Computer Science Research in Nigeria from 1991-2021: A Bibliometric Analysis

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Abstract

The Computer Science research landscape in Nigeria has not received substantial attention tailored toward analyzing the performance of research constituents, conceptual, social, and intellectual structures. Prior studies have looked at the history of Computer Science in Nigeria without examining some key development indexes such as conceptual evolution and funding. This study aims to gather a proper perspective of the development landscape of Computer Science research in Nigeria. Therefore, a bibliometric analysis of 4,333 bibliographic records of Computer Science research in Nigeria in the last 31 years (1991-2021) was carried out. The bibliographic data were extracted from the Scopus database and analyzed using VOSviewer and the bibliometrix R package through the biblioshiny web interface. The findings of this study revealed that Computer Science research in Nigeria has a growth rate of 24.19%. The most developed and well-studied research areas in the Computer Science field in Nigeria are machine learning, data mining, and deep learning. The social structure analysis result revealed that there is a need for improved international collaborations. The funding analysis result showed that Computer Science research in Nigeria is under-funded. The findings of this study will be useful for researchers conducting Computer Science related research in Nigeria.

Keywords: Bibliometric Analysis, Computer Science, Bibliometrix, VOSviewer, Science Mapping, Nigeria, Biblioshiny

1 Introduction

In 1965, the IBM world trade corporation donated the IBM African Education Centre established in 1963 to the University of Ibadan (Anyanwu, 1978). This marked the beginning of computer education in Nigeria. The premier university, the University of Ibadan established in 1948 as one of the colleges of the University of London established the department of Computer Science in 1974 (University of Ibadan, n.d.) two years after the University of Ife (now Obafemi Awolowo University, ile-ife) started the degree programme in Computer Science (Anyanwu, 1978). The University of Nigeria, Nsukka, started offering Computer Science as a combined degree with Mathematics, Physics, and Statistics in 1975 (University of Nigeria, n.d.). Constructive research in Computer Science in Nigeria could not have started until some of the first-generation universities in Nigeria started a postgraduate programme save for a few Nigerians that studied Computer Science at the postgraduate level in universities abroad and conducted research in this field during the early years. University of Nigeria, Nsukka, established in 1960 started a Masters of Science programme in Computer Science in 1991 and Ph.D. in computer science programme in 2007 (University of Nigeria, n.d.). The postgraduate programme in Computer Science began at the University of Ibadan in 2000 (University of Ibadan, n.d.). Although the span of Computer Science research in Nigeria is relatively short, it has continued to grow in importance and popularity. The future improvements in productivity and quality of life are certainly going to be driven by the applications of Computer Science and its sub-fields such as artificial intelligence, the internet of things, blockchain technology, machine learning, big data, and so on. Therefore, to advance the field of computer science, it is important to understand its landscape in terms of research and scientific contributions. The landscape of Computer Science research had been examined in other countries (Bakri & Willett, 2011; Gaskó et al., 2016; Gupta & Dhawan, 2017; Hew et al., 2021; Ibáñez et al., 2013; Parry, 2019; Uddin et al., 2015), in Africa (Harsh et al., 2021) and globally (Fiala & Tutoky, 2017). However, from available records, this is the first study to look at the developments and patterns of Computer Science research in Nigeria. This study aims to examine the landscape of developments in Computer Science research in the last 31 years (1991-2021) in a bid to answer the research questions enumerated in section 3.1. The authors believe that answers to these questions regarding the impact of a publication based on the number of citations and other indicators could help to measure how influential research is, how its contributions have been improved, and what constitutes future research direction in the area of topics, themes, and the publications. Meanwhile, answers to funding patterns could inform the need for improved funding, increased productivity, and research growth. In addition, answers to how Computer Science research evolved over the years will provide insights into the trending topics and new research focus. Furthermore, Bibliometric analysis, which is the methodology for this study has been used to uncover intellectual and social structures and development patterns in different domains (Friday Joseph Agbo et al., 2021a; Ampese et al., 2022; Choijil et al., 2022). This methodology is quite efficient when the scope of the review is broad and large data is required. In comparison with systematic review its results

are more reliable as systematic review is susceptible to bias interpretation by the researcher. However, the two methods can be used complementarily (Liang et al., 2021).

2 Theoretical background

Investigation into the development of a scientific field is not new as literature has shown its relevance over the last five decades (Baranson, 1967). Recent studies are trying to understand different characteristics that measure the growth and progression of scientific fields (Agbo et al., 2021b; Ampese et al., 2022; Choijil et al., 2022). While many scientometrics exists, which scholars have used to evaluate the growth of a field, one prominent metric is the citation score of the academic literature (Jurgens et al., 2018). A citation score is often assumed to provide insight into how impactful an article is. When collectively evaluated, citation scores of articles within a field can reflect the impact of such a field (Aksnes et al., 2019). Although many studies have appraised the investigation of scientific impact in a field through the lenses of citation score, the number of article production and other indicators (Aksnes et al., 2019; Régibeau & Rockett, n.d.), limitations of this approach have been argued (Haustein & Larivière, 2015).

Notwithstanding, scholars have particularly investigated contextual phenomena surrounding the growth and development of computer science using a bibliometric approach. The study by Bakri and Willett (2011) examined how Computer Science faculty in Malaysia fared by analyzing their publications from Scopus and Web of Science databases. One unique finding from Bakri and Willet's study was the fact their research impact was low due to the over-concentration of faculty in teaching Computer Science and paying less attention to research and innovation. Similarly, Gaskó et al. (2016) investigated how Romanian Computer Science scholars have been collaborating by analyzing their bibliometric co-authorship network. Their study, which aimed to improve the methods of analyzing collaboration networks, unravels practices in the field that the kind of sense of community that exists among scholars. Furthermore, Gupta and Dhawan (2017) examined the role scholars and research organizations have played in advancing Computer Science research in India. Their study discovered that teamwork and multi-institutional collaboration were weak and scholars must be motivated to strengthen Computer Science research in that context.

Indeed, examining the evolution of computing and innovation in the context of developing countries exposes several factors to understanding the present and the future. A study conducted by Krishnan in 2003 revealed how India, as a developing country, had gained the industrial and human capacity to propel software development and information technology-based innovations for the country's prosperity but would require liberalization, policy formulation, and other support from the government (Krishnan, 2003). The growing and rapid changes in technology have influenced computing globally. Besides, research and development remain one of the major drivers of national development in major countries in the world (Tudor & Sova, 2022). A recent article adopted a bibliometric approach to uncover research activities from the context of sub-Saharan Africa (Harsh et al., 2021). Although the study by Harsh and colleagues focused on scientific research in general from a region in Africa, it revealed that Nigeria is among the first five countries advancing Computer Science research. However, our research focuses on Nigeria to deepen the knowledge in this field. Moreover, this type of study is important as developed

nations have shown how research and innovation are key to achieving sustainable development goals (European Commission, 2020).

3 Methodology

Bibliometric analysis is the method used in this study to carry out performance analysis of research constituents such as authors, sources, and affiliations, and science mapping of conceptual, social, and intellectual structures of Computer Science research in Nigeria. Biblioshiny, the web interface provided for the bibliometrix R package (Aria & Cuccurullo, 2017), and VOSviewer version 1.6.17 were used to carry out the bibliometric analysis. The choice of these software was informed by their robust analytical features and powerful visualization capabilities.

3.1 Study design

This study was designed to survey the development landscape of Computer Science research in the last 31 years specifically from 1991 to 2021. The specific questions answered by this study are:

RQ1: What is the scientific production, growth rate, and doubling time of Computer Science research in Nigeria?

RQ2: Who are the most relevant authors, sources, and institutions?

RQ3: What is the pattern of authors, institutions, and country collaboration of Computer Science research in Nigeria like?

RQ4: How has Computer Science research in Nigeria evolved in the last 31 years?

RQ5: Which are the most important documents in Computer Science research in Nigeria in the last 31 years?

RQ6: What is the funding pattern for Computer Science research in Nigeria?

3.2 Data collection

A total of 9,020 bibliographic data were extracted on the 27th of January 2022 from the Scopus database. Scopus is a bibliographic database owned by Elsevier. The choice of Scopus as the bibliographic data source for this study was informed by the wider coverage (Pranckutė, 2021) in comparison to Web of Science which is also a giant in the league of publication metadata providers. Also, studies (Bar-Ilan, 2018; Grégoire et al., 2016; Martín-Martín et al., 2021) have confirmed the high overlap of information between the two databases with Scopus having more distinct records (Singh et al., 2021). This research was targeted at looking at the landscape of development of Computer Science research in the last 31 years (1991 - 2021) in the context of Nigeria. However, it is not possible to extract more than 2000 bibliographic data from Scopus at once therefore, an advanced search query was used to break the search by year such that the search result is not greater than 2000 records. The document search query was defined to search by subject "Computer Science" and affiliation country "Nigeria" with limitation to the year of

interest. The search query and the total number of results extracted for the years are presented in Table 1.

Table 1. Queries and the total number of documents resulting from each query

S/N	Query	Year	No of Documents
1	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2021)	2021	1,166
2	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2020)	2020	1,140
3	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2019)	2019	1,366
4	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017)	2017-2018	1,667
5	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013)	2013-2016	1,549
6	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND PUBYEAR > 1997 AND PUBYEAR < 2013	1998-2012	1,990
7	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND PUBYEAR > 1990 AND PUBYEAR < 1998	1991-1997	142

Table 1b. Re-Queries

S/N	Query	Year	No of Documents
x	SUBJAREA ("COMP") AND AFFILCOUNTRY ("Nigeria") AND (LIMIT-TO (PUBYEAR,2022))		1564
1	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2021)	2021	1,411
2	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2020)	2020	1,195
3	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2019)	2019	1,405
4	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017)	2017-2018	1,681
5	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013)	2013-2016	1,266
6	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND PUBYEAR > 1997 AND PUBYEAR < 2013	1998-2012	1,990
7	SUBJ (“COMP”) AND AFFILCOUNTRY (“Nigeria”) AND PUBYEAR > 1990 AND PUBYEAR < 1998	1991-1997	142

The queries resulted in 7 BibTex files that were converted to a .xlsx files through biblioshiny for convenient merging. The records were filtered such that Editorial, Note, Letter Retracted document types, records with missing values, duplicates, and records that were not closely related to the field of Computer Science were removed using MS-excel. A single document containing the merged records was saved as a .csv file and uploaded to the biblioshiny web interface. Therefore, 4,333 data that met the inclusion criteria were analyzed in this study. The unintelligent search result produced by the query was because Scopus uses a source-based subject classification (Singh et al., 2021). Hence, a source that is classified as being in a particular subject area may publish documents in a related field but not closely related to the subject area. Although the data collected may not include all Computer Science publications by researchers based in Nigeria, the data is quite representative of the possible total publications within the period of interest. The summary of the data collected and analyzed is presented in Table 2.

Table 2. Summary of the analyzed dataset

Description	**Results**
Timespan	1991:2021
Sources (Journals, Books, etc)	1,209
Documents	4,333
Average years from publication	5.29
Average citations per document	4.377
Average citations per year per document	0.8079
References	123,277
Document types	
Article	1,824
Book	5
book chapter	163
conference paper	2,241
Erratum	5
Review	95
Document contents	
Keywords Plus (ID)	19,023
Author's Keywords (DE)	12,386
AUTHORS	
Authors	8,139
Author Appearances	15,861
Authors of single-authored documents	263
Authors of multi-authored documents	7,876

Authors collaboration	
Single-authored documents	346
Documents per Author	0.532
Authors per Document	1.88
Co-Authors per Documents	3.66
Collaboration Index	1.98

Fifty-one (51) percent of the total number of documents published from 1991 to 2021 are conference papers while forty-two (42) percent (1,824) are journal articles (Table 2).

4 Results and Discussion

4.1 What is the scientific production, growth rate, and doubling time of Computer Science research in Nigeria?

The scientific production of publications of Computer Science research peaked at a total of 4,333 in 2021 with the highest number of annual productions recorded in 2019 (Figure 1) representing 16.89% (732) (Table 3) of the total number of publications. Figure 1 also revealed that there was a sharp drop in the production of publications in 2020; this could be a result of the COVID-19 pandemic.

The growth rate is a measure of the change in production either increasing or decreasing over time. It is an important measure as it helps to forecast the future of Computer Science research in Nigeria in terms of publication production. In Table 3, the analysis of the annual growth rate and the doubling time of scientific production in this field is presented. The doubling time is a measure to determine how long it will take for the number of productions to double. It can be calculated using the "Rule of 70" thus:

$$Doubling\ Time = \frac{0.693}{RGR} \quad (1)$$

where 0.693 is the natural log of 2 which is approximately 0.7 (70%). RGR is the relative growth rate which can be determined as:

$$RGR = \frac{\ln(W_2) - \ln(W_1)}{T_2 - T_1} \quad (2)$$

where:

W_1 is the initial number of publications;

W_2 is the final number of publications over a time interval;

$T_2 - T_1$ is the time difference between the initial and final number of publications.

Table 3. Growth rate and doubling time of Computer Science research in Nigeria

S/N	Year	No. of Publications Per Year	Percentage of Publications Per year	Cummulative Growth of Publications Per Year	Percentage Cummulative Growth of Publications Per Year	Annual Growth Rate (AGR) of Publications (%)	Natural Log of the Initial Cummulative Growth of Publications Per Year (W1)	Natural Log of the Final Cummulative Growth of Publications Per Year Over a Time Interval (W2)	Relative Growth Rate (RGR) of Publications Per Year	Doubling time (DT) of Publications Per Year
1	1991	1	0.02	1	0.02			0.00		
2	1992	3	0.07	4	0.09	200.0	0.00	1.39	1.39	0.50
3	1993	5	0.12	9	0.21	66.7	1.39	2.20	0.81	0.85
4	1994	2	0.05	11	0.25	-60.0	2.20	2.40	0.20	3.45
5	1995	3	0.07	14	0.32	50.0	2.40	2.64	0.24	2.87
6	1996	6	0.14	20	0.46	100.0	2.64	3.00	0.36	1.94
7	1997	16	0.37	36	0.83	166.7	3.00	3.58	0.59	1.18
8	1998	7	0.16	43	0.99	-56.3	3.58	3.76	0.18	3.90
9	1999	6	0.14	49	1.13	-14.3	3.76	3.89	0.13	5.31
10	2000	8	0.18	57	1.32	33.3	3.89	4.04	0.15	4.58
11	2001	9	0.21	66	1.52	12.5	4.04	4.19	0.15	4.73
12	2002	7	0.16	73	1.68	-22.2	4.19	4.29	0.10	6.87
13	2003	14	0.32	87	2.01	100.0	4.29	4.47	0.18	3.95
14	2004	15	0.35	102	2.35	7.1	4.47	4.62	0.16	4.36
15	2005	25	0.58	127	2.93	66.7	4.62	4.84	0.22	3.16
16	2006	30	0.69	157	3.62	20.0	4.84	5.06	0.21	3.27
17	2007	41	0.95	198	4.57	36.7	5.06	5.29	0.23	2.99
18	2008	46	1.06	244	5.63	12.2	5.29	5.50	0.21	3.32
19	2009	94	2.17	338	7.80	104.3	5.50	5.82	0.33	2.13
20	2010	86	1.98	424	9.79	-8.5	5.82	6.05	0.23	3.06
21	2011	131	3.02	555	12.81	52.3	6.05	6.32	0.27	2.57
22	2012	104	2.40	659	15.21	-20.6	6.32	6.49	0.17	4.03
23	2013	130	3.00	789	18.21	25.0	6.49	6.67	0.18	3.85
24	2014	209	4.82	998	23.03	60.8	6.67	6.91	0.23	2.95
25	2015	217	5.01	1,215	28.04	3.8	6.91	7.10	0.20	3.52
26	2016	291	6.72	1,506	34.76	34.1	7.10	7.32	0.21	3.23
27	2017	312	7.20	1,818	41.96	7.2	7.32	7.51	0.19	3.68
28	2018	484	11.17	2,302	53.13	55.1	7.51	7.74	0.24	2.94
29	2019	732	16.89	3,034	70.02	51.2	7.74	8.02	0.28	2.51

30	2020	635	14.65	3,669	84.68	-13.3	8.02	8.21	0.19	3.65
31	2021	664	15.32	4,333	100.00	4.6	8.21	8.37	0.17	4.17
		4,333	**100**							

The highest and lowest annual growth rates were recorded in 1992 (200.0) and 1994 (-60.0) with a relative growth rate (Eq. (2)) of 0.31 and 0.12 respectively. The total number of publications produced in 2021 is expected to double in 4 years.

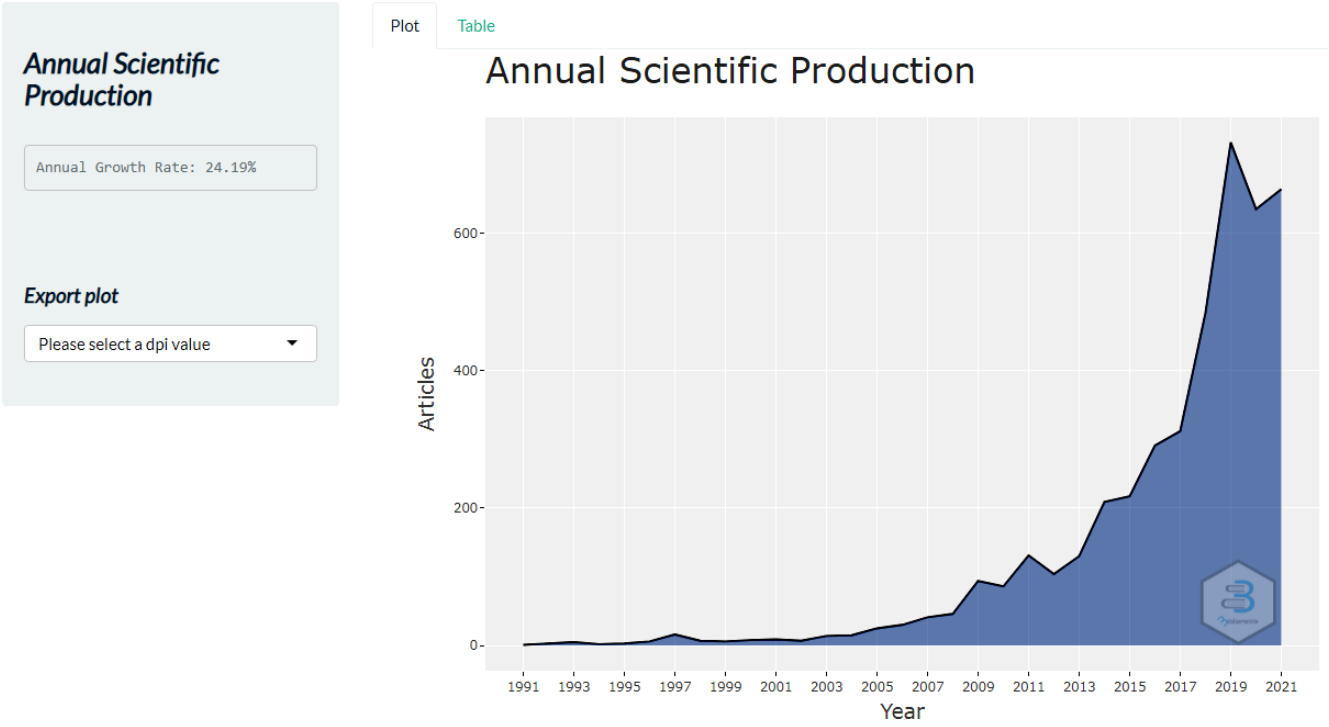

Figure 1. Annual Scientific Production of Computer Science Research in Nigeria from 1991 to 2021

The compound annual growth rate (Eq. (3)) of scientific production of Computer Science research is 24.19% as shown in Figure 1**.**

$$Compound\ Annual\ Growth\ Rate = \left(\frac{\omega}{\alpha}\right)^{\left(\frac{1}{\rho-1}\right)-1} \quad (3)$$

α is the total number of publications produced at the start year, ω the total number of publications produced at the end year, and ρ is the number of years covered.

Table 4 presents the time series analysis result of the publication trends of Computer Science research from 1991 to 2021. Time series analysis is a statistical technique for analyzing sequences of data generated over a steady time interval in a bid to forecast future trends based on the existing data.

Table 4. Time-series analysis of publications in Computer Science research in Nigeria

S/N	Year	Publications (Y)	X	X^2	XY
1	1991	1	-15	225	-15
2	1992	3	-14	196	-42
3	1993	5	-13	169	-65
4	1994	2	-12	144	-24

5	1995	3	-11	121	-33
6	1996	6	-10	100	-60
7	1997	16	-9	81	-144
8	1998	7	-8	64	-56
9	1999	6	-7	49	-42
10	2000	8	-6	36	-48
11	2001	9	-5	25	-45
12	2002	7	-4	16	-28
13	2003	14	-3	9	-42
14	2004	15	-2	4	-30
15	2005	25	-1	1	-25
16	2006	30	0	0	0
17	2007	41	1	1	41
18	2008	46	2	4	92
19	2009	94	3	9	282
20	2010	86	4	16	344
21	2011	131	5	25	655
22	2012	104	6	36	624
23	2013	130	7	49	910
24	2014	209	8	64	1,672
25	2015	217	9	81	1,953
26	2016	291	10	100	2,910
27	2017	312	11	121	3,432
28	2018	484	12	144	5,808
29	2019	732	13	169	9,516
30	2020	635	14	196	8,890
31	2021	664	15	225	9,960
		4,333	**0**	**2,480**	**46,390**

$$Yc = a + bX \qquad (4)$$

$\sum X = 0$

$a = \frac{\sum Y}{N} = \frac{4333}{31} = 139.77$

$b = \frac{\sum XY}{\sum X^2} = \frac{46390}{2480} = 18.71$

Estimated number of publications in 2026 = 139.77 + (18.71*(2026-2001)) = 607.42

Estimated number of publications in 2031 = 139.77 + (18.71*(2031-2001)) = 700.94

Estimated number of publications in 2041 = 139.77 + (18.71*(2041-2001)) = 888.00

Estimated number of publications in 2051 = 139.77 + (18.71*(2051-2001)) = 1075.06

Using Eq. (4) the estimated number of publications; 607.42, 700.94, 888.00, and 1075.06 for the future years 2026, 2031, 2041, and 2051 respectively were forecasted. The result

revealed a steady increase in the growth of Computer Science publications in the future years.

4.2 Who are the most relevant authors, sources, and institutions?

The top 15 most relevant authors in this field based on the number of documents published and author contribution to each document are presented in Table 5. The most relevant author in Computer Science research in Nigeria is Misra Sanjay from Covenant University with 273 publications and 66.99 articles fractionalized. Article fractionalized is a measure determined by fractional counting of the author's contribution to a publication. The fractionalized score of an author in an n-authored publication is 1/n. Therefore, the sum of this fraction for all documents by this author is the number of articles fractionalized. Misra Sanjay has an H-index of 16 and a Total Citation (TC) count of 1,346. His research in this field spans 11 years. Awotunde J. B. is the 12th most relevant author in this field with 30 publications and a total citation count of 98. His earliest document in this field was in 2020 and he has the lowest score for articles fractionalized. This means that he has more multi-authored documents compared to Adeshina with 30 publications and Folorunso, Aderounmu, and Daramola with less than 30 publications but a higher measure of articles fractionalized. Aderounmu G. A. from Obafemi Awolowo University has the longest research span of 19 years (2002-2021) in this field on the top 10 list. He has 28 publications, 8.20 articles fractionalized and a total citation count of 74. The top 15 most relevant authors list is dominated by researchers from Covenant University.

Table 5. Top 15 most relevant authors in Computer Science research in Nigeria

S/N	Authors	Articles	Articles Fraction-alized	H-index	Total Citations	Year of First Publication	Affiliation
1	Misra S.	273	66.99	16	1,346	2010	Covenant University, Ota
2	Atayero A. A.	71	19.63	10	363	2005	Covenant University, Ota
3	Chiroma H.	52	9.36	13	1,008	2014	Federal College of Education (Technical), Gombe
4	Popoola S. I.	50	9.83	10	346	2016	Covenant University, Ota
5	Adewumi A.	45	11.14	7	176	2004	Covenant University, Ota
6	Ahuja R.	39	7.45	7	118	2018	Covenant University, Ota
7	Odun-Ayo I.	36	10.59	7	191	2017	Covenant University, Ota
8	Aibinu A. M.	33	7.64	8	166	2014	Federal University of Technology, Minna
9	Ogundokun R. O.	33	7.54	7	114	2018	Landmark University, Omu-Aran

10	Abdulhamid S. M.	31	7.41	12	573	2014	Federal University of Technology, Minna
11	Adeshina S. A.	30	9.62	4	57	2014	Nile University, Abuja
12	Awotunde JB	30	6.70	6	98	2020	University of Ilorin, Ilorin
13	Folorunso O.	29	9.02	6	126	2006	Federal University of Agriculture, Abeokuta
14	Aderounmu G. A.	28	8.20	5	74	2002	Obafemi Awolowo University, Ile-ife
15	Daramola O.	28	9.62	6	157	2012	Covenant University, Ota

The top 10 most relevant sources in terms of the number of documents published in this field are presented in Figure 2. Forty percent of the top 10 sources are conference proceedings while the remaining 60% are journals. It can be observed in Figure 2 that Lecture Notes in Engineering and Computer Science has the highest number of publications (n=188) in this dataset and from the available data, it has an h-index of 8 and a total citation of 300. The most impactful source is IEEE Access with the highest h-index of 16 and a total citation count of 1,384. However, only 85 documents in the dataset were published by this journal. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) has the second-highest number of publications (n=168; Figure 2) in this field, it has an h-index of 11 and a total citation count of 730.

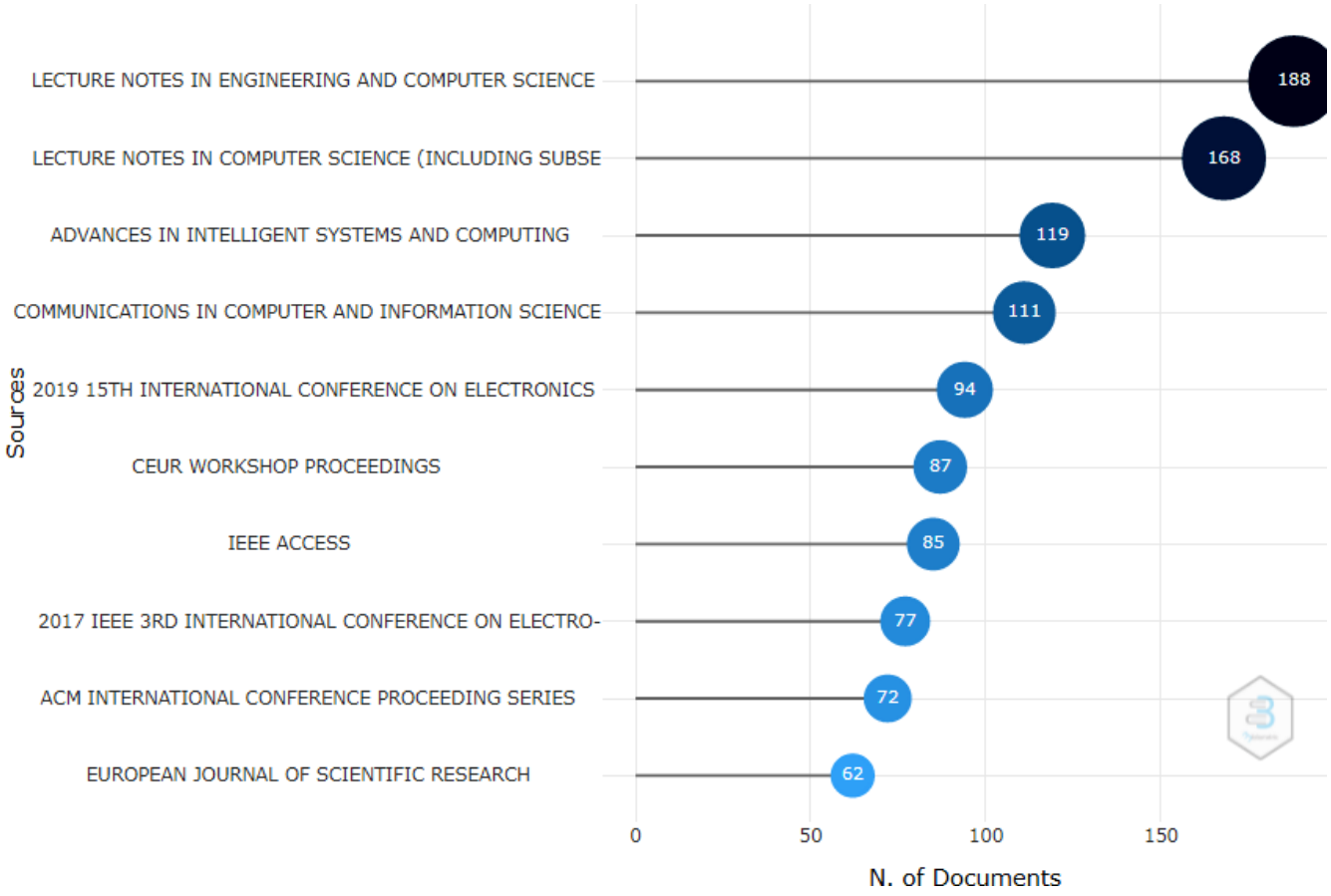

Figure 2. Top 10 Most Relevant Sources in the Field. The number of publications determines the intensity of the colour of the ball and its size; deeper colour and bigger size indicate a higher number of publications.

The top 10 most relevant institutions in terms of the number of documents produced are presented in Table 6. Covenant University, a private university located in the southwestern part of Nigeria tops the list with a total of 460 publications. The university is ranked the 3rd best university in Nigeria, the overall best Nigerian university in research, and also the best Nigerian university in Computer Science research in 2022, (Times Higher Education, 2022), which corroborates the finding of this study. Followed but not closely is the University of Ilorin in second place with 181 publications. This University is the 4th best university in Nigeria according to Times Higher Education world university ranking. The University of Ibadan is in third place with 148 publications in this field. The university is ranked the overall best university in Nigeria in 2022 (Times Higher Education, 2022).

Table 6. Top 10 most relevant institutions in Computer Science research in Nigeria

S/N	Institutions	Geopolitical Zone	No. of Documents
1	Covenant University, Ota	South West	460
2	University of Ilorin, Ilorin	North Central	181
3	University of Ibadan, Ibadan	South West	148
4	University of Lagos, Lagos	South West	136
5	University of Nigeria, Nsukka	South East	127

6	Obafemi Awolowo University, Ile-ife	South West	111
7	Ahmadu Bello University, Zaria	North West	96
8	Landmark University, Omu-Aran	North Central	95
9	Bayero University, Kano	North West	81
10	Federal University of Agriculture, Abeokuta	South West	58

There are thirty-six (36) states in Nigeria grouped into six (6) geopolitical zones; North Central (6), North East (6), North West (7), South East (5), South-South (6), and South West (6). Fifty percent (50%) of the top 10 universities in Computer Science research are located in the southwestern part of Nigeria, 10% in the southeast, and 20% each in the north-central and northwest. No university from the south-south and northeastern part of Nigeria is in the top 10 list.

Covenant University and Landmark University are private universities founded by David Oyedepo (Covenant Univesity, n.d.; Landmark University, n.d.) in 2002 and 2011 respectively. The other 8 universities on the top 10 list are owned by the Federal Government of Nigeria. None of the 57 state universities in Nigeria made the top 10 list.

4.3 What is the pattern of authors, institutions, and country collaboration of Computer Science research in Nigeria like?

The social structure of Computer Science research in Nigeria was analyzed through the collaboration networks of authors, institutions, and countries, the results are presented in Figures 3, 4, and 5 respectively. The network graphs in Figures 3, 4, and 5 are based on the Louvain clustering algorithm developed by Blondel et al. (2008). The following parameters were set on the biblioshiny interface to generate the network graphs; the number of nodes =50, the minimum number of edges=2, normalization = "association", remove isolated nodes = "yes", layout = "Automatic Layout", clustering algorithm= "Louvain algorithm". In the collaboration network map, the nodes represent the authors, institutions, and countries while the edges indicate one or more established collaborations between two connected nodes. The weight or thickness of the edges indicates the degree of collaboration. The size of the nodes indicates how important the node is within the network. The authors, institutions, and countries are grouped by clusters of different colours.

In Figure 3, the author's collaboration network map is shown. The network is a sparse network which revealed that generally author collaboration in this field is low and this corroborates the collaboration index of 1.98 presented in Table 2. In the network, the red cluster is the most profound. The analysis result shows that Misra S. has a betweenness centrality of 238.36 which makes him the most influential author in that cluster. Betweenness centrality is a measure of how often a node facilitates connections with other nodes (Brandes, 2008). Atayero A. A. and Ayo C. K. are the most influential authors in clusters of blue and brown with a betweenness centrality of 17.55 and 22.48 respectively. The weight of the edges connecting Misra to authors such as Ahuja R, Adewumi A, Soto R, Crawford B. shows a higher frequency of collaborations. There is also a strong collaboration between Popoola S. I. and Atayero A. A. in the blue cluster as indicated by the weight of the edges. Misra S, Odun-ayo I, Ahuja R, Omoregbe N., and Adewumi A. are based in Covenant University, Nigeria, and have established international collaborations with

Crawford B, Soto R both from Pontifica Catholic University, Chile, and Damaeviius R. from Basilicata University, Italy, Gervasi O. from the University of Perugia, Italy, Damasevicius R from Vytautas University, Lithuania and Maskeliunas R. from the Kaunas University of Technology, Lithuania.

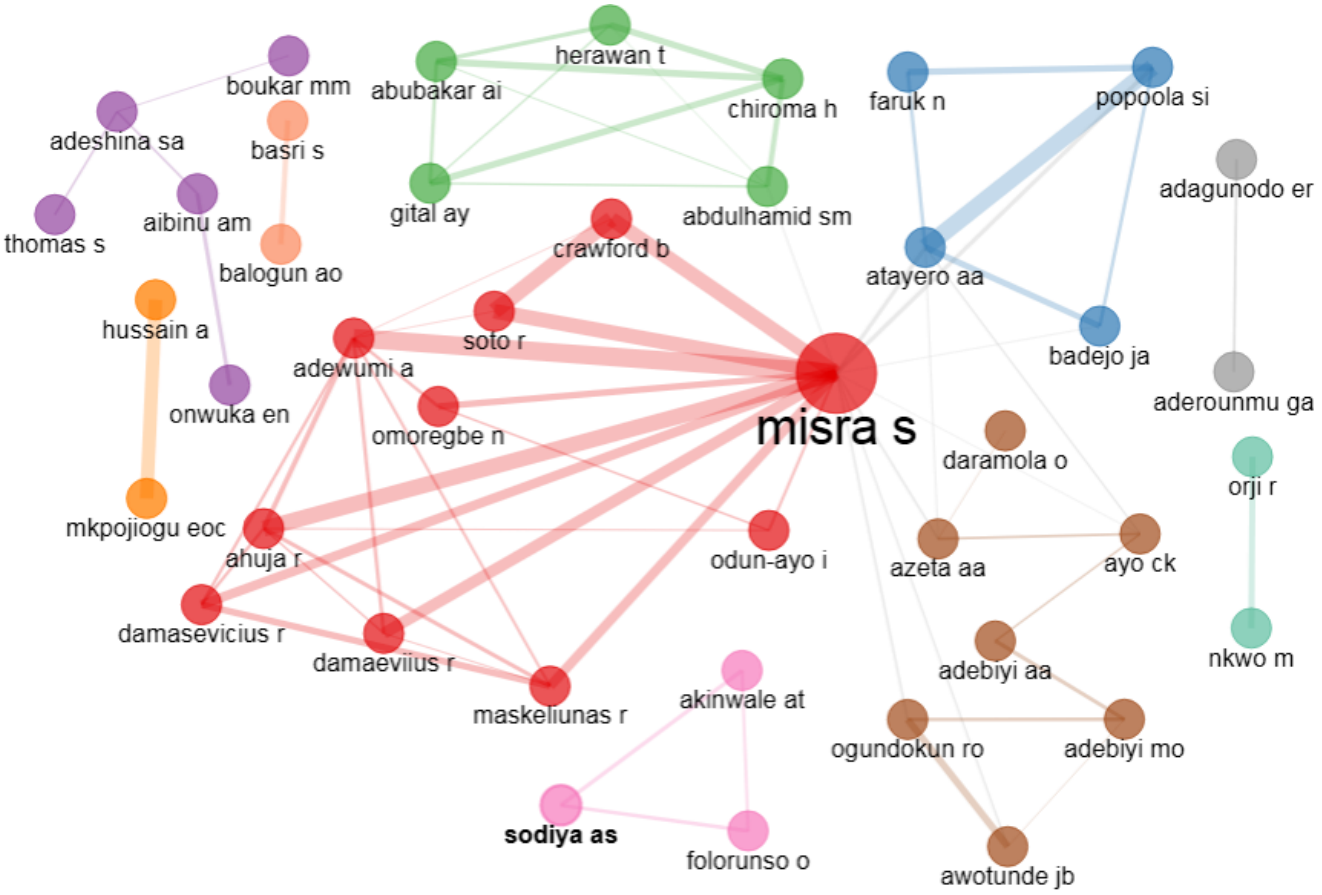

Figure 3. Author collaboration network map. The vertices show that the connected authors have published at least two documents together. The size of the nodes indicates the number of documents published by the author in collaboration, and the thickness of the vertices indicates the frequency of collaboration; a thicker vertex means more collaborations between the connected nodes.

Aderounmu G. A. and Adagunodo E. R. (grey cluster) are based in Obafemi Awolowo University, Osun State. Ogundokun and Awotude's network (brown cluster) is also within the same state; Kwara State. This shows that authors within the same region have a high probability of collaboration. In the purple cluster, Onwuka E. N and Aibinu A. M. are based at the Federal University of Technology, Minna while Adeshina S. A. and Thomas S. are based at Nile University, Abuja. The author collaboration index of 1.98 reported in Table 2 agree with the sparse author collaboration network which indicates the need for improved local and international collaborations.

The pattern of institutional collaboration in Computer Science research in Nigeria is shown in Figure 4. There are five (5) clusters depicted in colours Blue, Purple, Green, Orange, and Red. The most important node in the network represents Covenant University, Nigeria (Red Cluster) with a betweenness centrality of 353.79. The institution has established

strong local and international collaborations with Atilim University Turkey, Durban University, South Africa, Kaunas University of Technology, Lithuania, and Pontifica Catholic University, Chile as indicated by the weight of the connecting edges. In the purple cluster, the premier university in Nigeria, the University of Ibadan established an international collaboration with Chongqing Three Gorges University, China. Covenant University, Ota (Red cluster), and Landmark University, Omu-Aran (Green Cluster) also have well-established collaborations with the University of Ilorin (Green Cluster). The majority of the connecting edges are thin, indicating that institutional collaborations are not well established in this field and collaboration patterns are largely influenced by geographic proximity.

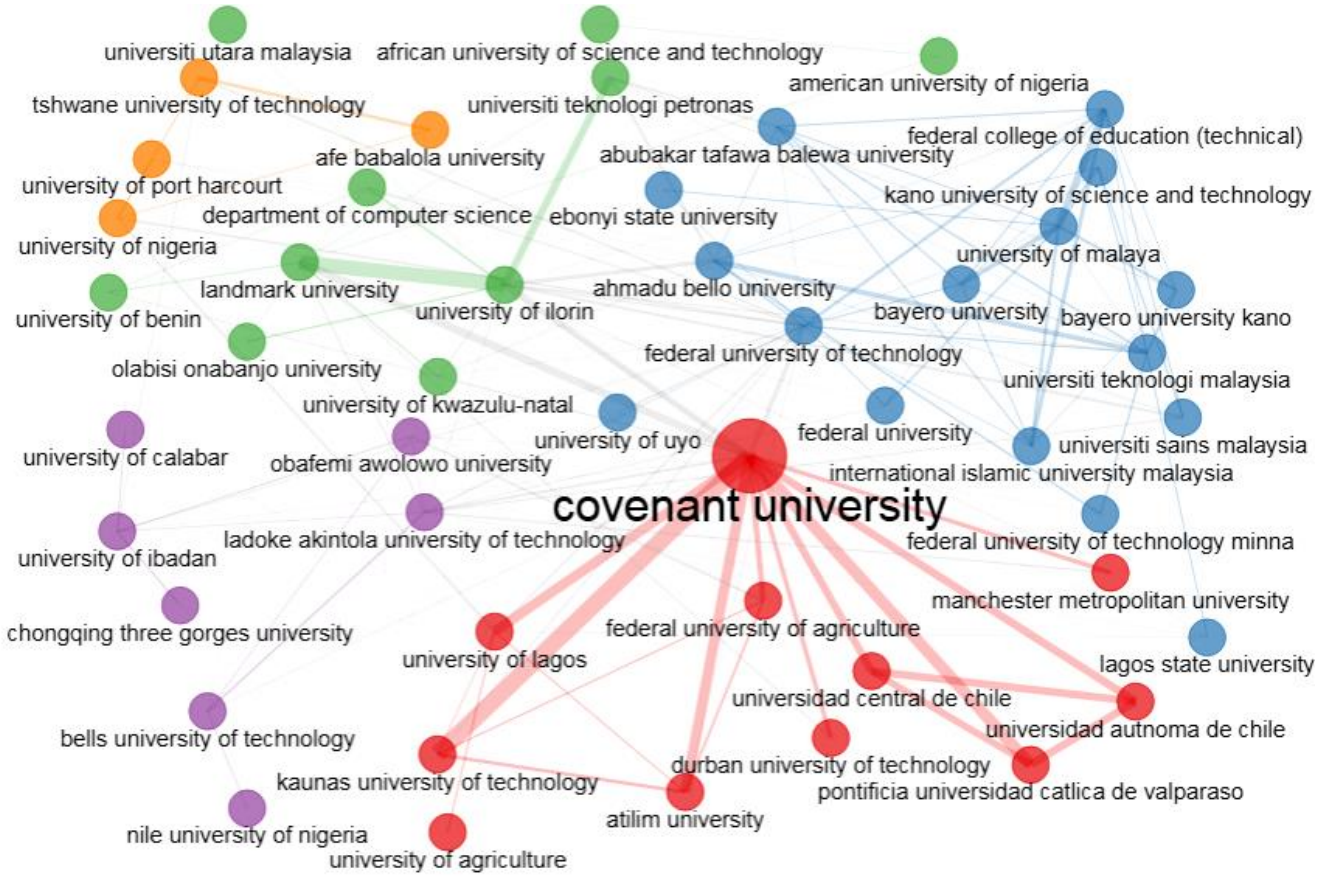

Figure 4. Institutional collaboration network map. The connection between nodes indicates institutional collaboration. The thickness of the vertices indicates the frequency of collaboration, and a thicker vertex means more collaborations between the connected institutions.

In Figure 5 the collaboration pattern of Computer Science researchers with other countries is shown. The available data shows that collaborations exist between Nigeria and 94 other countries. The top 5 well-established collaborations are with Malaysia, the United Kingdom, South Africa, the United States of America, and India with a collaboration frequency of 628, 299, 245, 176, and 142 respectively. These strong collaborations are indicated by the thickness of the edges connecting the nodes. It can be observed that the edge between Nigeria and Malaysia is the most pronounced indicating strong collaboration between the two countries. The well-established collaboration with Malaysia must have been influenced

by the fact that many Nigerian academics in the field of Computer Science carried out their graduate studies in Malaysia. The number of Nigerians studying in Malaysia has increased in recent times due to the relatively affordable cost of schooling, especially when compared to the United Kingdom which used to be the preferred country by most Nigerians for graduate studies (Page, 2021).

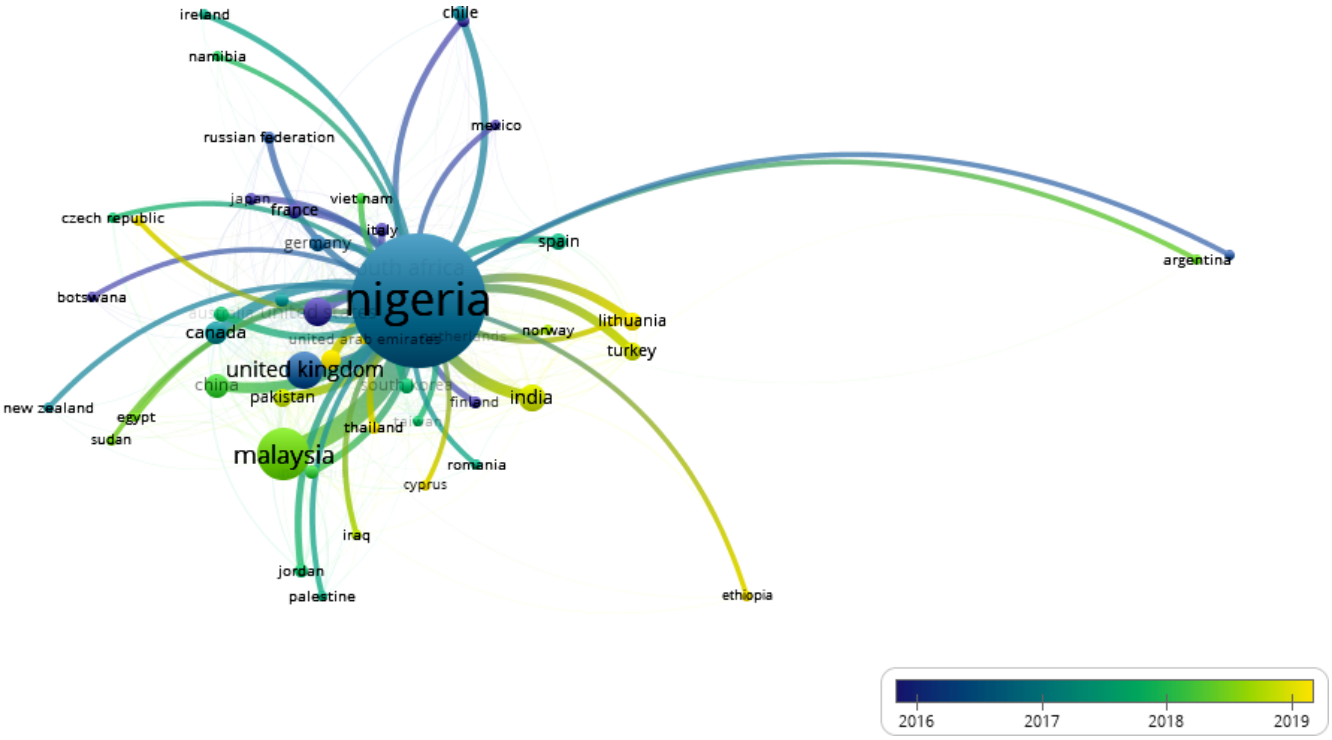

Figure 5. Country collaboration network map (VOSviewer overlay visualization).

The colour bar in Figure 5 indicates that collaborations with countries such as Lithuania, Thailand, Cyprus, and Ethiopia were established recently (between 2020 and 2021) as indicated by the yellow colour. Collaborations with Malaysia, China, and Vietnam were between 2018 and 2019, Jordan, Palestine, Taiwan, and Spain between 2017 and 2018 while the purple colour indicates collaborations established between 1991 and 2016.

4.4 How has Computer Science research in Nigeria evolved in the last 31 years?

The thematic evolution map in Figure 6 revealed how the field evolved between 1991 – and 2021. The following parameters were set to generate the thematic evolution map; No of Words= 300, No. of Clusters per thousand docs=5, label size = 0.3, Number of labels for each cluster = 1, and Weight Index = "Inclusion index weighted by word-occurrences". To avoid bias all keywords that appeared in the search query *("computer science" and "Nigeria"*) were removed alongside "Matlab" and "students" which are not necessarily Computer Science themes. There are two major time slices on the map; 1991-2018 and 2019-2021. The themes that dominated the first time slice were Artificial Intelligence (AI), network security, optimization, and cloud computing. It is interesting to note that only network security exists in the second (2019-2021). The other themes had metamorphosed; cloud computing into the internet of things and intelligent systems, AI into forecasting and learning systems, mobile telecommunication systems into the internet of things, and optimization into intelligent systems. This implies that the field is very

dynamic. The drastic change in the thematic areas of the second slice could be a result of the ongoing fourth industrial revolution (4IR) and COVID-19. The COVID-19 pandemic necessitated the need for alternative teaching and learning mode (Omotehinwa et al., 2021) which led to AI being used for personalized learning, collaborative learning, and grading system (Elzainy et al., 2020; Van Heuvelen et al., 2020; Whalley et al., 2021). The thematic evolution analysis did not show many themes in this field. Hence, a thematic map is generated in Figure 7. This is necessary to know how important these themes are and how well they have developed.

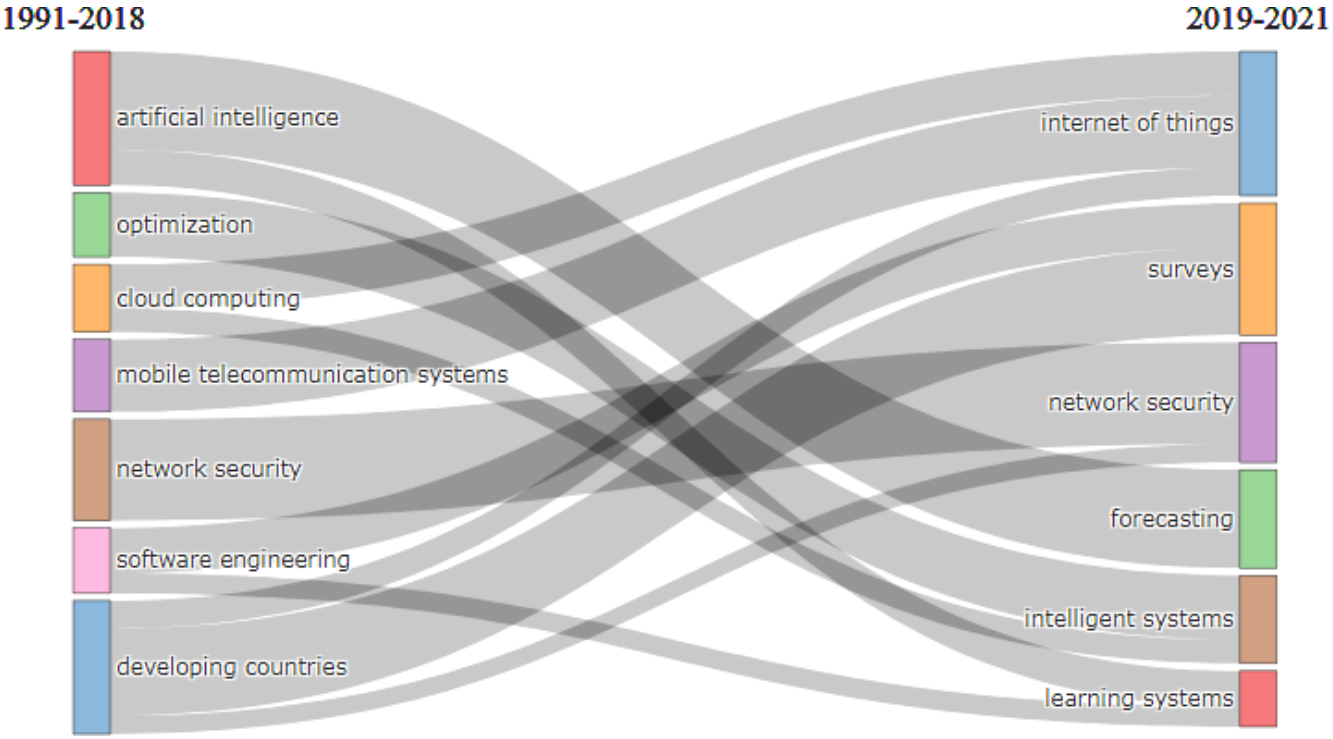

Figure 6. The thematic evolution of themes in Computer Science Research in Nigeria

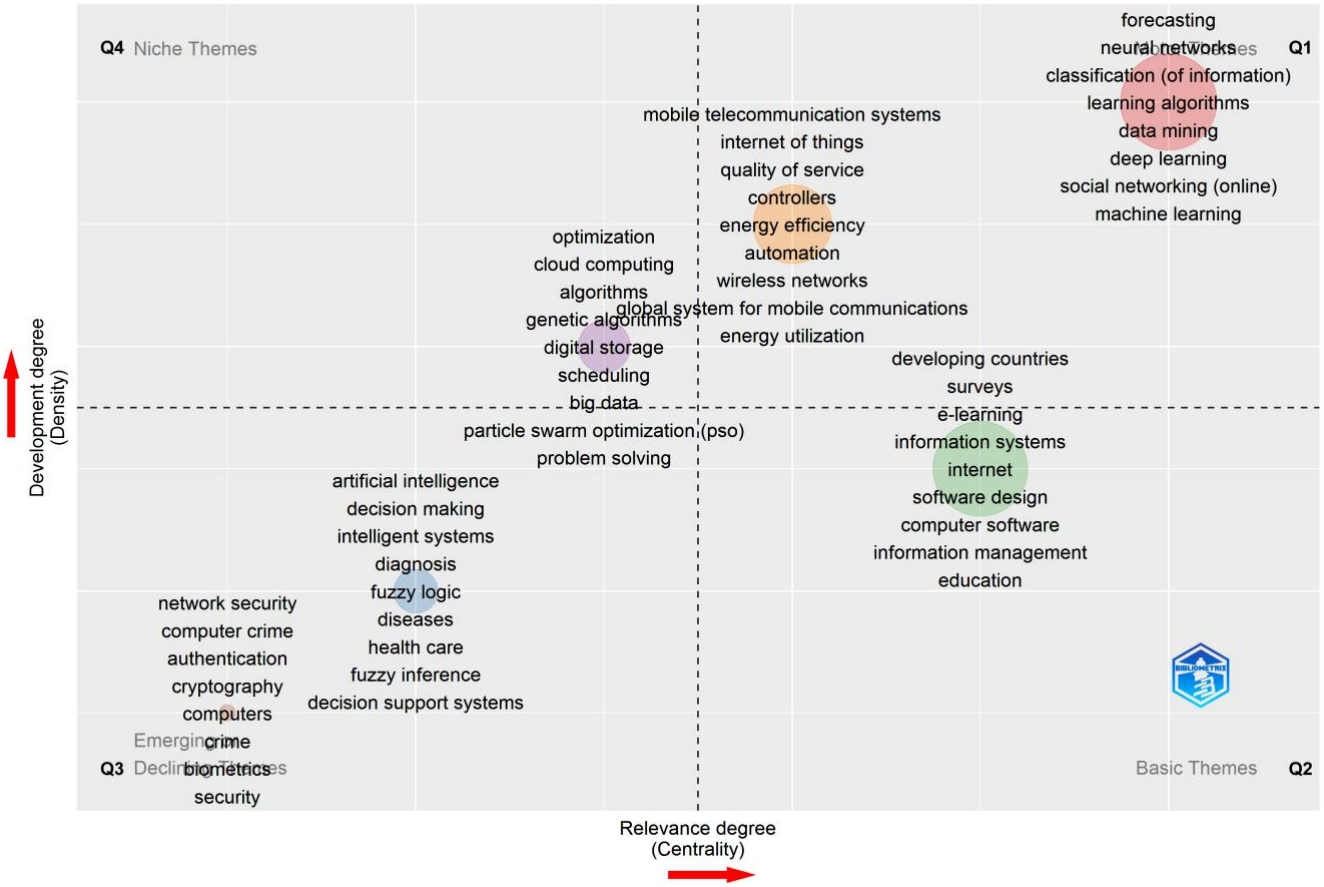

Figure 7. The thematic map of themes in Computer Science Research in Nigeria. 1st quadrant Q1 (motor themes), 2nd quadrant Q2 (Basic themes), 3rd quadrant Q3 (emerging or declining themes), 4th quadrant Q4 (niche themes).

The thematic map in Figure 7 is generated based on the co-occurrence frequency of keywords in documents in the dataset and similarities of keywords measured by the association index method. It is based on the approach by Cobo et al. (2011). To avoid deviant results, the keywords in the search string; "Computer Science" and "Nigeria" were indicated for exemption during the analysis. Also, the keywords "Matlab" and "students" were exempted. The parameters set for this analysis are No of Words= 250, No. of Clusters per thousand docs=5, labels = 9 and label size = 0.3. There are 6 clusters in the thematic map shown in Figure 7 representing the major themes in this field. The map is divided into four. The 1st quadrant is the motor theme. The motor theme (Q1) shows the most developed and important themes in this field. The red cluster contains the most developed themes such as neural networks, classification (information), learning algorithms, data mining, machine learning, and so on. The themes such as the internet of things, energy efficiency, energy utilization, and so on, in the orange cluster, are not as developed as those in the red cluster. However, they are also relevant and well-studied in the Computer Science field in Nigeria just like those in the red cluster. In Q2 we have the basic themes such as e-learning, information system, and software design (green cluster), which are developing and are quite important in this field in Nigeria. The emerging or declining themes (Q3) in this field are in the 3rd quadrant. The themes in the brown cluster are declining as they are characterized by low density and centrality. These themes are not

getting the attention of Computer Science researchers in Nigeria while the themes in the blue cluster are likely to be emerging as they have a higher relevance compared to those in the brown cluster. They are not yet well developed in this field but are capable of becoming relevant and well developed. The 4th quadrant which is the niche themes are the isolated themes (purple cluster). These themes are developed but are understudied in Nigeria. New research related to the themes in the 1st quadrant is likely to gain relevance quickly in terms of citation since it is in a well-developed and important thematic area.

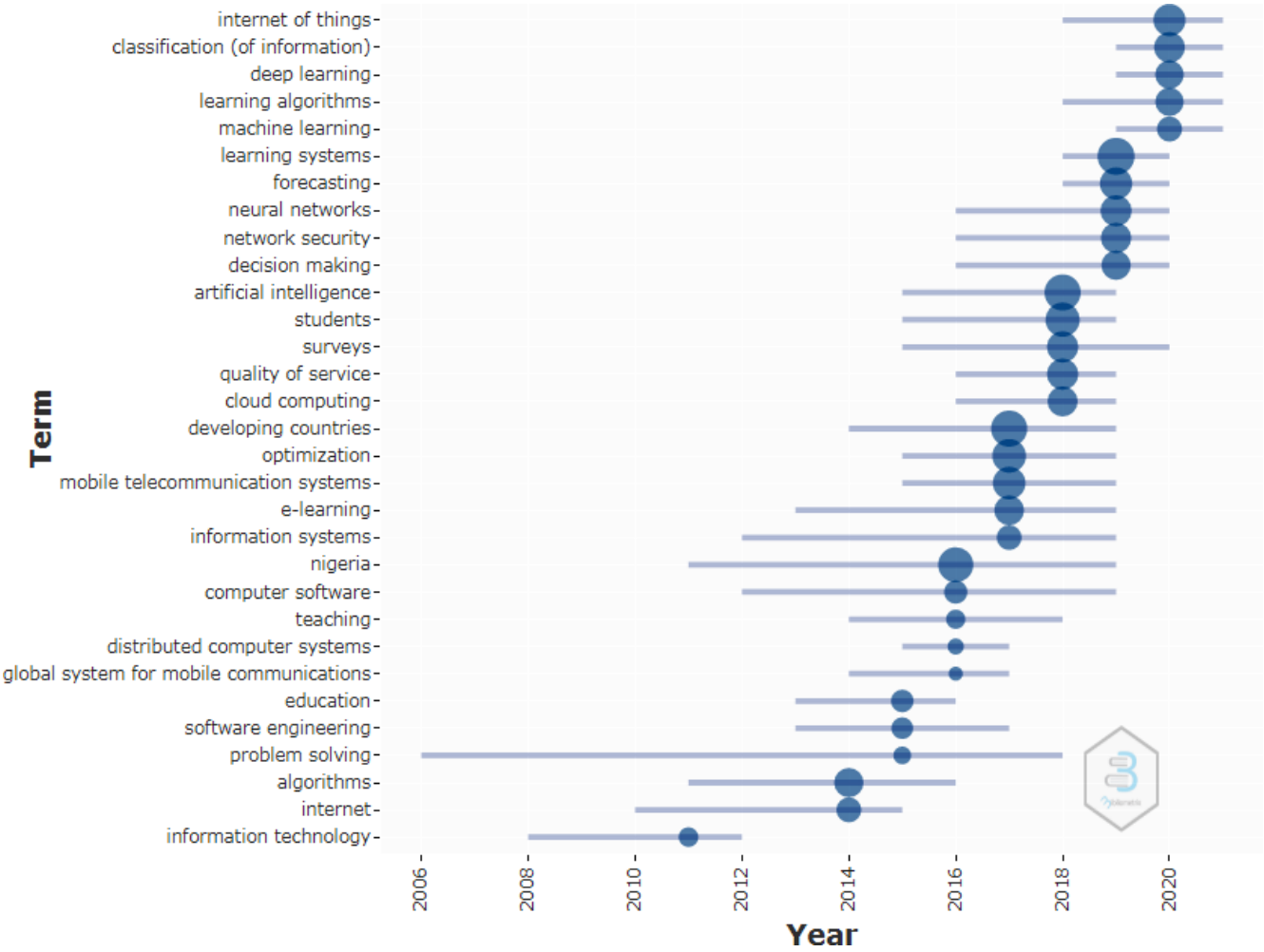

Figure 8. The trend of topics in Computer Science Research in Nigeria. The size of the bubble indicates the frequency of each term. The horizontal rule indicates the period the term spanned. The point on the horizontal rule where the bubble appeared is the median year for the term.

The keyword plus (Author keywords, Keywords in title, and abstract) was used to generate the trends of topics in this field. Only terms that have a minimum frequency of 50 were selected during the analysis. The size of the bubble indicates the frequency of each term. The horizontal rule indicates the period the term spanned. The point on the horizontal rule where the bubble appeared is the median year for the term. It can be observed (Figure 8) that the biggest bubble in the plot represents learning systems with a frequency of 167. Artificial intelligence started trending in 2015 in Computer Science research in Nigeria. It evolved into other subfields of AI as succeeding years began to feature terms like machine

learning, deep learning, and learning algorithms. This was also depicted in the thematic evolution analysis (Figure 6) but the trend topics analysis gives a more comprehensive view of the major themes. The top 5 most trending topics in this field in Nigeria in 2021 are the internet of things (Freq. =123), classification of information (Freq. =114), deep learning (Freq. =98), learning algorithms (Freq. =97), and machine learning (Freq. =79).

4.5 Which are the most important documents in Computer Science research in Nigeria?

The most relevant top 10 publications in Computer Science research in the last 31 years are presented in Table 7. The local citation measures the number of citations a publication received from other publications in this dataset while the global citation refers to the number of citations received from other documents in the entire Scopus database. The most locally cited publication is the study of Balogun et al., (2019). It has a total local citation count of 13 and a global citation count of 32. The most relevant publication globally is the study of Abdullahi et al., (2016), published by the Future Generation of Computer Systems. It has 224 global citations and was cited 12 times within the dataset. The 224 global citations show that the study is very relevant and contributes to many studies in other fields. The study by Adesina and Ayo (2010) has the second-highest global citation count of 103. It is important to note that Nkwo Makuochi has 3 publications on the top 10 list of most relevant publications.

Table 7. Top 10 most important publications in Computer Science research in Nigeria based on the local and global citation counts

Authors & Year of Publication	Publication Title	Source	Local Citations (LC)	Global Citations (GC)	LC/GC Ratio (%)
(Balogun et al., 2019)	Performance analysis of feature selection methods in software defect prediction: A search method approach	Applied Sciences	13	32	40.63
(Nkwo & Orji, 2018)	Persuasive technology in African context deconstructing persuasive techniques in an African online marketplace	ACM International Conference Proceeding Series	12	13	92.31
(Nkwo, 2019)	Mobile persuasive technology: Promoting positive waste management behaviors in developing African nations	Conference on Human Factors in Computing Systems - Proceedings	12	12	100.00
(Abdullahi et al., 2016)	Symbiotic Organism Search optimization-based task scheduling in cloud computing environment	Future Generation Computer Systems	12	224	5.36

(Balogun et al., 2020)	Impact of feature selection methods on the predictive performance of software defect prediction models: An extensive empirical study	Symmetry	11	19	57.89
(Odun-Ayo et al., 2017)	Cloud-based security-driven Human Resource Management system	Frontiers in Artificial Intelligence and Applications	10	31	32.26
(Nkwo et al., 2018)	Persuasion for Promoting Clean and Sustainable Environment	ACM International Conference Proceeding Series	10	7	142.86
(Alsariera et al., 2020)	AI Meta-Learners and Extra-Trees Algorithm for the Detection of Phishing Websites	IEEE Access	9	26	34.62
(Adesina & Ayo, 2010)	An Empirical Investigation of the Level of Users' Acceptance of E-Banking in Nigeria	Journal of Internet Banking and Commerce	8	103	7.77
(Samuel et al., 2013)	A web-based decision support system driven by fuzzy logic for the diagnosis of typhoid fever	Expert Systems with Applications	8	66	12.12

Table 7 also revealed how dynamic the field is, this is exemplified by the diverse sub-fields of Computer Science; cloud computing, machine learning, human-computer interaction, and so on represented on the list.

The recent and most impactful (based on citation) articles in Computer Science research and their area of research are presented in Table 8. There 4 top articles published in 2021 and 3 each published in 2020 and 2019.

Table 8. Recent most impactful publications in Computer Science research in Nigeria based on total citation

Authors & Year of publication	**Title**	**Source Title**	**Total Citation**	**Research Area**
(Behera et al., 2021)	Co-LSTM: Convolutional LSTM Model for Sentiment Analysis in Social Big Data	Information Processing and Management	34	Sentiment Classification | Data Mining | Product Review

(ur Rehman et al., 2021)	Modified Popov's Explicit Iterative Algorithms for Solving Pseudomonotone Equilibrium Problems	Optimization Methods and Software	21	Equilibrium Problem | Extragradient Method | Variational Inequalities
(Salau et al., 2021)	Vehicle Plate Number Localization Using a Modified Grabcut Algorithm	Journal of King Saud University - Computer and Information Sciences	17	Character Recognition | Tesseract | Number
(Oyewola et al., 2021)	Detecting Cassava Mosaic Disease Using a Deep Residual Convolutional Neural Network with Distinct Block Processing	PeerJ Computer Science	15	Object Detection | Deep Learning | IOU
(Alsharif, Kelechi, Albreem, et al., 2020)	Sixth Generation (6g) Wireless Networks: Vision, Research Activities, Challenges and Potential Solutions	Symmetry	70	Beyond 5G | Massive MIMO | Intelligent Reflecting Surface
(Alsharif, Kelechi, Yahya, et al., 2020)	Machine Learning Algorithms for Smart Data Analysis in Internet of Things Environment: Taxonomies and Research Trends	Symmetry	29	Hadoop | Big Data | Data Mining
(Da'u et al., 2020)	Recommendation System Exploiting Aspect-Based Opinion Mining With Deep Learning Method	Information Sciences	29	Sentiment Classification | Data Mining | Product Review
(Ikpehai et al., 2019)	Low-Power Wide Area Network Technologies For Internet-Of-Things: A Comparative Review	IEEE Internet of Things Journal	101	Internet of Things
(Gill et al., 2019)	Transformative Effects of IoT, Blockchain and Artificial Intelligence on Cloud Computing: Evolution, Vision,	Internet of Things (Netherlands)	101	Virtual Machine | Data Center | Cloud Computing

	Trends and Open Challenges			
(Omoniwa et al., 2019)	Fog/Edge computing-based IoT (FECIOT): Architecture, Applications, and Research Issues	IEEE Internet of Things Journal	88	Fog Computing | Network Protocol | Internet of Things

4.6 What is the funding pattern for Computer Science research in Nigeria like?

Content analysis of the funding information field "FX" was carried out to determine the funding status of the 4,333 publications in this dataset. The funding analysis result is presented in Figure 9. The documents were classified into four categories; Funding Information Not Available, Supported, Self-funded and Other. Funding information was not available or provided for about 80% (3,460) of the documents. From Figure 9 it can be observed that 3.92% (170) of the research received support which ranged from access to the research laboratory, data for analysis, "enabling environment", payment of article processing fee, and so on. A total of 697 (16.09%) research was funded by the federal government of Nigeria, state governments in Nigeria, research funds of individual private universities, and international funding bodies. There are 57 state-owned universities in Nigeria but only 0.7% (5) of Computer Science research was funded by the state government in the last 31 years.

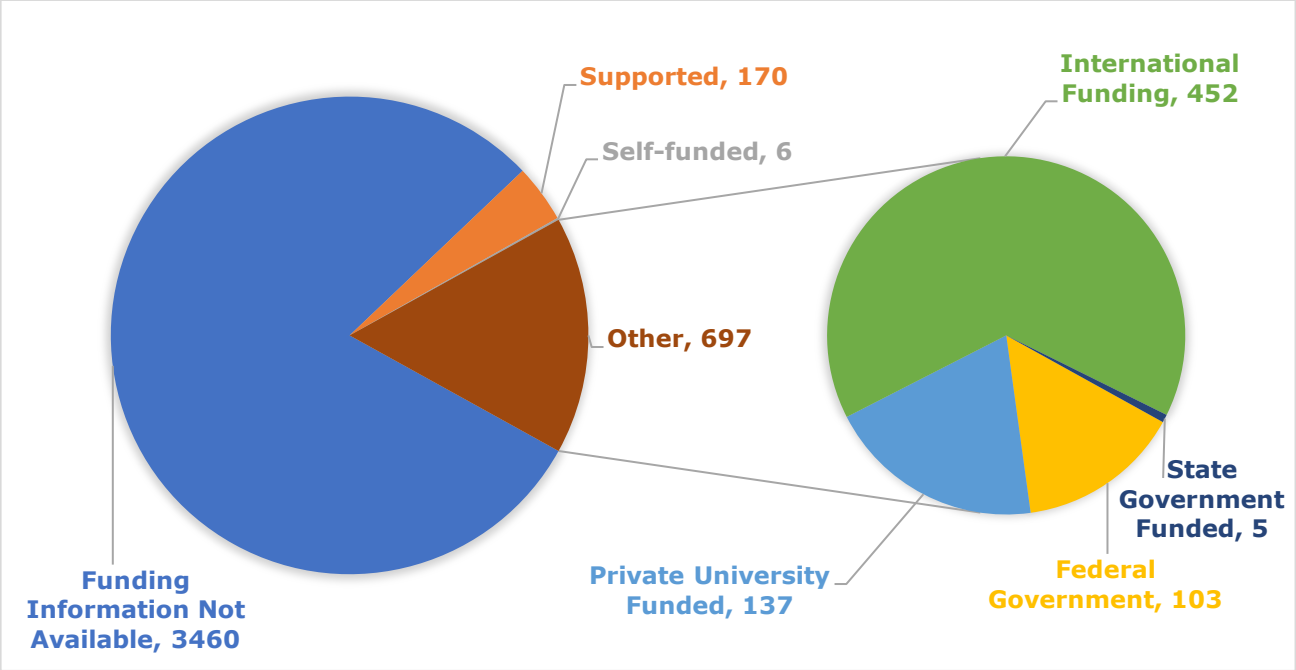

Figure 9. Funding distribution chart of Computer Science research in Nigeria

International organizations and foreign institutions such as the United States Agency for International Development (USAID), National Research Foundation (NRF) South Africa, University of KwaZulu-Natal (UKZN), and the CSIR Meraka Centre for Artificial Intelligence

Research South Africa, University Malaya research fund and so on were seen as main funders of Computer Science research in Nigeria. In the last 31 years, only 14.8% (103) of the 679 funded Computer Science research was funded by the federal government through the Tertiary Education Trust Fund (TETFUND), Petroleum Technology Development Fund (PTDF), Education Trust Fund (ETF), and government agencies such as Nigerian Communications Commission (NCC), National Information Technology Development Agency (NITDA), National Space Research and Development Agency (NARSDA) and so on. Private universities funding Computer Science research are largely dominated by Covenant University and Landmark University which account for 19.7% (137) of the 679 funded Computer Science research. The funding analysis result revealed that Computer Science research in Nigeria is underfunded.

5 Conclusion

The study revealed that the majority of the Computer Science studies are published in journals. While it seems that scholars in Computer Science in Nigeria try to push through the rigor of getting their study published in peer-reviewed journals, which is commendable, it is also important to emphasize that dissemination of research outputs in conferences should be given attention. This is because, scholarly discussions that take place in conferences can provide useful feedback on how experts from other contexts view study findings, which can, in turn, improve the quality of research from Nigeria.

In addition, the study shows that universities from the Southwest region of Nigeria are more productive in terms of the number of publications and citation counts. Surprisingly, there were no data on Computer Science research from universities in the Northwest and Southsouth regions of Nigeria. Furthermore, the universities seen to be very active in Computer Science research are the private universities. This finding revealed that the Nigerian government must support federal universities in terms of providing more funding for research and development. Particularly in the universities where their research outputs in Computer Science are not visible, there must be practical ways to motivate scholars in those regions through funding.

Regarding the impact of Computer Science research in Nigeria, this study found that studies focusing on the application of emerging technology mainly in the AI field – machine learning, deep learning, neural networks, data mining, and system optimization - are gaining more global impact than local impact. This can be true since the application of these technologies as seen from the data are in the scope of fintech, health, and industrial automation where Nigerian companies are still developing whereas, the global south seems to have advanced in them.

Interestingly, the evolution of Computer Science in Nigeria within the past three decades revealed that AI, which is one of the popular sub-field in Nigeria that emerged recently (Okunola, 2018) is penetrating the industry, developing intelligent systems, and forecasting. In addition, software engineering which had remained a typical Computer Science topic taught in the university is gaining ground in the development of learning systems.

For sustainable growth in Computer Science in Nigeria, the impact of research collaboration both locally and internationally cannot be overemphasized. As revealed in this study, the collaboration network between Nigerian universities remains marginal and concentrated in the Southwest region. However, reasonable collaboration has been established between scholars in Nigerian universities and abroad. While the global collaboration seems good, there must be synergy between the local universities developed through research to advance the field of Computer Science and create a more innovative society driven by computing. At the global level, the enormous opportunity in different sectors in Nigeria as the most populous African nation with a fast-growing economy can be tapped through a purposeful collaboration between scholars in the local universities and those from abroad.

An earlier study conducted over 40 years ago revealed that Computer Science education in Nigeria was threatened by a lack of hardware and its maintenance policies at that time (Anyanwu 1978). On the contrary, computer hardware including desktops, laptops, smartphones, and other handheld computers is omnipresent nowadays in Nigeria. Therefore, the main issues have now shifted to the utilization of the computer, i.e., programming the computer to innovatively solve complex problems facing the people, particularly in the context of a developing country. Oftentimes, these innovations come from the output of research and development carried out by scholars in the university. Hence, this study unraveled a huge problem related to underfunding of research, which will hinder the level of computing and in turn negatively affect several key sectors in the nation that are meant to propel economic and social development. One of the limitations that this study encounters is the fact that publications of Nigerian scholars working in the universities abroad but who may be conducting contextual studies that touch on Nigeria are not included in our data based on the search parameters. The authors acknowledge that findings from this study could have been greatly impacted if these data were also included in the analysis. Besides, the search result contains some outliers of data that were not focused on Computer Science, which is because the search algorithm was not intelligent enough. However, the authors manually screen these data out to ensure that the result is not affected. Furthermore, this study did not claim to have collected all possible data, which is a general limitation of this kind of study. Hence, there is a possibility that some data which were published in local journals or conferences and not indexed by Scopus are unintentionally left out. Notwithstanding, the number of data analyzed in this study is considered to significantly represent the field investigated.

The findings of this study will be useful for researchers conducting Computer Science related research in Nigeria in several ways. For example, experts can gain insights into how to develop a strategic framework that will advance the field in a more impactful manner. Government agencies and policymakers can also utilize the outcome of this research by providing more support to facilitate research in areas of Computer Science that received less funding.

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This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability Statement

The data that support the findings of this study are openly available in figshare at https://doi.org/10.6084/m9.figshare.19630353

Declaration of interest: None

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