Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2024, Volume 15, Issue 5, Page 609-626

http://www.jmaterenvironsci.com

Bibliometric Analysis of Publications in Web of Science Category of Chemical Engineering in Africa

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Received *23 Feb 2024,*
Revised *24 Apr 2024,*
Accepted *25 Apr 2024*

Keywords:
- ✓ *Chemical engineering;*
- ✓ *Africa;*
- ✓ *Web of Science Core; Collection*
- ✓ *TCyear;*
- ✓ *CPPyear;*

Citation: *Tchuifon T.D.R., Kouteu N.P.A., Tagne T.R.F, Ho Y.S. (2024) Bibliometric Analysis of Publications in Web of Science Category of Chemical Engineering in Africa, J. Mater. Environ. Sci., 15(5), 609-626*

Abstract: This study aims to assess Africa's scientific output in chemical engineering in the Science Citation Index Expanded in the Web of Science database from 1992 to 2021. Document type, trends, keywords, research institutions, publication reviews and collaborations were analyzed. The study showed a grouping of work into 14 categories in three fields of multidisciplinary materials science, nanoscience and technology, and physical chemistry. The articles represent 96% of the publications followed by the proceeding paper with 7.4%. This study showed that Egypt, South Africa, and Algeria dominate the ranking as the best African countries with 71% of publications and as the country with the best research institutions on the continent. Desalination and Water Treatment and Desalination are the two leading scientific journals with more than 1,000 publications each. These two journals as well as the top used world in article title, words in article abstract, authors keyword and keywords more respectively show that the field of water treatment occupies the first place of the concerns of African countries and this is due to the presence of waterborne diseases on the continent. France, Saudi Arabia, USA and China dominate the ranking of countries that collaborate with African researchers.

1. Introduction

Africa is a continent which covers 6% of the surface of the Earth and 20% of the surface emerged lands (Ramdoo, 2019). Its surface area is 30,415,873 km^2 with he is, which makes it the third in the world if the America is counted as one continent (Ramdoo, 2019). This continent although being the 3rd largest, remains the last in terms of development (Ramdoo, 2019). The dependence of the manufacturing, agricultural as well as knowledge-based economy within this region necessitates a high population of skilled workers and researchers of which chemical engineers constitute a significant portion (Kumar *et al.*, 2004). Therefore, due to the fact the chemical engineering involves the production and manufacturing of product through chemical processes and the poor development

success of Africa, the contribution of the transformation of the wealth of the African soil and subsoil by relying on chemical engineering must be studied (Ramdoo, 2019). The practice of engineering is no longer restricted to a particular country, region, or continent. It is becoming increasingly international and, to some extent, multicultural. The engineers' training programme in Africa, with special reference to Western and Eastern Sub-Saharan Africa, is yet to fully awakentoa changing environment (Kumar et al., 2004). According to the work of Kim in 2002, the origin of chemical engineering could be traced back to George E. Davis with his work which constituted a textbook of chemical engineering in 1887 (Scholtz, 2021; Simpson, and Sastry, 2013). The first courses of chemical engineering appeared in the 1880s (Cohen, 1996). Likewise, the Institution of Chemical Engineers (IChemE) and the American Institute of Chemical Engineers (AIChE) were born out of chemical companies rather than engineers (Cohen, 1996). Currently, with the development of the Essential Science Indicators (ESI) database as a research tool in the Web of Science, it becomes possible for researchers to access a unique and comprehensive compilation of essential statistics on scientific performance (Chuang *et al.*, 2013; Lrhoul et al., 2023), this by allowing quick and convenient identification of researchers and important articles in the subject categories. Previous studies have used it to assess an institution (Pouris, 2007; Hammouti et al., 2023), or the countries (Hammouti, 2010, Tchuifon et al., 2017). Some have used it for an international comparison of research performance (Pouris and Ho, 2014) or to analyze the trend of a category of individual subjects (Fu *et al.*, 2014). There are several important events that are stimulating the evolution of research in Africa.

In the field of chemical engineering, the analysis of co-authors and word-words have been used as institutional identification and authors to analyze their gradual change in research topics (Peters and van Raan, 1991) and bibliometric characteristics (Peters and van Raan, 1994), without forgetting the work of Fu *et al*, in 2013 in China, which is today the world leader in terms of publication. Citation analysis has also been applied to assess information on geographic origins, journals, research groups, and interdisciplinary relationships (Shama *et al.*, 2000). For example, the chemical engineering research activities of Southeast Asia of major journal articles and keywords were studied (Yin, 2009). However, changing citations or the number of publications may not offer enough evidence for estimating search trends. More detailed information about the publications including words in the title and abstract, author keywords, and Keywords Plus could also be separated into different time periods to analyze variations in search trends more thoroughly and precisely (Zhang *et al.*, 2010). In addition, the SCI-EXPANDED database could provide additional search terms taken from the title of the article cited by the authors in their bibliographies and footnotes (Garfield, 1990).

This African study aims to use a comprehensive bibliometric analysis method to provide a detailed graph of chemical engineering research on the continent, covering all 54 countries. Different bibliometric indicators were used to analyze the publication patterns of document types, languages, annual output, journals, and collaborations. Temporal distributions of words in the title, abstracts, author keywords, and most cited articles were also analyzed to study search trends.

2. Methodology

Data used in this study were retrieved from the Clarivate Analytics Web of Science Core Collection, the online version of the Science Citation Index Expanded (SCI-EXPANDED) on 17 January 2023. The 2021 journal Impact Factor (IF2021) was reported in the Journal Citation Report (JCR) on 30 June 2022. According to the definition of journal impact factor, it is best to search documents published in 2021 from SCI-EXPANDED after IF2021 and before IF2022 were presented. The SCI-EXPANDED indexes a total of 9,649 journals across 178 Web of Science categories, and 143

of them are classified in the Web of Science category of chemical engineering in 2021. The search strategies including African countries: "Algeria", "Angola", "Benin", "Botswana", "Burkina Faso", "Burundi", "Cameroon", "Cape Verde", "Cent Afr Empire" (Central African Empire), "Cent Afr Republ" (Central African Republic), "Chad", "Comoros", "Congo", "Congo Peopl Rep" (People's Republic of the Congo), "Congo Republic", "Cote Ivoire", "Ivory Coast", "Dem Rep Congo" (Democratic Republic of the Congo), "Rep Congo" (Republic of the Congo), "Djibouti", "Egypt", "Equat Guinea" (Equatorial Guinea), "Eritrea", "Eswatini", "Ethiopia", "Gabon", "Gambia", "Ghana", "Guinea", "Guinea Bissau", "Kenya", "Lesotho", "Liberia", "Libya", "Madagascar", "Malagassy Republ" (Malagasy Republic), "Malawi", "Mali", "Mauritania", "Mauritius", "Morocco", "Mozambique", "Namibia", "Niger", "Nigeria", "Rwanda", "Sao Tome & Prin" (Sao Tome and Principe), "Senegal", "Seychelles", "Sierra Leone", "Somalia", "South Africa", "South Sudan", "Sudan", "Swaziland", "Tanzania", "Togo", "Tunisia", "Uganda", "Zaire", "Zambia", "Zimbabwe", and "Senegambia" were searched in terms of the country (CU) from 1992 to 2021 and then refined by the Web of Science category of chemical engineering. These records were downloaded into spreadsheet software and checked. Additional coding was manually performed using Excel Microsoft 365 for analysis (Li and Ho, 2008).

