some specific research areas. Africa has recovered from its colonial bondages that limited it from advancing in science. With the attainment of political independence, several countries on the continent have taken science, technology and innovation more seriously than ever as their applications to development were becoming indispensable. The strengths of Africa are more vivid in research areas that are more applied in nature. They are applicable to addressing many of the problems that Africa is facing today.

While Africa suffers from challenges such as political instability, internal strife, wars, corruption, epidemics, poverty, natural disasters, and lack of adequate resources many countries have made progress in their science domains.

However, they admit that structural constraints, continued reliance on international funding, the effects of the brain drain of the previous century, and the lack of support for the next generation scientists all limit African science.

Africa needs to take strong measures if it aims to become a formidable force in the field of science and make use of science for its developmental needs. In order for Africa to continue with their science enterprise, a set of conditions is a prerequisite. More resources need to be pumped into the R&D. With the available Figures on GERD, it is obvious that Africa is short of the world average. No country in Africa can claim that 1% of its GDP is allocated to R&D. Determined political leadership, institutions that are capable of training scientists, researchers and engineers, laboratories with cutting edge technology, library resources, able administrative leaders in research and higher learning institutions, and decent salaries for research personnel are important for Africa and for its science and development.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

REFERENCES

1. Sooryamoorthy R. The production of science in Africa: An analysis of publications in the science disciplines, 2000-2015. *Scientometrics*. 2018;115(1):317-49. doi: 10.1007/s11192-018-2675-0.
2. Irikefe V, Vaidyanathan G, Nordling L, Twahirwa A, Nakkazi E, Monastersky R. Science in Africa: the view from the front line. *Nature*. 2011;474(7353):556-9. doi: 10.1038/474556a, PMID 21720341.
3. Tijssen RJW. Africa's contribution to the worldwide research literature: New analytical perspectives, trends, and performance indicators. *Scientometrics*. 2007;71(2):303-27. doi: 10.1007/s11192-007-1658-3.
4. Schemm Y. Africa doubles research output over past decade, moves towards a knowledge-based economy. *Res Tre*. 2013;35.
5. Mouton J, Blanckenberg J. African science: A bibliometric analysis. In: Beaudry C, Mouton J, Prozesky H, editors. *The next generation of scientists in Africa*. Cape Town: African Minds; 2018;13-25.
6. Blom A, Lan G, Adil M. Sub-Saharan African science, technology, engineering, and mathematics research: A decade of development. Washington, DC: International Bank for Reconstruction and Development/The World Bank; 2016.
7. Adams J, Gurney K, Hook D, Leydesdorff L, editors. *Collaboration in Africa*:

- networks or clusters? 14th International Society of Scientometrics and Informetrics conference; 2013;15-19. Vienna: Austrian Institute of Technology.
8. Maartens R, Ellis G. A new dawn for science in Africa. *Science*. 2012;337(6097):889. doi: 10.1126/science.1228453, PMID 22923548.
 9. Mouton J. African science: A diagnosis. In: Beaudry C, Mouton J, Prozesky H, editors. *The next generation of scientists in Africa*. Cape Town: African Minds; 2018;1-12.
 10. Narváez-Berthelot N, Russell JM, Arvanitis R, Waast R, Gaillard J. Science in Africa: An overview of mainstream scientific output. *Scientometrics*. 2002;54(2):229-41. doi: 10.1023/A:1016033528117.
 11. Waast R. *The state of science in Africa: An overview*. [Paris: L'Institut de Recherches pour le Développement]; 2002.
 12. Waast R, Krishna VV. Introduction: The status of science in Africa. *Science, Technology and Society*. 2003;8(2):145-52. doi: 10.1177/097172180300800201.
 13. Gruhn IV. Towards scientific and technological independence? *The Journal of Modern African Studies*. 1984;22(1):1-17. doi: 10.1017/S0022278X00056743.
 14. Barré R. Indications of world science today. In: UNESCO, editor. *World Science report*. Vol. 1998. Paris: UNESCO; 1998;22-30.
 15. Jonathan A, Christopher K, Daniel H. *Global research report Africa*. Leeds: Evidence, Thomson Reuters; 2010.
 16. Confraria H, Godinho MM. The impact of African science: A bibliometric analysis. *Scientometrics*. 2015;102(2):1241-68. doi: 10.1007/s11192-014-1463-8.
 17. NPCA. *African innovation Outlook 2014*. NEPAD Planning and Coordinating Agency. Pretoria: NPCA; 2014.
 18. Pouris A. A scientometric assessment of the Southern Africa Development Community: Science in the tip of Africa. *Scientometrics*. 2010;85(1):145-54. doi: 10.1007/s11192-010-0260-2.
 19. Boshoff N. South-South research collaboration of countries in the Southern African Development Community (SADC). *Scientometrics*. 2010;84(2):481-503. doi: 10.1007/s11192-009-0120-0.
 20. Cherry M. South African science: Black, white and grey. *Nature*. 2010;463(7282):726-8. doi: 10.1038/463726a, PMID 20148009.
 21. Hassan MHA. Can science save Africa? *Science*. 2001;292(5522):1609. doi: 10.1126/science.292.5522.1609, PMID 11387443.
 22. Sooryamoorthy R. *Transforming science in South Africa: Development, collaboration and productivity*. Hampshire and New York: Palgrave Macmillan; 2015.
 23. Boshoff N. Neo-colonialism and research collaboration in Central Africa. *Scientometrics*. 2009;81(2):413-34. doi: 10.1007/s11192-008-2211-8.
 24. Schubert T, Sooryamoorthy R. Can the centre-periphery model explain patterns of international scientific collaboration among threshold and industrialised countries? The case of South Africa and Germany. *Scientometrics*. 2010;83(1):181-203. doi: 10.1007/s11192-009-0074-2.
 25. AOSTI (African Observatory of Science, Technology and Innovation). *Assessment of scientific production in the African Union 2005– 2010*. Malabo, Equatorial Guinea: African Observatory of Science, Technology and Innovation (AOSTI); 2014.
 26. Adams J, Gurney K, Hook D, Leydesdorff L. International collaboration clusters in Africa. *Scientometrics*. 2014;98(1):547-56. doi: 10.1007/s11192-013-1060-2.
 27. Lee S, Bozeman B. The impact of research collaboration on scientific productivity. *Social studies of science*. 2005;35(5):673-702. doi: 10.1177/0306312705052359.
 28. Abramo G, D'Angelo CA, Di Costa FD. Research collaboration and productivity: Is there correlation?. *Higher education*. 2009 ed. 2009;57(2):155-71. doi: 10.1007/s10734-008-9139-z.
 29. He ZL, Geng XS, Campbell-Hunt C. Research collaboration and research output: A longitudinal study of 65 biomedical scientists in a New Zealand university. *Research Policy*. 2009;38(2):306-17. doi: 10.1016/j.respol.2008.11.011.
 30. Gaillard J. Science policies and cooperation in Africa: Trends in the production and utilization of knowledge. *Knowledge*. 1992;14(2):212-33. doi: 10.1177/107554709201400212.
 31. Gaillard J, Hassan M, Waast R, Schaffer wD. Africa. In: UNESCO, editor. *UNESCO science report*. Vol. 2005. France: UNESCO; 2005;177-201.
 32. Beaudry C, Mouton J, Prozesky H. Conclusions and recommendations. In: Beaudry C, Mouton J, Prozesky H, editors. *The next generation of scientists in Africa*. Cape Town: African Minds; 2018;175-82.
 33. Davies J, Mullan Z. Research capacity in Africa-will the sun rise again? *Lancet Diabetes Endocrinol*. 2016;4(5):375. doi: 10.1016/S2213-8587(16)30004-3. PMID 27049281.
 34. Pouris A, HoYS. Research emphasis and collaboration in Africa. *Scientometrics*. 2014;98(3):2169-84. doi: 10.1007/s11192-013-1156-8.
 35. Mouton J. Africa's science decline: The challenge of building scientific institutions. *Harvard International Review*. 2008;30(3):46-51.
 36. Sooryamoorthy R. *Science, Policy and Development in Africa: Challenges and Prospects*. London: Cambridge University Press; 2020.