DOI: 10.5958/0976-2469.2021.00001.4

LIBRARY HERALD
Vol 59 No 1
March 2021

Quantum Cloud Computing - A Scientometric Assessment of Global Research for the Period 1999-2020

S.M.DHAWAN*
B.M.GUPTA**
ASHOK KUMAR***
JIVESH BANSAL****

The study provides a quantitative and qualitative description of global quantum cloud computing research for the period 2000-2019, using metrics. The data for the study was sourced from Scopus database. During the period, the global research output in the subject totalled 459 publications, registered 39.63% annual average growth rate and 19.85 citations per paper. In addition, the study provides the distribution of global research output by country of publication, lists the top 10 most productive countries in the subject, identifies the leading research organizations as well as leading contributing authors in the subject. The study also provides the distribution of research output by major disciplines in order to bring out the most sought areas of research in quantum cloud computing. The study also identifies the most popular source journals in the subject. IEEE Access (10 papers), Physical Review Letters (6 papers) and Nature (4 papers) were found to be the most productive journals. Information Sciences, Science and Physical Review Letters were found to be the most impactful journals.

Keywords: *Quantum cloud computing, Quantum technology, Cloud computing, Global publications, Scientometrics, Bibliometrics*

1 INTRODUCTION

Quantum cloud computing is all about giving clients, access to a quantum computer on-demand typically over the internet ("the cloud"). The cloud

* *Formerly with CSIR-NPL, New Delhi 11012.*

** *Formerly with CSIR-NISTADS, New Delhi 11012.*

*** *Maharishi Markandeshwar University, Mullana-Ambala, Haryana 133207*

*** *Panjab University, Central Library, Chandigarh*

users have the advantage that they get access to an incredible amount of computing power of quantum computers having major potential to solve computing problems that are otherwise intractable by classic computers[1]. Unlike classic computers, quantum computers derive their computing power by harnessing the power of quantum mechanics, the subfield of physics that describes the behaviour of very small (quantum) particles. Superposition and entanglement, the two unique properties in quantum physics, give quantum computers more computational power to run transactions, say, 100 million times faster than the classic computers. Quantum computers are viewed as the next generation computers, with potential to spur technological breakthroughs in science and medicine that can benefit humanity and save human lives. Quantum computers are exceedingly difficult to engineer, build and program. The power of quantum computing comes from the ability to store a complex quantum state in a single qubit (quantum bit) [2]. This indeed is the basic task that makes it difficult to build, verify, and design quantum systems. Quantum states are fragile, so fabrication must be precise, and more over bits quite often operate at very low temperatures. At present, only a select few organizations like IBM, Google, D-Wave and Honeywell have succeeded in building quantum computers. Gradually, the computing capacities of quantum computers have started to expand, initially from 2-qubit, to 5-qubit, 17-qubit, and later to 49-qubit in size. The more the qubits in a system, the more its processing power. D-Wave is the first company to sell quantum computers to exploit quantum effects [3]. It has now built a 5000+ qubit size quantum computer. Some of the organizations in the industry like the IBM, are nowadays offering their quantum computers for free on the cloud to run experiments [4].

1.1 LITERATURE REVIEW

There are no studies till date in the body of bibliometric literature that are per se related to evaluation of quantum cloud computing research on metrics. However, the bibliometric literature does include quite a few studies related to broader topics such as quantum computing technologies and cloud computing research.

Dhawan and Gupta sought to analyze the global quantum computing research (4703 publications) for the period 2000-19 in terms of bibliometric features such as the top 10 most productive countries, top 30 most productive organizations as well as authors, top 20 leading source journals, and highly cited papers in the subject [5]. Tolcheev highlighted the bibliometric

characteristics of quantum technologies research during 2000-2016, identified and evaluated the key areas of research, and defined the publication activities of select countries in this research [6] . Gupta, Singh and Gupta examined 21397 global publications and 1206 Indian publications in cloud computing research using data as covered in Scopus database during 2004–2013 [7,8] . In another study, Gupta examined 469 global publications on social cloud research publications during 2009-2018 on a series of bibliometric indicators, using data derived from Scopus international database [9] . Gupta, Dhawan and Gupta examined 3779 mobile cloud computing research publications using data as indexed in Scopus database during 2007-2016 [10] . Most of the studies discussed above evaluated research on metrics such as volume of publications, growth rate, leading productive countries, leading research organizations and authors, key areas of research, leading channels of research communications and characteristics of highly cited papers. In view of non-availability of any bibliometric research studies on the topic of quantum cloud computing as well as keeping in view the growing significance of research in the subject, the authors believe that a bibliometric study on the proposed subject will certainly fill the gap in research.

2 OBJECTIVES

This study seeks to assess and evaluate the global cloud computing research on publication and citation metrics such as publication volume, type and source, publication growth and citation impact, subject-wise publications spread, profile of leading most productive countries, leading most productive organizations as well as authors, leading source journals for publishing research and to highlight features of highly cited papers. The publications data for the study is sourced from the Scopus international database for the period 2000-2019.

3 METHODOLOGY

The study retrieved and downloaded publications data on quantum cloud computing research from the Scopus database (http://www.scopus.com) using a well-defined search strategy (shown below), on 29.9.2020. The keywords that were used for formulating the search strategy were "quantum cloud computing". The TITLE-ABS-KEY tag of Scopus database was used for conducting the search. The search output was

confined to the publication period 2000-2019. The database search yielded a total output of 459 publications, published globally during the 20-year period. To generate additional information, the search strategy was subsequently refined by publication-country name one by one to identify leading most productive countries. The global publications on quantum cloud computing research were further analyzed by broad subjects, collaborating countries, author-wise counts, organization-wise counts, source journal-wise counts, etc., by using analytical provisions of the Scopus database. Citations to publications were counted from date of their publication till 29.9.2020.

TITLE-ABS-KEY(quantum cloud computing) AND PUBYEAR > 1999 AND PUBYEAR < 2020

4 ANALYSIS AND RESULTS

4.1 PUBLICATIONS ANALYSIS

Global research in the domain of quantum cloud computing resulted in a total of 459 publications during 2000-2019. The annual publications output in the subject increased from just 1 in the year 1990 to 101 publications in 2019, with 39.63% average annual growth. The ten-year cumulative output increased from 18 in 1990-09 to 441 publications in 2010-19. The citation impact of quantum cloud computing research since publication in 2000-2019 averaged to 19.85 citations per paper (CPP). It was 18.78 CPP in 2000-09 and 19.89 CPP in 2010-19 (Table 1).

Of the 459 publications, 137 (29.85% of 459 papers) appeared as part of research projects, supported and funded by more than 50 national and international research agencies. These 137 project-funded research papers scored a total of 3014 citations in 2000-2019, an average of 29.85 citations per paper, which is far above the global average. The research agencies that had supported quantum cloud computing research during the period were: National Natural Science Foundation of China (65 papers), National Science Foundation of Jiangsu Province (11 papers), National Science Foundation, USA (10 papers), Engineering & Physical Science Research Council(5 papers), European Research Council (5 papers), etc. Of the global publications output, conference papers accounted for the largest, i.e. 38.56% , articles 36.82% , followed by conference reviews (18.74%), book chapters (2.83%), reviews (1.96%), books (0.87%) and notes (0.22%).

Table 1. Global Quantum Cloud Computing Research: Publications Output and Citations, 2000-2019

Publication Period	World			
	TP	TC	CPP	FP
2000	1	3	3.00	1
2001	1	0	0.00	
2003	1	0	0.00	
2004	2	31	15.50	
2006	2	28	14.00	
2007	3	217	72.33	
2008	2	1	0.50	1
2009	6	58	9.67	1
2010	4	29	7.25	
2011	5	14	2.80	
2012	15	402	26.80	4
2013	25	43	1.72	6
2014	35	1746	49.89	3
2015	50	641	12.82	12
2016	47	383	8.15	11
2017	56	311	5.55	19
2018	103	5032	48.85	39
2019	101	172	1.70	40
2000-09	18	338	18.78	3
2010-19	441	8773	19.89	134
2000-19	459	9111	19.85	137

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; FP=Funded Papers

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; FP=Funded Papers

4.1.1 MOST PRODUCTIVE COUNTRIES

A total of 50 countries participated in global research on cloud computing . Of these, 40 countries contributed 1-10 papers each, 5 countries 11-20 papers each, 3 countries 21-50 papers each and 2 countries 51-139 papers each. The top 10 most productive countries accounted for a 76.47% global publication share and 39.60% global citation share. China leads the ranking with a global publication share of 30.28%, followed by India and USA (11.98% and 11.55%), U.K. (5.66%) and other 6 countries contributed from 2.18% to 3.49% during 2000-19. During the period between 2000-2009 to 2010-2019, the global publication share of four countries namely China, India, Canada and Egypt increased by 2.49% to 25.74%, whereas in the case of 6 other countries it declined by 2.83% to 16.89%. Seven countries registered their relative citation count above the group average (0.52): Canada (1.19), U.K. and Italy (1.13) each, Japan (1.05), Germany (0.84), Egypt (0.60) and USA (0.53). The publications output of of top 10 most productive countries as a share of international collaborative papers varied from 12.73% to 90.91%, with an average of 35.90% (Table 2).

4.1.1.1 COLLABORATIVE LINKAGES AMONG TOP 10 COUNTRIES

All of the top 10 countries had one to one collaborative linkages, as observed from Table 3. The top three countries i.e. China, U.K. and USA had the largest collaborative linkages (22, 19 and 11) in the network, collaborating with as many as 4 to 8 network nodes (nodal countries). The countries with least collaborative linkages are Egypt, India and Australia (1, 5 and 6) collaborating with 1-3 network nodes (nodal countries). Among country-country collaboration, China-Canada had registered highest number of collaborative linkages (6), followed by China-U.K., U.K.- Germany and U.K. – Japan (4 linkages each), etc.(Table 3)

Table 2. Global Publication Share of Top 10 Most Productive Countries in Quantum Cloud Computing Research, 2000-2019

Name of the Country	Number of Papers			Share of Papers			TC	CPP	ICP	%ICP	RCI
	2000-09	2010-19	2000-19	2000-09	2010-19	2000-19	2000-19				
China	1	138	139	5.56	31.29	30.28	872	6.27	28	20.14	0.32
India	0	55	55	0.00	12.47	11.98	181	3.29	7	12.73	0.17
USA	5	48	53	27.78	10.88	11.55	561	10.58	18	33.96	0.53
U.K.	2	24	26	11.11	5.44	5.66	585	22.50	21	80.77	1.13
Germany	2	14	16	11.11	3.17	3.49	267	16.69	11	68.75	0.84
Canada	0	15	15	0.00	3.40	3.27	354	23.60	11	73.33	1.19
Italy	1	12	13	5.56	2.72	2.83	291	22.38	7	53.85	1.13
Japan	2	11	13	11.11	2.49	2.83	272	20.92	6	46.15	1.05
Egypt	0	11	11	0.00	2.49	2.40	131	11.91	10	90.91	0.60
Australia	1	9	10	5.56	2.04	2.18	94	9.40	7	70.00	0.47
Total of 10 countries	14	337	351	77.78	76.42	76.47	3608	10.28	126	35.90	0.52
World total	18	441	459				9111	19.85			
Share of top 10 countries in global total	77.78	76.42	76.47				39.60				

ɔtal Papers; TC=Total Citations; CPP=Citations Per Paper; ICP=International Collaborative Papers; ECI=Relative Citation Index

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; ICP=International Collaborative Papers; ECI=Relative Citation Index

Table 3. Collaboration Linkages among Top 10 Countries during 2000-19

S.No	Name of the Country	Number of collaborative linkages with other countries	Total collaborative linkages(Number of countries)
1	China	2(1), 3(3), 4(4), 5(1), 6(6), 8(1), 9(1), 10(3))	22(8)
2	India	1(1), 3(2), 6(2)	5(3)
3	USA	1(3), 2(2), 4(1), 6(2), 8(2), 10(1)	11(6)
4	U.K.	1(4), 3(1), 5(4), 6(1), 7(3), 8(4), 10(2)	19(7)
5	Germany	1(1), 4(4), 7(2)	7(3)
6	Canada	1(6), 2(2), 3(2), 4(1)	11(4)
7	Italy	1(1), 4(3), 5(2), 8(2)	8(4)
8	Japan	1(1), 3(2), 4(4), 7(2)	9(4)
9	Egypt	1(1)	1(1)
10	Australia	1(3), 3(1), 4(2)	6(3)

4.2 SUBJECT-WISE DISTRIBUTION OF RESEARCH OUTPUT

Computer Science, Engineering and Mathematics contributed the largest publication share (71.46%, 33.77% and 28.98%) to global quantum cloud computing research, followed by Physics and Astronomy (15.25%) and other 4 subjects contributed from 3.70% to 8.06% during 2000-19. In terms of activity index, the subjects showing increase were Computer Science (from 46.65 to 102.18), Engineering (from 82.36 to 100.72), Mathematics (from 57.52 to 101.73), Decision Science (from 0.0 to 104.08), Materials Science (from 283.33 to 92.52) and Chemistry (from 255.0 to 93.67), as against decrease in Physics & Astronomy (from 437.14 to 86.24) during 2000-09 to 2010-19. Among 8 subjects, Decision Science registered the highest citation count per paper (42.22) and Social Sciences the least (5.88) (Table 4).

Table 4. Subject-Wise Breakup of Global Publications on Quantum Cloud Computing during 2000-19

S.No	Subject	Number of Papers			Activity Index		TC	CPP	%TP
		2000-09	2010-19	2000-19	2000-09	2010-19	2000-19		
1	Computer Science	6	322	328	46.65	102.18	2604	7.94	71.46
2	Engineering	5	150	155	82.26	100.72	2369	15.28	33.77
3	Mathematics	3	130	133	57.52	101.73	2121	15.95	28.98
4	Physics & Astronomy	12	58	70	437.14	86.24	905	12.93	15.25
5	Decision Science	0	37	37	0.00	104.08	1562	42.22	8.06
6	Materials Science	3	24	27	283.33	92.52	234	8.67	5.88
7	Chemistry	2	18	20	255.00	93.67	336	16.80	4.36
8	Social Sciences	0	17	17	0.00	104.08	100	5.88	3.70
	Total	18	441	459			9111		
TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper									

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

4.3 SIGNIFICANT KEYWORDS

Thirty three keywords (assumed to be significant) have been identified from the global literature on quantum cloud computing research, which throw light on the research trends in this area. These keywords are listed in Table 5 in decreasing order of the frequency of their occurrence in the literature during 2000-19. The maximum frequency (182) was observed for Cloud Computing, followed by Quantum Computers (103), Quantum Cryptography (73), Quantum Computing (55), Quantum Theory (552), etc.

4.4 TOP 25 MOST PRODUCTIVE GLOBAL ORGANIZATIONS

Two hundred and forty seven organizations unevenly participated in global quantum cloud computing research during 2000-19: 239 organizations published 1-5 papers each, 7 organizations 6-10 papers each and 1 organization 12 papers. Of the top 25 organizations, 14 from China, 2 from Austria, 1 each from Egypt, France, Hungary, India, Italy, Japan, Taiwan, Ukraine and U.K. The productivity of top 25 most productive organizations varied from 3 to 12 publications per organization. Together, they contributed 28.32% (130) global publications share and 16.13% (1470) global citations share during 2000-19. The scientometric profile of top 8 most productive and top 8 most impactful organizations is presented in Table 6.

- Eight of 25 organizations registered publication output above the group average (5.2) of all organizations : Ministry of Education, China (12 papers), Nanjing University of Information Science & Technology, China (10 papers), Southeast University, Nanjing, China (8 papers), Dalian Jiaotong University, China, University of Electronics Science & Technology, China, University of Science & Technology of China, Kharkiv National University of Radio Electronics, Ukraine and Nanjing University of Aeronautics & Astronautics, China (6 papers each)
- Five of 25 organizations registered citation per paper and relative citation above the group average (11.31 and 0.57 respectively): Osterreichische Academie der Wissenschaften, Austria (85.0 and 4.28), Nanjing University, China (78.6 and 3.96), University of Wien, Austria (49.4 and 2.49), University of Oxford, U.K.(14.8 and 0.75) and CNRS, France (11.5 and 0.58).

Table 5. List of Significant Keywords Appearing in Global Publications on Quantum Machine Learning Research during 2000-19

S.No	Name of the Keyword	Frequency	S.No	Name of the Keyword	Frequency
1	Cloud Computing	182	19	Cloud Computing Environment	15
2	Quantum Computers	103	20	Quantum Key Distribution	14
3	Quantum Cryptography	73	21	Cloud Storage	13
4	Quantum Computing	55	22	Genetic Algorithims	12
5	Quantum Theory	55	23	Quantum Mechanics	12
6	Network Security	43	24	Clouds	11
7	Cryptography	42	25	Cloud Computing Platforms	10
8	Digital Storage	36	26	Cloud Models	10
9	Distributed Computer Systems	31	27	Quality of Service	10
10	Quantum Optics	31	28	Cloud Services	9
11	Quantum Chemistry	24	29	Neural Networks	8
12	Big Data	23	30	Quantum Algorithms	8
13	Quantum Entanglement	22	31	Cloud Security	7
14	Optimization	21	32	Mobile Cloud Computing	7
15	Particle Swarm Optimization (PSO)	21	33	Cloud Service Providers	7
16	Authentication	19			
17	Public Key Cryptography	18			
18	Quantum Communication	18			

- All of 25 most productive organizations significantly differ in their rank order by total papers (Col 1) and citation/ paper (Col 10). This implies that these organizations differ in the quantity and quality of research. For instance, Osterreichische Academie der Wissenschaften, Austria ranks top in citations per paper but ranks at bottom (rank 25) in publications output.

Table 6. Top 25 Most Impactful Organizations in Quantum Cloud Computing Ranked by Productivity 2000-2019

TP RANK	Name of the Organization	TP	TC	CPP	HI	ICP	ICP(%)	RCI	CPP RANK
1	Ministry of Education, China	12	52	4.33	4	2	16.67	0.22	13
2	Nanjing University of Information Science & Technology, China	10	34	3.40	4	3	30.00	0.17	15
3	Southeast University, Nanjing, China	8	23	2.88	2	2	25.00	0.14	17
4	Dalian Jiaotong University, China	6	0	0.00	0	0	0.00	0.00	25
5	University of Electronics Science & Technology, China	6	43	7.17	2	1	16.67	0.36	9
6	University of Science & Technology of China	6	51	8.50	4	2	33.33	0.43	7
7	Kharkiv National University of Radio Electronics, Ukraine	6	21	3.50	2	3	50.00	0.18	14
8	Nanjing University of Aeronautics & Astronautics, China	6	19	3.17	2	2	33.33	0.16	16
9	Ain Shams University, Egypt	5	13	2.60	1	5	100.00	0.13	19
10	Tsinghua University, China	5	39	7.80	2	2	40.00	0.39	8
11	University of Wien, Austria	5	247	49.40	3	2	40.00	2.49	3
12	University of Oxford, U.K.	5	74	14.80	4	5	100.00	0.75	4
13	Budhapest University of Technology & Economics, Hungary	5	34	6.80	3	4	80.00	0.34	10

14	Nanjing University, China	5	393	78.60	1	0	0.00	3.96	2
15	CNRS, France	4	46	11.50	3	3	75.00	0.58	5
16	Southwest Jiaotong University, China	4	9	2.25	1	1	25.00	0.11	21
17	Tamagawa University, Japan	4	8	2.00	2	0	0.00	0.10	22
18	Beijing University of Posts & Telecommunications, China	4	26	6.50	2	1	25.00	0.33	11
19	Southwest Petroleum University, China	4	41	10.25	2	1	25.00	0.52	6
20	Henan Polytechnic University, China	4	4	1.00	1	0	0.00	0.05	23
21	JNTU College of Engineering, Pulivendula, India	4	10	2.50	2	0	0.00	0.13	20
22	Quanta Cloud Technology, Taiwan	3	3	1.00	1	3	100.00	0.05	24
23	Shenzhen University, China	3	8	2.67	2	0	0.00	0.13	18
24	Universida degli studi di Perugia, Italy	3	17	5.67	2	2	66.67	0.29	12
25	Osterreichische Academie der Wissenschaften, Austria	3	255	85.00	3	2	66.67	4.28	1
		130	1470	11.31	2.2	46	35.38	0.57	
		459	9111	19.85					
		28.32	16.13						

*TP=Total publications; TC=Total citations; CPP=Citations per paper; ICP=International collaborative papers; RCI=Relative citation index

4.5 TOP 25 MOST PRODUCTIVE AUTHORS

A total of 208 authors participated in global quantum cloud computing research during 2000-19. Of these, 122 authors published 1 paper each, 51 authors 2 papers each, 21 authors 3 papers each, 12 authors 4 papers each and 2 authors 5 papers each. Of the 25 authors, 12 were from China. 5 from Ukraine, 4 from Egypt and 1 each from Geogia, India, Japan and Taiwan. The research productivity of top 25 most productive authors varied from 3 to 5 publications per author. Together they contributed 19.83% (91) global publications share and 6.18% (563) global citations share during 2000-19. The scientometric profile of top 25 most productive and most impactful authors is presented in Table 7.

- Fourteen authors registered their publications output above the group average of 3.64: V. Hahanov and W. Liu (5 papers each), S. Abbas, S. Chumachenko, E.S.M. El-Horbaty, A. Hahanova, O. Hirota, H.L.Huang, E. Litvinova, G. Murali, A.M.M.Salem, X. Wang, C. Xu and X. Zhang (4 papers each).
- Seven authors registered their citation per paper and relative citation count above the group average (6.19 and 0.31) of all authors: B. Abd-El-Atty (29.33 and 1.48), R.C. Fortenberry (19.0 and 0.96), C. Xu at University of Science & Technology of China (13.67 and 0.69), C. Xu at University of Electronics Science & Technology, China (10.25 and 0.52), X. Zhang (10.25 and 0.52), H.L.Huang (9.75 and 0.49) and X. Wang (6.75 and 0.34).
- All of 25 most productive authors significantly differ in their rank order by total papers (Col 1) and by citations/ paper (Col 11 for Rank)). This implies the authors differ in the quantity and quality of research. For instance, B. Abd-El-Atty ranks top in citations per paper but ranks 15th in publications output.

Table 7. Top 25 Most Impactful Authors in Quantum Cloud Computing Ranked by Author Productivity 2000-2019

TP RANK	Name of the Author	Affiliation of the Author	TP	TC	CPP	HI	ICP	ICP (%)	RCI	CPP RANK
1	V. Hahanov	Kharkiv National University of Radio Electronics, UKraine	5	21	4.20	2	3	60.00	0.21	14
2	W. Liu	Nanjing University of Information Science & Technology, China	5	12	2.40	2	1	20.00	0.12	21
3	S. Abbas	Ain Shams University, Egypt	4	13	3.25	1	4	100.00	0.16	17
4	S. Chumachenko	Kharkiv National University of Radio Electronics, Ukraine	4	15	3.75	2	1	25.00	0.19	16
5	E.S.M, El-Horbaty	Ain Shams University, Egypt	4	13	3.25	1	4	100.00	0.16	18
6	A. Hahanova	Kharkiv National University of Radio Electronics, Ukraine	4	6	1.50	2	3	75.00	0.08	23
7	O.Hirota	Tamagawa University, Japan	4	8	2.00	2	0	0.00	0.10	22
8	H.L.Huang	University of Science & Technology of China	4	39	9.75	3	1	25.00	0.49	6
9	E. Litvinova	Kharkiv National University of Radio Electronics, Ukraine	4	19	4.75	2	3	75.00	0.24	13
10	G. Murali	JNTUA College of Engineering, India	4	10	2.50	2	0	0.00	0.13	20
11	A.M.M.Salem	Ain Shams University, Egypt	4	13	3.25	1	4	100.00	0.16	19
12	X. Wang	University of Science & Technology of China	4	27	6.75	3	0	0.00	0.34	7

13	C.Xu	University of Electronics Science & Technology, China	4	41	10.25	2	1	25.00	0.52	4
14	X.Zhang	University of Electronics Science & Technology , China	4	41	10.25	2	1	25.00	0.52	5
15	B. Abd-El-Atty	Manofia University, Egypt	3	88	29.33	3	3	100.00	1.48	1
16	W.S.Bao	University of Science & Technology of China	3	17	5.67	2	0	0.00	0.29	8
17	S. Chang	Quantia Cloud Technology, Taiwan	3	3	1.00	1	2	66.67	0.05	24
18	H. Chen	Southeast University, Nanjing, China	3	12	4.00	1	1	33.33	0.20	15
19	W. Ding	Nantong University, China	3	15	5.00	1	1	33.33	0.25	12
20	A. Doroshenko	Natrional Academy of Science, Ukraine	3	1	0.33	1	0	0.00	0.02	25
21	R.C. Fortenberry	Georgia Southern University, Georgia	3	57	19.00	3	2	66.67	0.96	2
22	X.Q. Fu	University of Science & Technology of China	3	17	5.67	2	1	33.33	0.29	9
23	F.G. Li	University of Science & Technology of China	3	17	5.67	2	0	0.00	0.29	10
24	T. Li	University of Science & Technology of China	3	17	5.67	2	1	33.33	0.29	11
25	C. Xu	University of Science & Technology of China	3	41	13.67	2	1	33.33	0.69	3
		Total of 25 organizations	91	563	6.19	1.88	38	41.76	0.31	
		THe global total	459	9111	19.85					
		Share of top 20 organizations in global total	19.83	6.18						

*TP=Total publications; TC=Total citations; CPP=Citations per paper; ICP=International collaborative papers; RCI=Relative citation index

4.6 MEDIUM OF RESEARCH COMMUNICATION

Of the total world output that appeared in the domain of quantum cloud computing research, 39.43% (181) appeared in journals, 35.95% (165) in conference proceedings, and 21.35% (98) as book series. The remaining output appeared as books, 2.61% (12), and as publications in trade journals 0.65% (3) in 2000-2019. A total of 122 journals reported 181 research papers in quantum cloud computing research. Of the 122 journals, 89 published 1 paper each, 22 published 2 papers each, 8 published 3 papers each, 2 published 4 papers each and 1 each published 6 and 10 papers during 2000-19.

The top 25 most productive journals accounted for a 41.44% share of global output in quantum cloud computing research output reported in journals 2000-2019. The top 6 leading journals in the subject are:: IEEE Access(10 papers), Physical Review Letters (6 papers), Nature, New Journal of Physics and Physical Review A (4 papers each) and Concurrency Computation (3 papers). The top 6 most impactful journals ranked by citation per paper are: Information Sciences (508.0), Science (79.5), Physical Review Letters (43.33), Nature (41.5), Physical Review A (39.75) and Optica (36.5). The top 6 journals in terms of total citations received were: Information Sciences (1524), Physical Review Letters (260), Nature (166), Science (159), Physical Review A (159) and IEEE Access (110) (Table 8).

Table 8. Top 25 Most Impactful Journals in Quantum Cloud Computing Ranked by Journal Productivity 2000-2019

JL PRODUC RANK	Journal Name	TP	TC	CPP	CPP RANK
1	IEEE Access	10	110	11.00	13
2	Physical Review Letters	6	260	43.33	3
3	Nature	4	166	41.50	4
4	New Journal of Physics	4	69	17.25	11
5	Physical Review A	4	159	39.75	5
6	Concurrency Computation	3	20	6.67	18
7	Future Generation Computer Systems	3	20	6.67	19

8	Information Sciences	3	1524	508.0	1
9	Internation Journal of High Performance Computing & Networking	3	25	8.33	17
10	International Journal of Recent Technology & Engineering	3	0	0.00	25
11	Nature Communication	3	98	32.67	7
12	Transactions of the Emerging Telecommunication & Technology	3	11	3.67	21
13	China Communications	2	10	5.00	20
14	Clustering Computing	2	6	3.00	22
15	Computer Physics Communications	2	35	17.50	10
16	Computing in Science & Engineering	2	41	20.50	9
17	IEEE Systems Journal	2	17	8.50	16
18	International Journal of Applied Engineering Research	2	1	0.50	24
19	International Journal of Quantum Chemistry	2	46	23.00	8
20	International Journal of Theoretical Physics	2	5	2.50	23
21	International Journal of Computational Chemistry	2	26	13.00	12
22	Journal of Network & Computer Applications	2	19	9.50	14
23	Journal of Physical Chemistry A	2	19	9.50	15
24	Science	2	159	79.50	2
25	Optica	2	73	36.50	6
TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper					

4.7 HIGHLY CITED PAPERS

Of the total 459 publications on quantum cloud computing across the world during 2000-2019, only eleven publications (2.34% share) registered 52 to 1481 citations per paper (assumed here as highly cited). These highly cited papers together received a total of 2379 citations, since their publication, averaging to 216.27 citations per paper.

The distribution of eleven highly cited papers is highly skewed: 6 papers registered citations in the range 52-100 per paper, 4 papers in the citation range 105-186 and 1 paper received 1481 citations.. Among eleven highly cited papers, the U.K. contributed the highest number of papers (4), followed by the USA (3), Canada and Italy (2 each), Austria, Denmark, France, Germany, Ireland, Israel, Japan, Macau, Singapore and Switzerland (1 each).

Among the eleven highly cited papers (10 articles and 1 conference paper), five did not involve any collaboration, and one was published in collaboration at national level and five published in collaboration at international level. These eleven papers were contributed by 57 authors from 27 organizations. Eight journals reported all of the eleven highly cited papers. Physical Review Letters published three papers, and Accounts of Chemical Research, Information Science, Nature, Nature Communication, Optica, Physical Review A and Science published one paper each.

5 SUMMARY

The study used metrics to provide a quantitative and qualitative description of the global research that appeared in the domain of quantum cloud computing for the period 2000-2019. The data for the study was sourced from the Scopus database. The global quantum cloud computing research accounted for a total of 459 publications in 20 years during 2000-2019, an average of 23 publications per year, registered a 39.63% average annual growth, and scored an average of 19.85 citations per paper (CPP) since publication. Nearly a 30% share of global research output (137 out of 459) resulted from research projects funded by more than 50 national and international research funding agencies. The sponsored research papers registered an average of 29.85 citations per paper, far above the global average of 19.85 CPP. Highly cited papers is another indicator to assess

the quality of research. The study notes that in all, eleven (2.34% share) publications out of the total output of 459 had received 52 to 1481 citations per paper (assumed here as highly cited papers). Together these highly cited papers received a total of 2379 citations, averaging to 216.27 citations per paper. Evidently, the quality of global research in the subject assessed on the indicator of highly cited papers has not been significant.

In all, 50 countries participated in global research on quantum cloud computing. The study notes that the top 10 most productive countries contributed a 76.47% global publication share and a 39.60% global citation share. China leads the ranking with a global publication share of 30.28%, followed by India and USA (11.98% and 11.55%), U.K. (5.66%) and the other 6 countries contributed from 2.18% to 3.49% share during the period. Seven of top 10 countries, namely Canada (1.19), U.K. and Italy (1.13 each), Japan (1.05), Germany (0.84), Egypt (0.60) and USA (0.53) registered their relative index above the group average - an indicator that describes the relative quality of their research. Their individual country research output as a share of international collaborative papers varied from 21.74% to 62.69%, with an average of 52.12%. This implies that international collaborative research undertaken with most productive countries did influence the quality of quantum cloud computing research. Computer Science is found to be the most sought after area of research in the subject. Statistically, it accounted for the largest global publication share (71.46%), followed by Engineering and Mathematics (33.77% and 28.98%), Physics & Astronomy (15.25%), etc.

A total of 208 authors from 247 academic and research organizations participated in global quantum cloud computing research during 2000-19. The top 25 global organizations as well as top 25 authors had contributed 28.32% and 19.83% global publication share and 16.13% and 6.18% global citation share respectively. The top 25 most productive journals (out of a total of 122 source journals) accounted for a significant 41.44% publications share.

6 CONCLUSION

The study concludes that quantum cloud computing as a topic of research has witnessed a high average annual growth 39.63%, but in terms of

institutional productivity its performance was unexpectedly low, 1.8 papers per organization in a 20-year period. This demonstrates that the quantum cloud computing research is still in its nascent stage of development. However, it is observed that as a technology, quantum computing has been making rapid strides. For instance, D-Wave the leading most IT company from Canada has since launched its fifth generation 5000+ qubit quantum computer.

REFERENCES

1. What is quantum cloud computing. http://quantumly.com/quantum-cloud-computer-computing.html
2. