

India's Research Collaboration Trend with the Selected African Countries: An Exploratory Study

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ABSTRACT

Historically India has had cordial relationships with the African countries. So, the aim of the present study is to find out the collaboration status and research emphasis of the leading five African countries with India as reflected in the Scopus database for the last three decades. In the context of India's collaborative research scenario, the five leading African countries are South Africa, Egypt, Ethiopia, Nigeria and Kenya. The African countries contribute a total 14,053 co-authored articles which may be further categorized on the basis of different aspects like country wise contribution, chronological output, nature of collaboration, focus areas, leading co-authoring foreign countries, leading affiliations, source journals, most prolific affiliations and scholarly impact. India has the strongest collaborative relationships with the countries of the Northern Africa region. The developed countries like the United States, the United Kingdom, and Germany have been found as the most influential collaborating partners. Conversely, the collaboration scenario confirms the fact that 'Physics and Astronomy', 'Medicine' and 'Engineering' are the primary emphasized areas among African countries.

Keywords: Collaboration, Research, Scientometrics, India, Africa, Egypt, Ethiopia, Nigeria, Kenya.

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INTRODUCTION

India is one of the largest emerging economies of the world with a consistent GDP growth of seven percent over last five years.^[1] According to the Global Innovation Index (GII)-2019,^[2] India has moved up to the 52nd rank at the Global level perspective in terms of innovation performance. On the contrary, Africa is the world's second-largest and second-most populous continent, after Asia^[3] and presently, six of the top 10 fastest growing economies are in the Africa.^[4] Historically, India has strong friendly relationship with Africa.^[5] In the year of 1953, the India's central government issued a circular, which suggested that state governments should sponsor at least two students from East and Central Africa.^[6] In the line with this commitment, the Delhi University established a School of African Studies in 1954 to promote research on history and culture of Africa.^[7] It is also worth noting that the first Afro-Asian conference at Bandung (1955), Indonesia was occurred to promote and strengthen South-South cooperation.^[8]

Besides, India's partnership with Africa is free of conditionalities and totally demands driven.^[9] Both the

countries have experienced the challenges of colonization and decolonization. India also supports Africa on the issues of struggling against colonialism and apartheid. Later on, peace and developmental issues also came on the agenda.^[10] In 2008 India entered into a new phase in its relations with the continent by hosting the first India-Africa Forum Summit (IAFS) to enhance bilateral cooperation.^[11] Further, in a speech to the Ugandan parliament, 2018 the Prime Minister, Government of India unveiled a strategic vision by outlining 10 guiding principles to boost India-Africa engagement.^[12]

Meanwhile, India has a strong research collaboration network at the global level. Among African countries India maintains a strong cordial relation with South Africa as they are common members in the BRICS^[13] and IBSA group.^[14] Further, India, Algeria, Egypt, Kenya, Nigeria, Senegal and Zimbabwe are part of G15 members and share strong bilateral co-operations with each other.^[15] India also has bilateral diplomatic relations with many of the other continental countries like Cameroon,^[16] Ethiopia,^[17] Morocco,^[18] Tanzania,^[19] Tunisia^[20] etc. to execute mutual interest and national priority. These strategic, diplomatic as well as political relationships influence and endorse further academic and research partnerships to foster developmental objectives. Therefore, the present effort aims to examine India's collaborative research trend beyond continent with special focus on Africa by addressing answers to the following questions:

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- i. Which African countries are major research partners of India in last three decades?
- ii. Which scientific disciplines are the key areas for research collaboration?
- iii. Which are the main African as well as Indian participated institutions that are actively engaged in research collaboration?
- iv. What are the most productive countries that are involved in the co-authored research productivity?

INDIA'S S&T INITIATIVES WITH AFRICAN COUNTRIES

India has launched several important initiatives and programmes to deepen engagement with Africa. These include the Exim Bank's Focus Africa,^[21] the Techno-Economic Approach for India-Africa Movement (TEAM-9) partnership,^[22] the India-Africa Forum Summit (IAFS)^[23] and Pan-African e-Network Project.^[24] Subsequently, India with the African counterparts takes several bilateral as well as multilateral Science and Technology (S&T) initiatives mutually to enhance research collaboration and capacity building for researchers of India as well as African countries. Some of the significant initiatives are highlighted below:

- i. The Federation of Indian Chamber of Commerce and Industry (FICCI) on behalf of Government of India launched the CV Raman Fellowship for African researchers in 2010 for conducting research in Indian institutions covering all areas of science and technology.^[25]
- ii. The Indian Council for Cultural Relations (ICCR) offers 900 scholarships for African students to pursue undergraduate, postgraduate and higher courses from the Indian institutions/universities.^[26]
- iii. The Africa-India Mobility Fund (AIMF) has been introduced by the African Academy of Sciences and the Welcome Trust/DBT India Alliance in 2018 to boost scientific collaboration among the researchers of Africa and India.^[27]
- iv. India and South Africa signed a bilateral agreement in science and technology in 1995. In the line of the agreement, the National Research Foundation (NRF), South Africa and the Department of Science and Technology (DST), India provide fund for joint research project for South African and Indian researchers.^[28]
- v. To promote grassroots innovation, India and South Africa signed a Memorandum of Understanding (MoU) in 2016. Under this MoU, the South-

African Department of Science and Technology (DST) through the Technology Localization Implementation Unit (TLIU) in partnership with the DST-India through the National Innovation Foundation (NIF)-India committed to a grassroots innovation technology exchange platform.^[29]

- vi. Further, India is also one of member states of the Square Kilometer Array (SKA) project, the next generation radio telescope hosted by South Africa.^[30]
- vii. India has entered into a bilateral Scientific and Technological Cooperation agreement with Egypt. Under this agreement, the Academy of Scientific Research and Technology (ASRT), Egypt and the DST, India collaborated to fund the research project jointly.^[31]
- viii. India and Ethiopia signed four agreements in the field of Science and Technology between the year 2011 and 2018 focusing on joint research, exchange of scientists, establishment of joint laboratory etc. There was also a Memorandum of Understanding (MoU) in academic and research collaboration between the Ministry of Science and Technology of the federal democratic republic of Ethiopia and the Indian Institute of Technology Madras India that mainly aim to enhance academic and research collaboration in the area of mutual interest.^[32]
- ix. In 1995, India-Tunisia signed an agreement on Scientific and Technological (S&T) cooperation. Under this agreement, both sides jointly provide fund for new research projects for scientists.^[33]

LITERATURE REVIEW

Many scientometric studies have showed Africa's collaboration trend and contribution to global scientific literature. In the central African collaborative research, Cameroon produced maximum research papers followed by Gabon and Democratic Republic of the Congo. Here European countries played an apparent role as collaborating counterparts.^[34] Additionally among West African countries, Nigeria, Ghana and Senegal produced maximum scientific output. However, the research integration between the regional countries of West Africa was negligible.^[35] In another study, Tijssen^[36] did an effort to quantify the characteristics of African scientific literature and assumed that African science was becoming increasingly internationalized. South Africa, Egypt and Morocco were the dominating countries in the African science research. Apart from these, majority of contributions by African countries were primarily skewed towards the fields of Clinical Medicine (36%), Biology (17%) and Chemistry (14%).^[37] Further, the

University of Cape Town, South Africa was found to be the most productive of all African institutions.^[37]

Besides, the collaborative research status in the sub-Saharan African countries pointed out that the African countries contributed minimal to each other's knowledge production in terms of research articles.^[38] Parallely, Pouris^[39,40] through his several studies narrated the research collaboration trend of the African countries at country and continental level. The scientific productivity and collaboration pattern of the five research universities of South Africa addressed the fact^[41,42] that the South African authors preferred to collaborate more with International authors (73.99%) than with national authors. Furthermore, Clinical Science (29.51%), Plant and Animal Science (20.85%) and Physics (13.88%) were considered as the most productive disciplines. Conversely, the collaborative scientific activity of South African scientists from 1945 to 2005 delineated that the developed countries like the USA, England and Germany were the leading collaborating countries.^[43]

Additionally, Patra and Muchie^[13,44] in their two attempts analysed the performance of South African Universities in terms of publications and patents and also assessed the S&T capacity building of India and South Africa. The trend of China–Africa Science and Technology (S&T) relationship during 1975– 2017 highlighted that the technology collaboration between Africa and China was quite weak.^[45] Furthermore, the scientific collaboration networks of the five BRICS countries from 1980 to 2012 showed^[46] that a strongest collaboration link existed between South Africa and India having Engineering as the most concentrated area.

From the studies mentioned above, the research trend of African continental countries had confirmed the fact that the developed countries like the United States and European nations were the main collaborating partners and inter-continental collaboration network was minimal. On the other hand, India is one of the largest R&D sector providers from the Asia and is also playing an important role in global research and development. Further, no such study is yet to found on research collaboration pattern between India and African countries except South Africa. Hence, to fill the research gap, the present study is an endeavor to identify the research collaboration trend between India and selected African countries.

OBJECTIVES OF THE STUDY

The main aim of the study is to identify the collaboration pattern and research emphasis of African countries beyond their continent with special reference to India. The other objectives are:

- i. To determine the African continental countries collaboration portfolio with India
- ii. To find out the chronological collaboration growth of leading African countries with India
- iii. To depict distribution of research articles by nature of collaboration
- iv. To assess research emphasis area in bilateral and multilateral collaboration
- v. To sketch leading co-authoring countries, collaboration network and their focus areas
- vi. To illustrate leading affiliations from African countries and India
- vii. To reveal popular source journals for scholarly communication
- viii. To report scholarly impact of the co-authored publications and citations pattern

SCOPE, COVERAGE AND METHODS USED

The present scientometric study explores the research collaboration pattern of Indian scientists with selected leading countries of Africa for the past 3 decades spanning from the period of 1990 to 2019. Among 55 member states of the African Union (AU),^[47] five most productive countries in terms of scientific collaboration output with India have been identified and considered for the study as reflected in the Scopus database during 2nd – 3rd week of April, 2020. Scopus is a largest citation and abstracting database of Elsevier.

The five most collaborating African counterparts are 'South Africa', 'Egypt', 'Ethiopia', 'Nigeria' and 'Kenya'. The names of five African countries and 'India' have been used individually as a search term for the search field - '*Affiliation country*'. Further, below search strings have been used to restrict the results for only 'Journal Articles'.

Document type— Article

Source type— Journals

Then the co-authored articles have been refined and collected. The five African countries contributed total 14,053 co-authored articles that count many collaborated papers in more than one category. On the other hand, from India's perspective, 12,958 unique co-authored articles have been found from the five collaborating partners. Finally, the records have been exported into a excel database and interpreted keeping in mind the objectives of the study. Besides, the VOSviewer software tool has also been used for mapping the collaboration networks.

RESULTS

The bibliographical details of the exported records have been analyzed and presented below in the following sub-sections:

African continental countries' collaboration portfolio with India

Table 1 chalks out the top 10 African collaborating partners of India and corresponding research publication status. Of these, South Africa produced largest number of 6,561 co-authored articles which account 2.75 percentage of total articles followed by Egypt having 3,276 articles and Ethiopia having 1,703 articles. Conversely, India played an imperative role as a collaborating partner with Ethiopia, Nigeria, South Africa and Egypt and it has been placed the position of 3rd, 6th,



Figure 1: Mapping of top 10 African collaborating countries with India.

8th and 10th rank respectively as a collaborator. It is significant to note that out of the top 10 productive countries as reflected in Figure 1, four countries are representing from Northern-Africa region, while three countries are from Eastern-Africa region and one country from rest 3 regions each.

Collaboration trend of leading African countries with India

Table 2 ascertains the triennial period wise break-up of collaboration trend of top 5 African counterparts with India during 1990–2019. Out of top 5 countries, South Africa produced lion's share of 46.69% i.e. 6,561 articles followed by Egypt with 3,276 articles (23.31%) while Kenya shared lesser number of 911 articles (6.48%). In total, highest 5,858 co-authored articles (41.7%) were contributed in the latest triennial period of 2017–2019 followed by the preceding year, 2014–2016 having 4,099 articles (29.16%). Overall, 22.24 percent Compound Annual Growth Rate (CAGR) has been seen during the study period. Further, it is evident from the data set that overall a gradual increasing trend is found up to the year 2007; thereafter a sharp rising trend is noticed in the co-authorship productivity of South Africa as well as Egypt.

The mathematical formula for calculation of Compound Annual Growth Rate (CAGR)^[48] is mentioned below:

$$CAGR = \left(\frac{\text{Ending value}}{\text{Beginning value}} \right)^{\frac{1}{n}} - 1$$

CAGR% = CAGR × 100; where *n* is the number of interval periods in the dataset.

Table 1: Leading African continental collaboration partners with India.

Rank	African Country	Region	Total Journal Articles	Co-authored Journal Articles with India		India's collaborative rank with the Country
				Articles	%	
1.	South Africa	Southern Africa	2,38,445	6,561	2.75%	8 th
2.	Egypt	Northern Africa	1,96,889	3,276	1.66%	10 th
3.	Ethiopia	Eastern Africa	24,246	1,703	7.02%	3 rd
4.	Nigeria	Western Africa	89,441	1,602	1.8%	6 th
5.	Kenya	Eastern Africa	33,350	911	2.73%	16 th
6.	Morocco	Northern Africa	53,173	674	1.27%	44 th
7.	Tunisia	Northern Africa	67,328	525	0.78%	17 th
8.	Algeria	Northern Africa	52,367	524	1%	14 th
9.	Cameroon	Central Africa	16,317	412	2.52%	12 th
10.	Tanzania	Eastern Africa	17,083	409	2.4%	19 th

Table 2: Triennial period wise collaboration growth of African countries with India.

Year	Collaboration output with India					Total Articles	%articles	CAGR%
	S. Africa	Egypt	Ethiopia	Nigeria	Kenya			
1990-1992	14	15	06	10	17	62	0.44	-
1993-1995	21	18	04	16	07	66	0.47	2.10
1996-1998	60	47	14	32	19	172	1.22	37.61
1999-2001	110	27	08	32	24	201	1.43	5.33
2002-2004	100	32	31	45	27	235	1.67	5.34
2005-2007	189	58	78	52	39	416	2.96	21
2008-2010	399	151	109	123	78	860	6.12	27.4
2011-2013	982	505	256	223	118	2,084	14.82	34.31
2014-2016	2123	892	413	410	261	4,099	29.16	25.3
2017-2019	2563	1531	784	659	321	5,858	41.7	12.64
Total=	6,561	3,276	1,703	1,602	9,11	14,053	100	22.24
%	46.69	23.31	12.12	11.40	6.48	100	-	-

*CAGR= Compound Annual Growth Rate

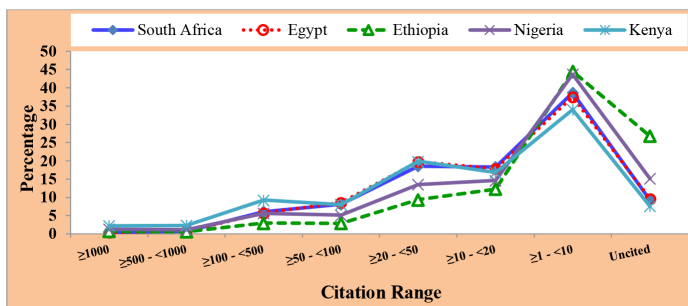


Figure 2: Citation wise distribution of articles.

Table 3: Distribution of papers according to collaboration types.

Partner Country with India	Bilateral papers		Multilateral papers		Total papers	Country's Collaborative Rank with India
	1990-2019	%	1990-2019	%		
South Africa	2563	39	3998	61	6,561	19 th
Egypt	545	16.63	2731	83.36	3,276	35 th
Ethiopia	1120	65.76	583	34.24	1,703	53 rd
Nigeria	785	49	817	51	1,602	54 th
Kenya	138	15.15	773	84.85	911	70 th
Total=	5152	36.65	8905	63.35	14057	-

Distribution of papers by nature of collaboration

Table 3 depicts the data related to collaboration types and corresponding output of African partners. Out of five countries, Ethiopia contributed maximum 65.76% i.e. 1,120 bilateral articles with India followed by Nigeria with 785

(49%) bilateral articles. On the contrary, Kenya produced highest share of 84.85% multilateral articles followed by Egypt with 83.36% multilateral articles.

In total, maximum 63.35 percent i.e. 8,905 articles were produced by the collaboration of multilateral countries, whereas rest 5,152 articles (36.65%) were the product of bilateral collaboration. From India's perspective, South Africa having 6,561 articles ranked 19th position as research collaborating partner followed by Egypt having 35th place.

Research emphasis on bilateral collaboration

The distribution of focus areas in bilateral collaboration have been depicted in the Table 4. For bilateral collaboration, the scientists of India and South Africa emphasized on the field of 'Physics and Astronomy' (32%) followed by 'Chemistry' (30.7%). On the other hand, Egypt and Ethiopia focused in the area of 'Engineering'. Conversely, Kenya and Nigeria concentrated maximum collaborative efforts towards the 'Agricultural and biological Sciences' discipline having share of 44.20% and 24.07% respectively.

Research emphasis of African countries

Table 5 discloses the data related to research emphasis area and the share of corresponding African countries. The scientists of Egypt and South Africa contributed majority of co-authored articles which account 41.24% and 32.37% respectively in the 'Physics and Astronomy' area. The 'Medicine' field has been found as their second focus area. Alternatively, Kenya, Nigeria and Ethiopia emphasized on the 'Medicine' discipline and shared maximum of 48.2%, 33.52% and 21.14% articles respectively. Furthermore, Ethiopia considered 'Engineering' domain as the second emphasized area while Nigeria and

Table 4: Distribution of bilateral collaboration focus area.

Partner Country	Focus Areas			
	Discipline-1	Discipline-2	Discipline-3	Discipline-4
India- S. Africa (2,563)	Physics and Astronomy (820; 32%)	Chemistry (787; 30.7%)	Materials Science (713; 27.82%)	Engineering (531; 20.72%)
India- Egypt (545)	Engineering (150; 27.52%)	Physics and Astronomy (117; 21.47%)	Materials Science (88; 16.14%)	Chemistry (79; 14.5%)
India-Ethiopia (1,120)	Engineering (266; 23.75%)	Chemistry (195; 17.41%)	Pharmacology, Toxicology and Pharmaceutics (154; 13.75%)	Agricultural and Biological Sciences (153; 13.66%)
India-Nigeria (785)	Agricultural and Biological Sciences (189; 24.07%)	Medicine (157; 20%)	Biochemistry, Genetics and Molecular Biology (138; 17.58%)	Pharmacology, Toxicology and Pharmaceutics (124; 15.8%)
India-Kenya (138)	Agricultural and Biological Sciences (61; 44.20%)	Biochemistry, Genetics and Molecular Biology (31; 22.46%)	Environmental Science (18; 13.04%)	Physics and Astronomy (16; 11.6%)

Table 5: Research focus areas of African countries.

Research Area	African countries					Total articles (n=12,958)	%articles*
	South Africa (n=6,561)	Egypt (n=3,276)	Ethiopia (n=1,703)	Nigeria (n=1,602)	Kenya (n=911)		
Physics and Astronomy	2124 (32.37%)	1351 (41.24%)	196 (11.51%)	125 (7.8%)	24 (2.63%)	3,767	16.8
Medicine	1349 (20.56%)	560 (17.1%)	360 (21.14%)	537 (33.52%)	439 (48.2%)	2,506	11.2
Engineering	916 (14%)	548 (16.73%)	308 (18.1%)	161 (10.05%)	13 (1.43%)	1,916	8.6
Chemistry	1196 (18.23%)	318 (9.7%)	260 (15.27%)	167 (10.42%)	08 (0.88%)	1,910	8.5
Materials Science	1146 (17.46%)	345 (10.53%)	144 (8.45%)	150 (9.36%)	09 (1%)	1,753	7.8
Agricultural and Biological Sciences	521 (7.94%)	265 (8.1%)	268 (15.73%)	305 (19.04%)	265 (29.1%)	1,520	6.8
Biochemistry, Genetics and Molecular Biology	680 (10.36%)	313 (9.55%)	192 (11.27%)	252 (15.73%)	135 (14.82%)	1,457	6.5
Environmental Science	413 (6.3%)	177 (5.40%)	191 (11.21%)	166 (10.36%)	123 (13.50%)	1,007	4.5
Earth and Planetary Sciences	733 (11.17%)	96 (2.93%)	58 (3.4%)	79 (4.93%)	18 (2%)	954	4.3
Chemical Engineering	514 (7.83%)	142 (4.33%)	139 (8.16%)	80 (5%)	05 (0.55%)	871	3.9

* Percentage calculation as per the Scopus data

Kenya gave priority to 'Agricultural and Biological Sciences' discipline. Overall, the five countries produced highest contribution in the field of 'Physics and Astronomy' having 3,767 (16.8%) articles followed by 'Medicine' having 2,506 articles (11.2%) and 'Engineering' having 1,916 articles (8.6%).

Leading Collaborating partners

Table 6 illustrates the leading collaborative foreign countries with the co-authored articles of India and African partners.

It is clearly seen from the observed data set that the United States was the major common collaborating partner with the five African countries. Apart from these, the United Kingdom also played major role and placed 2nd position in the context of 4 countries. As an inter-continental partner, South Africa played an apparent role and secured 3rd place with Ethiopia, Nigeria and Kenya. It is significant to note that the United Kingdom was the former colonizer with each country except

Table 6: Distribution of leading collaborating countries.

African Country	Leading co-authoring partners			
	Country-1	Country-2	Country-3	Country-4
South Africa (6,561)	United States (34.81%)	United Kingdom (27%)	Germany (19.35%)	Brazil (19.12%)
Egypt (3,276)	United States (46%)	China (39.2%)	Germany (38.36%)	United Kingdom (37.7%)
Ethiopia (1,703)	United States (14.68%)	United Kingdom (11.51%)	South Africa (9.75%)	Australia (8.3%)
Nigeria (1,602)	United States (26.07%)	United Kingdom (22.46%)	South Africa (18.71%)	China (17.22%)
Kenya (911)	United States (55.32%)	United Kingdom (40.28%)	South Africa (27.88%)	Australia (25.35%)

Table 7: Most prolific countries and focus areas.

Country	No of Articles	Focus Areas			
		Discipline-1	Discipline-2	Discipline-3	Discipline-4
United States	4,150	Physics and Astronomy (1,824; 43.95%)	Medicine (1396; 33.64%)	Earth and Planetary Sciences (430; 10.36%)	Biochemistry, Genetics and Molecular Biology (386; 9.3%)
United Kingdom	3,165	Physics and Astronomy (1631; 51.53%)	Medicine (957; 30.23%)	Earth and Planetary Sciences (294; 9.3%)	Engineering (241; 7.61%)
Germany	2,529	Physics and Astronomy (1,654; 65.4%)	Medicine (458; 18.11%)	Earth and Planetary Sciences (286; 11.31%)	Engineering (221; 8.74%)
China	2,490	Physics and Astronomy (1,495; 60%)	Medicine (537; 21.56%)	Engineering (256; 10.28%)	Biochemistry, Genetics and Molecular Biology (163; 6.54%)
Brazil	2,384	Physics and Astronomy (1,451; 60.86%)	Medicine (658; 27.6%)	Engineering (207; 8.7%)	Earth and Planetary Sciences (145; 6.08%)
France	2,334	Physics and Astronomy (1,590; 68.12%)	Medicine (438; 18.76%)	Earth and Planetary Sciences (272; 11.65%)	Engineering (211; 9.04%)
Italy	2,277	Physics and Astronomy (1,514; 66.5%)	Medicine (477; 21%)	Engineering (210; 9.22%)	Earth and Planetary Sciences (187; 8.21%)
Switzerland	2,104	Physics and Astronomy (1,457; 69.25%)	Medicine (451; 21.43%)	Engineering (194; 9.22%)	Earth and Planetary Sciences (154; 7.32%)
Spain	2,077	Physics and Astronomy (1,442; 69.43%)	Medicine (410; 19.74%)	Earth and Planetary Sciences (206; 9.92%)	Engineering (190; 9.15%)
Russia	1,888	Physics and Astronomy (1,472; 78%)	Medicine (247; 13.1%)	Engineering (196; 10.4%)	Earth and Planetary Sciences (134; 7.1%)

Table 8: Most prolific institutions from African countries.

African Country	Leading co-authoring institutions			
	Institution-1	Institution-2	Institution-3	Institution-4
S. Africa (6,561)	University of KwaZulu-Natal, South Africa (1219)	University of Cape Town, South Africa (1126)	University of Witwatersrand, South Africa (938)	University of Johannesburg, South Africa (842)
Egypt (3,276)	The Ohio State University, United States (975)	Wayne State University, United States (968)	University of California, Los Angeles, United States (965)	Imperial College London, United Kingdom (960)
Ethiopia (1,703)	Addis Ababa University, Ethiopia (317)	Mekelle University, Ethiopia (198)	Haramaya University, Ethiopia (172)	Jimma University, Ethiopia (165)
Nigeria (1,603)	University of Ibadan, Nigeria (280)	University of Lagos, Nigeria (117)	Universidade de Sao Paulo – USP, Brazil (117)	University of Nigeria, Nigeria (112)
Kenya (9,11)	University of Oxford, United Kingdom (132)	University of Nairobi, Kenya (125)	The Aga Khan University, Pakistan (122)	University of Cape Town, South Africa (107)

Ethiopia and colonial impact has been playing an important role.

Leading collaborating countries and focus areas

Table 7 exhibits the data related to top 10 leading co-authoring countries' contribution and corresponding focus areas. Out of 12,958 articles, the United States produced highest number of 4,150 articles as a collaborator followed by the United Kingdom (3,165), Germany (2,529) and China (2,490). The Table clearly shows that the top 10 countries' involvement primarily lies in the domain of 'Physics and Astronomy' followed by 'Medicine'. On the contrary, 'Earth and Planetary Sciences' and 'Engineering' disciplines were also found to be the apparent and interest area of research among the co-authoring countries.

Leading affiliations

Table 8 illustrates the country wise leading institutions who have actively participated in the scientific collaboration. In the context of South Africa's collaborative efforts, the *University of KwaZulu-Natal* shared maximum contributions with 1,219 articles followed by the *University of Cape Town* with 1,126 articles. In Ethiopia, the *Addis Ababa University* occupied the leading position while the *University of Ibadan* played the key role in Nigeria. However, it is significant to note that in case of Egypt, the affiliations from the United States i.e. *the Ohio State University*, *Wayne State University* and *University of California* played the dominant role among most productive institutions and the affiliation from the United Kingdom i.e. *University of Oxford* lead among Kenya's institutions. In case of Egypt, it is amply clear from the dataset that the scientists of India and Kenya frequently participated in the USA funded research projects.

Leading affiliations from India

The leading 5 Indian institutions and the data regarding their collaboration output along with focus areas have been

figured out in the Table 9. The *Panjab University* produced maximum contributions of 1,254 co-authored articles and published majority of 955 articles with Egypt. This is followed by the *Saha Institute of Nuclear Physics* with 1,142 articles and the *University of Delhi* with 1,087 articles. Meanwhile, the *National Institute of Science, Education and Research* contributed maximum 357 co-authored articles with South Africa. It is evident from the empirical data that the leading 5 Indian institutes emphasized their research activities in the domain of 'Physics and Astronomy'. Additionally, out of 5 leading institutions, 3 institutes are under the umbrella of the *Department of Atomic Energy (DAE)*.

Leading source journals for scholarly communication

Table 10 lists most productive source journals for scholarly communication of co-authored articles. Out of leading 10 source journals, the *Journal of High Energy Physics* having SJR score of 1.016 published majority of 398 articles followed by the *Physics Letters Section B: Nuclear, Elementary Particle and High Energy Physics* with 336 articles and the *European Physical Journal C* with 219 articles. Alternatively, the scientists of South Africa published highest number of 125 co-authored articles in the *Monthly Notices of the Royal Astronomical Society* having SJR of 2.422 and the scientists of Egypt contributed highest number of 292 articles to the *Journal of High Energy Physics*. Besides, the *Lancet* journal was the most preferred scholarly communication channel among the scientists of Ethiopia, Nigeria and Kenya having contributions of 38, 56 and 56 articles respectively.

Scholarly impact of the co-authored publications

Table 11 depicts the scholarly impact of the co-authored publications. Out of 5 collaborating countries, the articles of Kenya received maximum of 102.89 average citations followed by Nigeria having average citations of 58.45. On the contrary, the articles of South Africa achieve maximum *h*-index of 211 and *A*-index of 734.25. In terms of *p*-index, the articles of

Table 9: Most Prolific Indian Institutes with African countries.

Sl. No.	Institution	Articles	Focus Area	Collaboration output with African Countries				
				S. Africa	Egypt	Ethiopia	Nigeria	Kenya
1.	Panjab University, Chandigarh	1,254	Physics and Astronomy (1,201)	308	955	18	19	12
2.	Saha Institute of Nuclear Physics, Department of Atomic Energy, Kolkata	1,142	Physics and Astronomy (1,126)	305	849	01	0	0
3.	University of Delhi, New Delhi	1,087	Physics and Astronomy (9,28)	149	922	36	40	31
4.	Tata Institute of Fundamental Research, Department of Atomic Energy, Mumbai	1,070	Physics and Astronomy (1,025)	186	889	02	02	07
5.	National Institute of Science, Education and Research, Department of Atomic Energy, Bhubaneswar	1,042	Physics and Astronomy (1,037)	357	698	0	0	0

Table 10: Most productive source journals.

Journals	SJR*	No of Articles	Co-authored research articles output with India				
			S. Africa	Egypt	Ethiopia	Nigeria	Kenya
Journal of High Energy Physics, Germany	1.016	398	111	292	0	0	0
Physics Letters Section B: Nuclear, Elementary Particle and High Energy Physics, Netherlands	1.806	336	112	226	0	0	0
European Physical Journal C, Germany	1.972	219	99	122	0	0	0
Physical Review D, United States	1.703	215	90	122	02	01	0
Physical Review Letters, United States	3.571	184	61	126	0	0	0
PLoS One, United States	1.100	141	87	20	14	16	25
Monthly Notices of the Royal Astronomical Society, United Kingdom	2.422	127	125	1	0	1	0
Astronomy and Astrophysics, France	2.527	122	122	0	0	0	0
Journal of Molecular Liquids, Netherlands	0.862	115	104	3	6	6	0
Lancet, United Kingdom	15.871	95	81	47	38	56	56

* SJR= SCImago Journal Rank, 2018

Table 11: Citation impact of the India-African countries' collaborative publications.

Country	Total Articles	Total Citations (C)	ACPP (c/p)	h-index	A-index	p-index	%Uncited
S. Africa	6561	2,93,718	44.77	211	734.25	236.03	09.25
Egypt	3276	1,30,885	40	143	480.68	173.64	09.58
Ethiopia	1703	57,676	33.87	83	542.29	125	26.78
Nigeria	1602	93,632	58.45	115	641.82	176.22	15.11
Kenya	911	93,731	102.89	118	663.55	212.85	7.57

*ACPP= Average citations per paper

South Africa received highest score of 236.03 followed by Kenya having 212.85. Additionally, maximum 26.78 percent co-authored articles of Ethiopia are still remaining uncited followed by Nigeria with 15.11 percent articles.

The *h*-index indicates that the *h* papers have cited at least *h* times and the remaining papers have received fewer than $\leq h$ citations each.^[49] Further, the *A*-index counts average number of citations of *h*-core papers in the *h*-index and it can be formulated as follows:^[50]

$$A = \frac{1}{h} \sum_{j=1}^h cit_j$$

where, *h* = *h*-index, and cit_j = Total citations counts of *h*-core papers

The composite performance index (*p*-index) or mock *h*-index was introduced by Prathap^[51] and can be measured as follows:

$$p\text{-index} = \left(C \cdot \frac{C}{p} \right)^{1/3}$$

Where, *C* = total number of citations; *P* = total number of papers

Citations Pattern

Table 12 illustrates the citation wise distribution of articles. Out of 5 African countries, Kenya gained highest share i.e. 2.20% and 2.31% of articles in case of at least 1000 and 500 citations respectively followed by Nigeria having percentage of 1.25% and 1.12%. On the other hand, it is apparent from the Figure 2 that the maximum percentage of articles from Ethiopia and Nigeria were found as lesser cited ($\geq 1 - < 10$) and uncited while the articles of Kenya gained largest share of most cited articles i.e. $\geq 100 - \geq 1000$.

In total, largest share of 39.36% articles i.e. 5532 get citations within $\geq 1 - < 10$ range followed by citations in the range of $\geq 20 - < 50$ having 2420 articles (17.22%). Total 1,688 articles (12.01%) still remain uncited.

CONCLUSION

Over the last three decades, a positive collaborative research effort among the scientists of India and five African countries is gradually increasing and since 2008, a quick increasing

Table 12: Distribution of articles according to citations.

Citation Range	Co-authored contributions					Total articles	%articles
	S. Africa	Egypt	Ethiopia	Nigeria	Kenya		
≥1000	32 (0.49%)	13 (0.40%)	12 (0.70%)	20 (1.25%)	20 (2.20%)	97	0.69
≥500 - <1000	42 (0.64%)	21 (0.64%)	10 (0.59%)	18 (1.12%)	21 (2.31%)	112	0.8
≥100 - <500	397 (6.05%)	187 (5.71%)	50 (2.93%)	90 (5.62%)	84 (9.22%)	808	5.75
≥50 - <100	531 (8.1%)	282 (8.61%)	49 (2.88%)	82 (5.12%)	73 (8.01%)	1,017	7.23
≥20 - <50	1217 (18.55%)	647 (19.75%)	159 (9.33%)	216 (13.48%)	181 (19.87%)	2,420	17.22
≥10 - <20	1200 (18.29%)	583 (17.80%)	209 (12.27%)	234 (14.61%)	153 (16.8%)	2,379	16.93
≥1 - <10	2535 (38.64%)	1229 (37.51%)	758 (44.51%)	700 (43.70%)	310 (34.03%)	5,532	39.36
Uncited	607 (9.25%)	314 (9.58%)	456 (26.78%)	242 (15.11%)	69 (7.57%)	1,688	12.01
Total =	6,561	3,276	1,703	1,602	911	14,053	100

progress has been found in the collaborative output. South Africa contributes the majority of collaboration output with India and it is also playing an imperative role as an inter-continental collaborating partner. Apart from these, India plays the most crucial role in the context of Ethiopia and Nigeria's collaboration. Further, out of top 10 collaborating partners, Cameroon having 9th rank is the only country representing from the Central-Africa region. Hence, it is revealed that India has the weakest collaboration partnership with the countries of Central-Africa region.

It is also noted that the attentive areas for bilateral collaboration vary country-wise. South Africa is primarily involved in the area of 'Physics and Astronomy'; Egypt and Ethiopia are more focused towards 'Engineering' whereas Nigeria and Kenya have given priority to the 'Agricultural and Biological Sciences' area. In case of bilateral collaboration, the partners should stress on their strengths and potentiality to set research priorities for gaining developmental goals.

Subsequently, the overall collaboration efforts mostly occurred in the field of 'Physics and Astronomy' and 'Medicine'. The United States and United Kingdom are the major partners in the India-Africa team efforts. However, in the case of Egypt and Kenya, the total collaboration scenario is overemphasized towards 'Physics and Astronomy' (41.24%) and 'Medicine' (48.2%) respectively. Similarly, the collaborative research of Egypt and Kenya is more influenced by the United States and both the countries produce minimal numbers of bilateral papers with India. But collaboration should be balanced,

not skewed in favour of one particular field or partner. This skewed trend raises concern and demands more attention from the policy makers of Egypt and Kenya. Small African countries having limited S&T budgets should come forward to set up research consortiums to fulfill mutual interest and developmental objectives.

Furthermore, the presence of the majority of the Indian DAE institutes indicates that high energy physics is the main sub-focus area under Physics for research collaboration. In terms of *p*-index, the research articles of South Africa and Kenya have been found as the most prominent. Hope, despite many hurdles, India and the African countries will identify their potentiality and quality scientific research will be continued too long for the enhancement of the mutual benefits.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest

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