It is pointed out that SCI-EXPANDED is mainly designed for researchers to find literature but is not used for bibliometric research (Ho, 2018). Thus, it is always necessary to perform data processing, but directly obtain data from SCI-EXPANDED for bibliometric research. In the SCI-EXPANDED, the corresponding author is labeled as a reprint author, but in this study, the term corresponding author was used (Ho, 2012). In a single-institution article where the corresponding author institution is unspecified, the single institution is classified as the first and the corresponding author institution (Ho, 2014). In a single-author article with multiple affiliations, only the affiliation in Africa was considered. In multi-corresponding author articles, all the corresponding authors, institutions, and countries were analyzed. Articles with corresponding authors in SCI-EXPANDED, that had only addressed but not affiliation names were checked out and the addresses were changed to affiliation names. We also use a special technique to deal with address change with time, the details were provided in the appendix.

To have accurate analysis results, affiliations originating from England, Scotland, North Ireland (Northern Ireland), and Wales were reclassified as being from the UK (United Kingdom) (Chiu and Ho, 2005). Affiliations from Hong Kong before 1997 were reclassified as being from China (Chuang et *al.*, 2011). Affiliations from Rep Congo (Republic of the Congo) were reclassified as being from Dem Rep Congo (Democratic Republic of the Congo). Affiliations from Yugoslavia, Czechoslovakia, Serbia Monteneg (Serbia and Montenegro) were checked and reclassified as being from Serbia, the Czech Republic, and Serbia respectively. The article was published by Papua N Guinea but African countries were not included.

Three citation indicators were used to analyze the citations received by the articles:

C_{year}: the total number of citations in a year from the Web of Science Core Collection. C_{2021} means the number of citations in 2021 (Ho, 2012).

TC_{year}: the total number of citations from the Web of Science Core Collection since the publication year to the end of the most recent year (Wang et al., 2011). In this study, the most recent year is 2021 (TC_{2021}).

CPP_{year}: average number of citations per publication ($CPP_{2021} = TC_{2021}/TP$) (Ho, 2012), TP is the total number of articles.

3. Results and Discussion

3.1 Document type and language of publication

In 2017, a connection between the number of publications in document types (TP), the average number of citations per publication (CPPyear), and the average number of authors per publication (APP) were proposed in the discussion of document types (Monge-Nájera and Ho, 2017). A total of 18,509 documents published from 1992 to 2021 were found as publications in the Web of Science category of chemical engineering in Africa. Table 1 illustrates the characteristics of 14 document types, including 17,812 articles (96% of the 18,509 documents) with an APP of 4.0. The document type of the reviews had the greatest CPP_{2021} of 42. Fifty of the 483 reviews were highly cited reviews with a TC2021 of 100 or more (Ho and Kahn, 2014). A review entitled "Sewage sludge combustion" (Werther and Ogada, 1999) published by J. Werther from the Technical University of Hamburg-Harburg in Germany and T. Ogada from Moi University in Kenya was the most frequently cited review in Africa in the Web of Science category of chemical engineering with a TC_{2021} of 777. The CPP_{2021} of the reviews was 2.2 times the CPP_{2021} of the articles. A total of 1,374 proceedings papers were published in 72 journals mainly in Desalination (472 proceedings papers; 34% of 1,374 proceedings papers). From 2001 to 2010, two meetings on Desalination: Maghrebian Conference on Water Treatment and Desalination in 2010 and 3rd Conference on Desalination Strategies in South Mediterranean Countries in 2004 were held in Tunisia and Morocco respectively. It is worth noting that documents in the SCI-EXPANDED can be split into two document types. For example, 1,374 proceeding papers, nine retracted publications, and one book chapter were also classified as document-type of articles, thus the sum of the percentages in Table 1 is greater than 100% (Usman and Ho, 2020).

Table 1. Citations and authors according to document type

Document type	TP	%	AU	APP	TC_{2021}	CPP_{2021}
Article	17,812	96	70,885	4.0	331,171	19
Proceedings paper	1,374	7.4	4,811	3.5	32,310	24
Review	483	2.6	2,103	4.4	20,048	42
Editorial material	74	0.40	191	2.6	72	1.0
Correction	73	0.39	326	4.5	32	0.44
Letter	29	0.16	48	1.7	53	1.8
Note	24	0.13	59	2.5	324	14
Retracted publication	9	0.049	31	3.4	204	23
Meeting abstract	6	0.032	16	2.7	30	5.0
Retraction	5	0.027	23	4.6	3	0.60
Book chapter	2	0.011	7	3.5	4	2.0
Addition correction	1	0.0054	3	3.0	0	0
Discussion	1	0.0054	8	8.0	0	0
News item	1	0.0054	1	1.0	0	0

TP: total number of publications; AU: number of authors; APP: average number of authors per publication; TC_{2021}: the total number of citations from Web of Science Core Collection since publication year to the end of 2021; CPP_{2021}: average number of citations per publication (TC_{2021}/TP).

Only 17,812 articles that included the introduction, methods, results and discussion, and conclusion were chosen for further analysis. One of the most important considerations in bibliometric research as big data analysis is the language of publishing (Wang and Ho, 2011). A total of 17,728

articles (99.5% of 17,812 articles) were published in English. These results are in agreement with the work of Monge-Nájera and Ho (2012) who reported that in order to have a wide reach, most publications are in English. These results can also be explained by the fact that most peer-reviewed journals in the field of chemical engineering require English as the language of publication and because Southern Africa and some countries in West Africa (Ghana, Nigeria, etc.) and East Africa (Kenya, Zambia, etc.) have English as their national language. Such a high percentage of English articles was also found in topics published in the journals of environmental engineering (Zhang et al., 2010a). Other languages also appeared: French (71 articles), German (9 articles), and Chinese (3 articles). The second position of French language can be explained by the fact that the colonial language of some part of Africa like North Africa, Central Africa (Cameroon, Chad, etc.) and West Africa (Burkina Faso, Ivory Coast, etc.) is French. Some German organizations such as DAAD (German Academic Exchange Service/Deutscher Akademischer Austauschdienst) and KAAD (Catholic Academic Exchange Service/Katholischer Akademischer Ausländerdienst) offer scholarships to young African students for academic work in Germany, work published in German could be accepted by the presence of certain Africans in German universities. In addition, two articles were unspecified in SCI-EXPANDED.

3.2 Characteristics of publication outputs

A relationship between the total annual number of articles (TP) and their average number of citations per publication ($CPP_{year} = TC_{year}/TP$) by year has been proposed by Ho (2013) to understand publication and their impact trends on a research topic. Figure 1 depicted the year-by-year distribution of TP and their CPP_{2021}. The mean number of CPP_{2021} was 19. Figure 1 shows the evolution of publications and citations over a period of 30 years, from 1992 to 2021. In 1992, Africa has already published 127 articles by Egypt (48 articles), South Africa (44), Algeria (9), Nigeria (9), Tunisia (4), Cameroon (3), Morocco (2), Tanzania (2), Gabon (2), Zimbabwe (1), Libya (1), Angola (1), and Kenya (1) in chemical engineering. In 2021, Africa has published 1,762 articles by Egypt (635 articles), South Africa (349), Algeria (242), Morocco (152), Tunisia (144), Nigeria (134), Cameroon (27), Ghana (16), Tanzania (16), Libya (15), Kenya (13), Sudan (12), Botswana (9), Mauritius (6), Mozambique (6), Uganda (6), Zimbabwe (6), Benin (4), Cote Ivoire (4), Zambia (4), Namibia (3), Rwanda (3), Togo (3), Dem Rep Congo (2), Guinea (2), Malawi (2), Senegal (2), Burkina Faso (1), Gabon (1), Liberia (1), Madagascar (1), and Mali (1).

From 1992 to 2003, there is not a significant increase in the number of publications during each year. On the other hand, from 2012 to 2021 a remarkable growth of these publications is observed each year to reach a value greater than 1,700 per year with some decreases in 2008, 2012, and 2018. These results can be explained by the development of the training offer in chemical engineering in the various countries and the acquisition and development of the infrastructure for research work in the field of chemical engineering. Dada et al. (2013) reported for example that in the 1980s in Nigeria the offer of training in chemical engineering was only provided in a few universities and the classes had only 16 to 20 students whereas in 2013, there were more than 26 Nigerian universities which offer chemical engineering degrees and produced an estimated 1500 to 2000 chemical engineers each year. Moreover, the structuring of chemical engineering society can also explain these results. This increase is to be credited to countries seeking to emerge from under development by thinking of industrialization through the transformation of raw materials and the multiplication of schools and departments of chemical engineering in their countries. This is true since the countries ranked first in Africa in terms of development are those with the largest number of publications and with the largest research institutions. Regarding citations, we observe that the trend does not depend on the number of

publications per year or even per institution, but rather on the quality of the result and the subject treated.

In 2002 with 250 articles had a higher CPP_{2021} of 42, which can be attributed to three of the top ten most frequently cited articles by Dry (2002), Lachheb et al. (2002), and Monser and Adhoum (2002) with TC_{2021} of 1,493, 1,231, and 515, respectively. Since 2015, a decrease of the citations per publication has been observed (Figure 1).

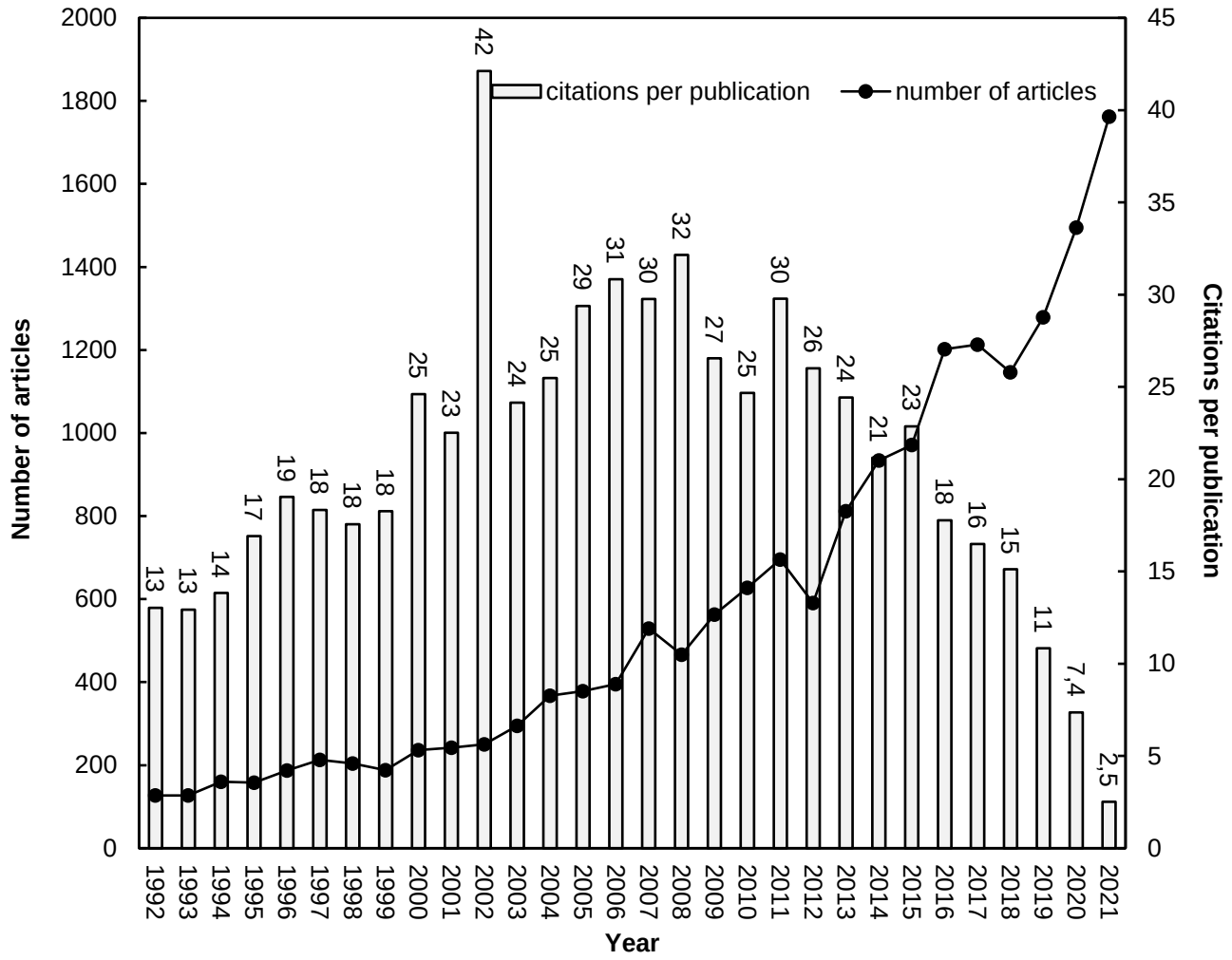

Figure 1. Number of articles in chemical engineering by Africa and their citations per publication by year

3.3 Journals

Recently, a relationship among number of articles and journals in a Web of Science category as well as a number of authors and average number of citations per publication were proposed (Giannoudis et al., 2021). The 17,812 chemical engineering articles by Africa were published in 183 journals in Web of Science category of chemical engineering. A total 489 of the 17,812 articles were published in 41 journals that are not classified in the Web of Science category of chemical engineering in 2021. For example, 156 articles published in the International Journal of Mineral Processing that is not in SCI-EXPANDED after 2017. Three articles published in Molecular Systems Design & Engineering with an IF_{2021} of 4.920. The journal is not listed in Web of Science category of chemical engineering in 2021 but in categories of multidisciplinary materials science, nanoscience and nanotechnology, and physical chemistry. The top ten African favour journals in chemical engineering are shown in Table 2. The Desalination and Water Treatment (IF_{2021} = 1.273) with 1,883 articles was

the most popular journal in chemical engineering in Africa. Compared to the top 10 journals in Table 2, articles with the greatest CPP_{2021} were published in the Chemical Engineering Journal (IF_{2021} = 16.744) with a CPP_{2021} of 47. The Applied Energy (IF_{2021} = 11.446) published 363 articles also had a higher CPP_{2021} of 45. An average number of authors per publication (APP) in the category of chemical engineering in Africa was 4.0 while the Energy & Environmental Science (IF_{2021} = 39.714; rank 1st in chemical engineering) with nine articles had an APP of 9.2. Figure 2 shows the publication trends of the top five most popular journals in chemical engineering in Africa with more than 60 articles in the most recent year of 2021. The Desalination and Water Treatment has been the most popular journal in Africa since 2012. The first article published in the journal was found in 2009. Articles have long been published in the Fuel by authors from Africa. In 1973, four articles about fossil energies were published in the Fuel by authors from South Africa (Briel and Savage, 1973; Liebenberg and Potgiete, 1973; Potgieter, 1973) and Egypt (El-Kaddah and Ezz, 1973). A sharply increased were found from 2018 to 2020. The first article was published in later years in Journal of Environmental Chemical Engineering and Processes in 2017 and 2016, respectively. However, these journals are most popular journals in Africa with 156 and 113 articles in 2021, respectively. In the category of chemical engineering, Africa still does not publish articles in the Progress in Energy and Combustion Science (IF_{2021} = 35.339; rank 2nd), the Annual Review of Chemical and Biomolecular Engineering (IF_{2021} = 9.700; rank 12nd), the Reviews in Chemical Engineering (IF_{2021} = 8.742; rank 15th), the Chemical & Engineering News (IF_{2021} = 0.713; rank 132nd), the Przemysl Chemiczny (IF_{2021} = 0.490; rank 138th), and the Kagaku Kogaku Ronbunshu (IF_{2021} = 0.338; rank 131st).

Table 2. The top 10 productive journals in category of chemical engineering.

Journal	TP (%)	IF2021 (rank)	APP	CPP2021
Desalination and Water Treatment	1,883 (11)	1.273 (111)	4.2	6.0
Desalination	1,034 (5.8)	11.211 (10)	3.5	37
Minerals Engineering	772 (4.3)	5.479 (33)	3.2	19
Journal of Environmental Chemical Engineering	512 (2.9)	7.968 (20)	5.0	12
Chemical Engineering Journal	510 (2.9)	16.744 (4)	5.0	47
Industrial & Engineering Chemistry Research	460 (2.6)	4.326 (52)	3.8	21
Fuel	438 (2.5)	8.035 (19)	4.3	27
Petroleum Science and Technology	428 (2.4)	1.695 (105)	2.8	4.6
Journal of Chemical and Engineering Data	424 (2.4)	3.119 (75)	3.5	14
Applied Energy	363 (2.0)	11.446 (9)	3.7	45

TP: number of publications; %: percentage of 16,169 articles; TC_{2021}: the total number of citations from Web of Science Core Collection since publication year to the end of 2021; CPP_{2021}: average number of citations (TC2021) per publication (TP); APP: number of authors per publication

3.4 Publication performances: countries and institutions

Of the 17,812 articles published in the Web of Science category of chemical engineering by authors from 46 African countries, 8,884 articles (49.9% of the 17,812 articles) were single-country articles across 30 different African countries, while 8,928 (50.1%) articles were international collaborations from 46 different African countries and 94 non-African countries. The top 25 productive countries with 25 articles or more are listed in Table 3. Six publication indicators were used for the comparison of publication performance: the total number of articles (TP), single-country articles (SPC), internationally collaborative articles (CPC), first-author articles (FP), corresponding-author articles (RP), and single-author articles (SAP) (Ho and Kahn, 2014; Hsu and Ho, 2014) as well as their

CPP_{2021} (Fu and Ho, 2018; Giannoudis et al., 2021). Egypt dominated among the six publication indicators with a TP of 5,802 articles (33% of 17,812 articles), an SPC of 3,242 articles (36% of 8,884 single-country articles), a CPC of 2,560 articles (29% of 8,928 internationally collaborative articles), an FP of 4,136 articles (23% of 17,812 first-author articles), an RP of 4,327 articles (24% of 17,718 corresponding-author articles), and an SAP of 587 articles (53% of 1,108 single-author articles). Compared to the top 25 countries in Table 3, articles published in the Web of Science category of chemical engineering by Burkina Faso with 46 total articles (rank 16th) had the greatest CPP_{2021} of TP with 27 and with 44 internationally collaborative articles (rank 15th) had the greatest CPP_{2021} of CPC with 28.

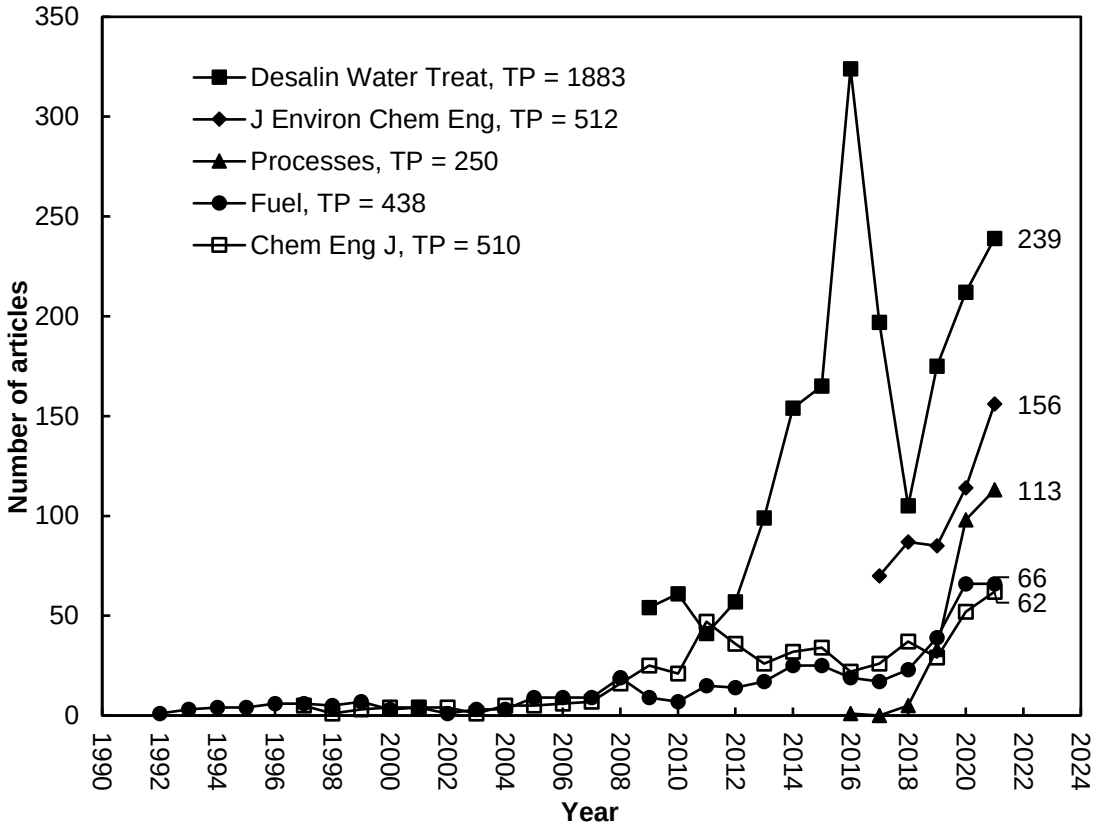

Figure 2. Development trends of the top five popular chemical engineering journals in Africa in 2021

Namibia published two single-country articles that had the highest CPP_{2021} of SPC with 27. Benin with 11 first-author articles (rank 22nd) had the greatest CPP_{2021} of FP with 27 and with 10 corresponding-author articles (rank 23rd) had the greatest CPP_{2021} of RP with 29. Ghana published five single-author articles (rank 9th) that had the highest CPP_{2021} of SAP with 71. Figure 3 shows a comparison of development trends among the top six leading countries with more than 1,000 articles. In most years, the annual number of articles was mainly published by Egypt, but South Africa ranked top in 1994, 2002, 2006, 2011, and 2012. Egypt and South Africa had similar development trends before 2013. Egypt has been ranked the top since 2013 and kept sharper increase of the annual number of articles. In the chemical engineering field, 94 countries had international collaborations with African countries from 1992 to 2021. Table 4 shows the top 14 non-Africa collaborative countries with more than 200 internationally collaborative articles with African countries. France was the most popular collaborative country in Africa with a CPC of 2,220 articles (25% of 8,928 internationally collaborative articles) including an FP of 709 articles (4.0% of 17,812 first-author articles in Africa), and an RP of 970 articles

(5.5% of 17,718 corresponding-author articles in Africa). The main collaborations with France were its colonies, for example Algeria (819 articles collaborated with France; 37% of 2,220 France collaborative articles), Tunisia (503; 23%), and Morocco (346; 16%). When African collaborative articles with authors from Australia, it had the greatest CPP_{2021} of TP, FP, and RP with 25, 25, and 29. The collaborative articles with corresponding authors from Japan, also had the greatest CPP_{2021} of RP with 29. When articles collaborated with the authors from Canada, China, and Saudi Arabia, CPP_{2021} of FP and CPP_{2021} of RP were lower than 20.

Table 3. Top 15 productive Africa countries

Country	*TP*	*TP*		SP_C		CP_C		*FP*		*RP*		*SAP*	
		R (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*
Egypt	5,802	1 (33)	17	1 (36)	16	1 (29)	19	1 (23)	16	1 (24)	16	1 (53)	15
South Africa	4,454	2 (25)	21	2 (27)	19	2 (23)	22	2 (18)	20	2 (19)	19	2 (22)	27
Algeria	2,389	3 (13)	17	3 (13)	15	3 (14)	19	3 (11)	16	3 (11)	16	4 (5.0)	13
Tunisia	1,744	4 (10)	22	4 (8.5)	22	4 (11)	23	4 (7.4)	21	4 (7.2)	21	6 (2.6)	28
Nigeria	1,348	5 (7.6)	16	5 (7.0)	15	5 (8.1)	18	5 (5.1)	14	5 (5.1)	14	3 (10)	17
Morocco	1,031	6 (5.8)	20	6 (4.6)	15	6 (6.9)	24	6 (4.0)	17	6 (4.0)	17	7 (1.2)	8.5
Ethiopia	216	7 (1.2)	15	10 (0.33)	19	7 (2.1)	14	9 (0.51)	19	9 (0.5)	19	8 (0.63)	18
Libya	194	8 (1.1)	9.3	7 (1.0)	6.0	10 (1.1)	12	7 (0.68)	6.2	7 (0.67)	7.0	5 (3.0)	7.9
Cameroon	181	9 (1.0)	13	8 (0.48)	7.7	8 (1.5)	14	8 (0.58)	13	8 (0.55)	12	12 (0.27)	7.7
Ghana	153	10 (0.86)	15	9 (0.36)	19	9 (1.4)	14	10 (0.32)	16	10 (0.35)	16	9 (0.45)	71
Tanzania	103	11 (0.58)	24	13 (0.18)	6.3	11 (1)	27	12 (0.16)	7.7	12 (0.2)	7.0	12 (0.27)	3.7
Kenya	98	12 (0.55)	18	11 (0.2)	16	12 (0.9)	18	11 (0.2)	17	11 (0.22)	15	19 (0.09)	0
Sudan	77	13 (0.43)	15	16 (0.090)	3.3	13 (0.77)	16	13 (0.14)	9.3	14 (0.15)	9.0	15 (0.18)	6.0
Botswana	57	14 (0.32)	12	17 (0.079)	10	14 (0.56)	12	15 (0.13)	14	14 (0.15)	13	9 (0.45)	13
Zimbabwe	49	15 (0.28)	17	14 (0.12)	25	17 (0.43)	15	16 (0.13)	18	16 (0.14)	17	12 (0.27)	2.0
Burkina Faso	46	16 (0.26)	27	26 (0.023)	3.5	15 (0.49)	28	16 (0.13)	19	18 (0.1)	21	N/A	N/A
Mauritius	46	16 (0.26)	13	12 (0.19)	17	20 (0.32)	10	13 (0.14)	17	13 (0.16)	15	11 (0.36)	18
Cote Ivoire	45	18 (0.25)	12	18 (0.068)	7.0	16 (0.44)	12	16 (0.13)	7.4	17 (0.11)	8.3	19 (0.090)	9.0
Senegal	37	19 (0.21)	26	23 (0.034)	23	18 (0.38)	27	20 (0.079)	20	21 (0.068)	21	N/A	N/A
Zambia	34	20 (0.19)	10	15 (0.10)	4.8	23 (0.28)	11	19 (0.084)	4.3	19 (0.079)	5.9	15 (0.18)	10
Uganda	33	21 (0.19)	12	23 (0.034)	16	19 (0.34)	12	26 (0.045)	13	20 (0.073)	14	N/A	N/A
Dem Rep Congo	30	22 (0.17)	15	23 (0.034)	6.3	22 (0.30)	16	21 (0.067)	9.2	26 (0.034)	7.8	19 (0.090)	0
Mozambique	28	23 (0.16)	11	N/A	N/A	21 (0.31)	11	28 (0.028)	6.8	29 (0.017)	10	N/A	N/A
Benin	25	24 (0.14)	20	19 (0.045)	11	25 (0.24)	22	22 (0.062)	27	23 (0.056)	29	N/A	N/A
Namibia	25	24 (0.14)	10	26 (0.023)	27	24 (0.26)	8.7	27 (0.034)	15	27 (0.028)	13	15 (0.18)	27

TP: number of total articles; *TP R* (%): total number of articles and the percentage of total articles; SP_C *R* (%): rank and percentage of single-country articles in all single-country articles; CP_C *R* (%): rank and percentage of internationally collaborative articles in all internationally collaborative articles; *FP R* (%): rank and the percentage of first-author articles in all first-author articles; *RP R* (%): rank and the percentage of corresponding-author articles in all corresponding-author articles; *SAP R* (%): rank and the percentage of first-author articles in all first-author articles; *CPP*: average number of citations per publication ($CPP = TC_{2021}/TP$); N/A: not available.

In the case of the performance of institutions, 5,876 articles (33% of 17,812 articles) with CPP_{2021} of SPI of 17 came from a single institution while 11,936 articles (67%) with CPP_{2021} of CPI of 19 were collaborative amongst institutions including 3,008 articles (25% of 11,936 institutionally collaborative articles) with CPP_{2021} of 16 were national collaboration among institutions in the same country and 8,928 articles (75% of 11,936 institutionally collaborative articles) with CPP_{2021} of 20 were international collaboration among institutions in the different countries.

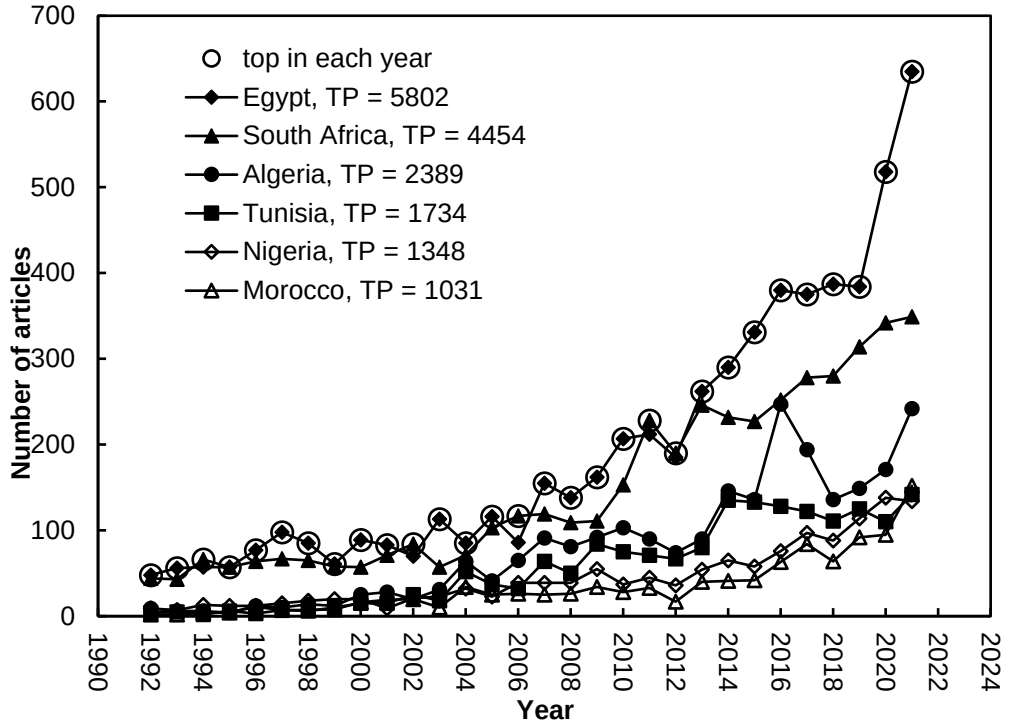

Figure 3. Comparison of development trends among the top six productive Africa countries in chemical engineering with TP > 1,000

Table 4. Top 14 collaborative non-Africa countries with more than 200 collaborative articles with Africa

Country	CP_C	CP_C *R* (%)	CP_C-CPP_{21}	*FP R* (%)	*FP*-CPP_{21}	*RP R* (%)	*RP*-CPP_{21}
France	2,220	1 (25)	24	1 (4,0)	31	1 (5.5)	28
Saudi Arabia	1,319	2 (15)	17	2 (3.3)	14	2 (3.7)	14
China	774	3 (8.7)	19	3 (3.1)	19	3 (3.2)	18
USA	639	4 (7.2)	21	4 (1.4)	22	4 (1.5)	22
the UK	545	5 (6.1)	20	5 (1.3)	21	5 (1.5)	23
Germany	531	6 (5.9)	21	8 (1.1)	24	7 (1.4)	21
India	455	7 (5.1)	24	7 (1.3)	19	6 (1.4)	20
Spain	391	8 (4.4)	25	11 (0.80)	25	9 (1.2)	23
Iran	360	9 (4.0)	26	6 (1.3)	26	10 (1.1)	25
Canada	339	10 (3.8)	16	10 (0.80)	18	11 (1,0)	18
Malaysia	318	11 (3.6)	21	9 (1.1)	26	8 (1.2)	24
Australia	316	12 (3.5)	28	13 (0.68)	33	13 (0.78)	29
Japan	263	13 (2.9)	25	12 (0.70)	25	12 (0.80)	29
Belgium	259	14 (2.9)	21	15 (0.52)	25	15 (0.69)	25

CPC: total number of collaborative articles with Africa; CPC R (%): rank of internationally collaborative articles and percentage in all internationally collaborative articles; FP R (%): rank of first-author articles and percentage in all first-author articles in Africa; RP R (%): rank of corresponding-author articles and percentage in all corresponding-author articles in Africa; CPP21: average number of citations per publication (TC_{2021}/TP).

The results showed that in Africa, collaboration increased citations more than single-institution articles and international collaboration increased citations more than national collaboration. Table 5 shows the top 20 institutions in Africa with six publication indicators: the total number of articles (TP), single-institution articles (SPI), inter-institutionally collaborative articles (CPI), first-author articles (FP), corresponding-author articles (RP), and single-author articles (SAP) Hsu and Ho (2014) as well as their CPP_{2021} Ho and Mukul (2021) were used for the comparison of publication performance.

Table 5. Top 20 productive African countries in chemical engineering field

Institution	*TP*	*TP*		*SP*$_I$		*CP*$_I$		*FP*		*RP*		*SAP*	
		R (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*
Natl Res Ctr, Egy	985	1 (5.5)	16	1 (6.4)	18	1 (5.1)	16	1 (3.7)	17	1 (3.8)	17	1 (5.8)	16
Univ KwaZulu Natal, South Africa	696	2 (3.9)	18	7 (2.5)	11	2 (4.6)	20	6 (1.7)	15	4 (2.0)	13	11 (2.0)	17
Univ Cape Town, South Africa	562	3 (3.2)	24	4 (4.2)	27	4 (2.6)	21	3 (2.2)	24	3 (2.2)	24	33 (0.63)	225
Cairo Univ, Egypt	554	4 (3.1)	16	10 (1.7)	14	3 (3.8)	17	8 (1.4)	13	8 (1.4)	14	4 (2.5)	12
Egyptian Petr Res Inst, Egypt	546	5 (3.1)	14	2 (4.6)	13	6 (2.3)	14	2 (2.5)	13	2 (2.6)	13	2 (4.6)	10
Univ Witwatersrand, South Africa	471	6 (2.6)	17	5 (3.6)	14	7 (2.2)	19	5 (1.8)	17	6 (1.8)	17	9 (2.1)	22
Univ Stellenbosch, South Africa	460	7 (2.6)	24	3 (4.3)	23	11 (1.8)	25	4 (1.9)	22	5 (1.9)	22	22 (0.90)	32
Univ Pretoria, South Africa	405	8 (2.3)	22	6 (2.8)	24	8 (2.0)	20	7 (1.6)	21	7 (1.8)	20	13 (1.8)	17
Ain Shams Univ, Egypt	357	9 (2.0)	15	13 (1.3)	11	5 (2.4)	16	16 (0.74)	11	16 (0.76)	12	7 (2.3)	12
Univ Alexandria, Egypt	329	10 (1.8)	24	8 (2.1)	22	12 (1.7)	25	9 (1.2)	24	9 (1.1)	24	3 (3.6)	25
Univ Johannesburg, South Africa	297	11 (1.7)	23	14 (1.1)	19	9 (1.9)	24	15 (0.75)	18	12 (0.90)	18	128 (0.09)	1.0
Mansoura Univ, Egypt	293	12 (1.6)	14	11 (1.5)	14	13 (1.7)	14	12 (0.81)	13	13 (0.88)	13	14 (1.7)	14
USTHB, Algeria	271	13 (1.5)	21	18 (1.0)	22	10 (1.8)	21	10 (1.0)	19	11 (0.92)	20	128 (0.09)	21
Tanta Univ, Egypt	234	14 (1.3)	28	20 (0.88)	38	16 (1.5)	26	19 (0.58)	34	19 (0.67)	33	17 (1.4)	25
Tshwane Univ Technol, South Africa	229	15 (1.3)	27	35 (0.51)	18	14 (1.7)	28	23 (0.46)	28	21 (0.55)	24	N/A	N/A
Univ Sfax, Tunisia	226	16 (1.3)	17	19 (0.92)	17	19 (1.4)	17	13 (0.80)	18	15 (0.78)	17	85 (0.18)	62
Atom Energy Author, Egypt	224	17 (1.3)	15	8 (2.1)	15	28 (0.85)	16	11 (0.94)	16	10 (1.0)	15	9 (2.1)	12
Zagazig Univ, Egypt	217	18 (1.2)	15	21 (0.85)	9.4	20 (1.4)	17	21 (0.54)	9.0	23 (0.53)	9.2	5 (2.4)	6.4
Alexandria Univ, Egypt	216	19 (1.2)	9.3	29 (0.68)	8.6	17 (1.5)	9.4	18 (0.61)	7.9	18 (0.68)	8.5	50 (0.36)	6.0
Helwan Univ, Egypt	213	20 (1.2)	15	41 (0.43)	14	15 (1.6)	16	31 (0.38)	14	28 (0.42)	14	15 (1.5)	26

TP: total number of articles; *TP R* (%): total number of articles and percentage of total articles; *SP*$_I$ *R* (%): rank and percentage of single-institute articles in all single-institute articles; *CP*$_I$ *R* (%): rank and percentage of inter-institutionally collaborative articles in all inter-institutionally collaborative articles; *FP R* (%): rank and percentage of first-author articles in all first-author articles; *RP R* (%): rank and percentage of corresponding-author articles in all corresponding-author articles; *SAP R* (%): rank and percentage of single-author articles in all single-author articles; *CPP*: average number of citations (TC_{2021}) per publication; N/A: not available

The National Research Centre (Egypt) dominated among the six publication indicators with a TP of 985 articles (5.5% of 17,812 articles), an SPI of 378 articles (6.4% of 5,876 single-institution articles), a CPI of 9,504 articles (5.1% of 11,936 inter-institutionally collaborative articles), an FP of 667 articles (3.7% of 17,812 first-author articles), an RP of 678 articles (3.8% of 17,661 corresponding-author

articles), and an SAP of 64 articles (5.8% of 1,108 single-author articles). Compared to the top 20 institutions in Table 5, the Tanta University (Egypt) had a TP of 234 articles, an SPI of 52 articles, an FP of 182 articles, and an RP of 104 articles, with the greatest of TP-CPP_{2021} of 28, SPI-CPP_{2021} of 38, FP-CPP_{2021} of 34, and RP-CPP_{2021} of 33 respectively. The Tshwane University of Technology (South Africa) had a CPI of 199 articles, with the greatest of CPI-CPP_{2021} of 28. The University of Cape Town (South Africa) had an SP of seven articles, with the greatest of SP-CPP_{2021} of 225. It should be noted that these results are dominated by the Maghreb countries and South Africa. According to the ranking of the best African academics, the universities of these different countries are in the lead because of their level of development. The sub-Saharan countries are still behind the times, and black Africa still has a long way to go to find a place for itself in research.

3.5 The most frequently cited articles

After publication, highly cited publications may or may not have a high impact or visibility (Ho and Kahn, 2014). The number of citations received in the most recent year of 2021 (C_{2021}) may offer readers extra information about the influence of a highly referenced work today (Ho, 2012). When the 16,169 articles published in the Web of Science category of chemical engineering by authors in Africa countries were sorted by TC_{2021}, a different ranking was generated compared to the ranking obtained from the C_{2021} sorting. A total of 6,002 articles (34% of 17,812 articles) did not receive any citation in the most recent year (C_{2021} = 0) and 1,717 (9.6%) articles had no citations from their publishing year until the end of 2021 (TC_{2021} = 0). Moreover, 36% of the top 100 C_{2021} articles were also among the top 100 TC_{2021} articles. Table 6 shows the top 10 articles in chemical engineering field by Africa. The six of the top 10 articles were international collaboration with non-African countries. The three and one of the top 10 single-country articles were published by South Africa and Tunisia, respectively.

Table 6. The top 10 most frequently cited articles in chemical engineering field by Africa.

R (TC_{2021})	*R* (C_{2021})	Title	Country	Reference
1 (1,493)	2 (127)	The Fischer-Tropsch process: 1950-2000	South Africa	Dry (2002)
2 (1,231)	13 (71)	Photocatalytic degradation of various types of dyes (Alizarin S, Crocein Orange G, Methyl Red, Congo Red, Methylene Blue) in water by UV-irradiated titania	France, Tunisia	Lachheb et al. (2002)
3 (612)	6 (92)	Food waste as a valuable Resource for the production of Chemicals, materials and fuels. Current situation and global perspective	China, the UK, Tanzania, Morocco, Greece, Spain	Lin et al. (2013)
4 (600)	14 (70)	Dual role of microalgae: Phycoremediation of domestic wastewater and biomass production for sustainable biofuels production	South Africa	Rawat et al. (2011)
5 (556)	44 (47)	Biodiesel from microalgae: A critical evaluation from laboratory to large scale production	South Africa	Rawat et al. (2013)
6 (515)	189 (26)	Modified activated carbon for the removal of copper, zinc, chromium and cyanide from wastewater	Tunisia	Monser and Adhoum (2002)
7 (468)	7 (88)	Modeling of competitive ultrasonic assisted removal of the dyes - Methylene blue and Safranin-O using Fe_3O_4 nanoparticles	Iran, India, South Africa, Saudi Arabia	Ghaedi et al. (2015)
8 (452)	455 (18)	Preparation and characterization of TiO_2 photocatalysts supported on various rigid supports (glass, quartz and stainless steel). Comparative studies of photocatalytic activity in water purification	France, Spain, Morocco	Fernandez et al. (1995)
9 (422)	8 (87)	Biogenic synthesis of metallic nanoparticles by plant extracts	Ethiopia, South Korea, India	Akhtar et al. (2013)
10 (412)	11 (73)	Removal of hazardous dyes-BR 12 and methyl orange using graphene oxide as an adsorbent from aqueous phase	India, Iran, Saudi Arabia, South Africa	Robati et al. (2016)

The only two classic articles with TC_{2021} of 1,000 or more Long et al. (2014) in the category of chemical engineering in Africa were "The Fischer-Tropsch process: 1950-2000" Dry (2002) by M.E. Dry from

the University of Cape Town in South Africa with a TC_{2021} of 1,493 and "Photocatalytic degradation of various types of dyes (Alizarin S, Crocein Orange G, Methyl Red, Congo Red, Methylene Blue) in water by UV-irradiated titania" Lachheb et al. (2002) by H. Lachheb and other seven authors from Ecole Centrale de Lyon in France and Ecole Nationnale d'Ingénieurs de Gabès (ENIG) in Tunisia with a TC_{2021} of 1,231. Articles by Dry (2002), Lachheb et al. (2002), Lin et al. (2013), Ghaedi et al. (2015), and Akhtar et al. (2013) ranked top ten in both TC_{2021} and C_{2021}.

Figure 4 shows the citation histories of the top ten most frequently cited articles. An article by Fernández et al. (1995) ranked 8th on TC_{2021} with 452 but ranked 455th on C_{2021} with 18. Similarly, an article by Monser and Adhoum (2002) ranked 6th on TC_{2021} with 515 but ranked 189th on C_{2021} with 26. An article by Lachheb et al. (2002) ranked top in chemical engineering in Africa from 2004 to 2007 and 2012. The article by Dry (2002) ranked the top from 2008 to 2011, 2013 to 2018, and 2020. An article by Ghaedi et al. (2015) ranked top in 2019. Furthermore, the article by Karimi-Maleh et al. (2021) had the greatest number of citations with a TC_{2021} of 208 in the publishing year and the most year of 2021 respectively. Articles by Sheldon (2018) with a C_{2021} of 119 (ranked 3rd), Abdelkareem et al. (2018) with a C_{2021} of 100 (ranked 4th), Oliv et al. (2017) with a C_{2021} of 97 (ranked 5th), Das et al. (2019) with a C_{2021} of 80 (ranked 9th), and Li et al. (2020) with a C_{2021} of 76 (ranked 10th) published in recent years do not have high time to accumulate citations but ranked the top ten in 2021.

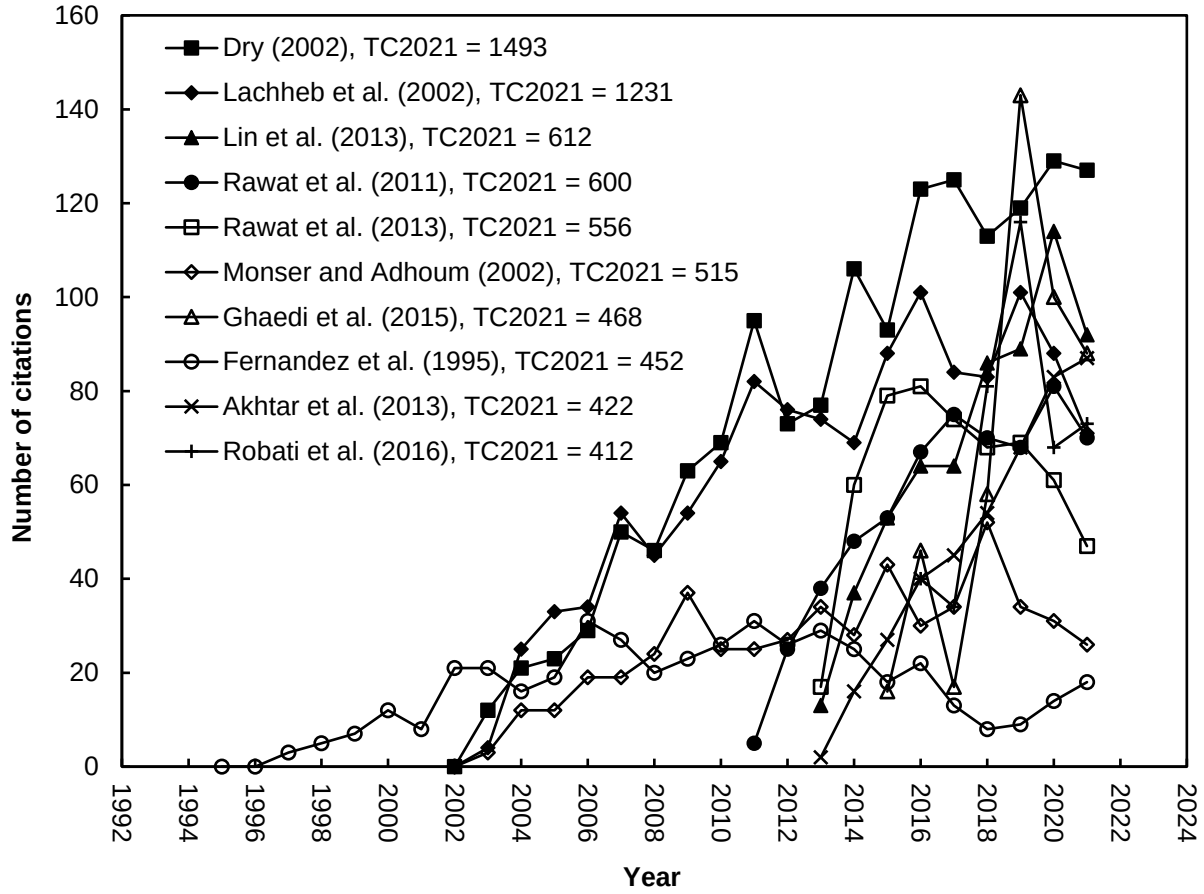

Figure 4. The citation histories of the top ten most frequently cited articles

3.6. Research Focuses

Analysis of used words in publication titles, abstracts, author keywords, and Keywords Plus was proposed for research focuses (Zhang et al., 2010b). In SCI-EXPANDED, 15,259 (86% of 17,812 articles) and 15,569 (87%) articles in the chemical engineering field by Africa contained author

keywords and Keywords Plus information, respectively. Authors have provided keywords in articles that generally include information that authors would be most likely to convey to their readers. The use of keyword analysis and other frequently used author's abstract words as information to find the direction of research has been developed (Mao et al., 2010; Wang and Ho, 2016). Table 7 shows the top 20 most frequently used authors' keywords. The results of word analysis for Africa in chemical engineering show a strong dominance in the field of water treatment. The most frequently used word in the title: removal, water, aqueous, adsorption, carbon, acid, and treatment; author keywords: adsorption, kinetics, desalination, activated carbon, optimization, modeling, wastewater, heavy metals, modelling, wastewater treatment, isotherm, and water treatment were evidence to prove that research in chemical engineering in Africa focused on water treatment especially using adsorption process.

Table 7. The top 20 most frequently used authors keyword.

Author keywords	TP	92-21 R (%)	92-01 R (%)	02-11 R (%)	12-21 R (%)
adsorption	1,036	1 (6.8)	2 (3.0)	1 (4.4)	1 (8.1)
kinetics	459	2 (3.0)	13 (1.3)	3 (2.3)	2 (3.4)
desalination	304	3 (2.0)	6 (2.1)	4 (2.2)	4 (1.9)
activated carbon	286	4 (1.9)	4 (2.5)	13 (1.2)	3 (2.1)
optimization	237	5 (1.6)	49 (0.66)	13 (1.2)	5 (1.8)
modeling	230	6 (1.5)	18 (1.2)	10 (1.4)	6 (1.6)
wastewater	221	7 (1.4)	119 (0.38)	8 (1.4)	7 (1.6)
heavy metals	191	8 (1.3)	119 (0.38)	13 (1.2)	10 (1.4)
modelling	186	9 (1.2)	12 (1.4)	2 (2.8)	35 (0.61)
photocatalysis	179	10 (1.2)	301 (0.19)	55 (0.55)	8 (1.5)
wastewater treatment	178	11 (1.2)	627 (0.095)	22 (0.92)	9 (1.4)
isotherm	165	12 (1.1)	627 (0.095)	45 (0.6)	10 (1.4)
water treatment	155	13 (1.0)	49 (0.66)	67 (0.5)	12 (1.2)
reverse osmosis	154	14 (1.0)	18 (1.2)	12 (1.3)	19 (0.89)
pyrolysis	153	15 (1.0)	1 (3.5)	72 (0.47)	17 (0.94)
nanofiltration	150	16 (1.0)	49 (0.66)	7 (1.4)	22 (0.86)
thermodynamics	150	16 (1.0)	49 (0.66)	61 (0.52)	14 (1.2)
mass transfer	145	18 (1.0)	10 (1.5)	6 (1.5)	29 (0.67)
methylene blue	141	19 (0.92)	N/A	91 (0.42)	13 (1.2)
biodiesel	135	20 (0.88)	N/A	81 (0.45)	15 (1.1)

TP: total number of articles containing the author keywords; *R*: rank in each period; N/A: not available.

According to the work of Wumbu and Ho in 2016 following a bibliometric analysis of drinking water research in Africa, we see that the same newspapers come back in the right positions, which shows that things have not really changed in other areas. The cause of this predominance of research in the field of water can be explained in two ways. First because of the waterborne diseases that strike know times namely cholera, diarrhea, typhoid, bilharzia, dracunculiasis, etc. (Feukam and Yemmafouo, 2020; Sy et al., 2017; Vissin et al., 2016). Secondly, it can be noted that the field of water treatment by adsorption (on activated carbon, clay, biomass), Fenton degradation, etc. does not require large equipment because the implementation of the process hence this dominance because for other areas, sophisticated equipment is needed. Also, Africa has a diversity of biomass whose potential for developing innovative absorbent materials has yet to fully explored. It should also be mentioned that research work requires

funds to carry it out. To finance them, African institutions are called upon to set up projects to submit them to certain local and international donors, most of whom place emphasis on the problems of water purification and the environment.

Conclusion

The work presented in this article was aimed at a bibliometric study of African publications in the field of chemical engineering. From the analysis of the results, it emerges that Africa is developing performance in 14 document types of the 18,509 publications found in Web of Science during 1992 to 2021. The main language for the African Research was English with a percentage of 99.5% of the publications found. 97% of publications represent articles that the work can be grouped into three categories namely multidisciplinary materials science, nanoscience and technology, and physical chemistry, that the works are published in journals of very good quality with a strong dominance with journals specializing in the field of water treatment. The results also indicated the most active journal in chemical engineering in Africa is Desalination and Water Treatment. Speaking of the performance of publications by country and institution, Egypt leads this ranking followed by South Africa and Algeria. Regarding institutions, South African and Egyptian institutions occupy the top 5 of this ranking. It is also good to note that the African work is done with a strong collaboration of the countries of the other continents and the top four collaborators of Africa in the field of chemical engineering are France, Saudi Arabia, the USA and China. This article has shown the progress of research in the field of chemical engineering in Africa from 1992 to 2021 and shows that researchers in this field must also intensify work in other sectors such as access to sustainable energy which is one of the key aspects of a continent's development.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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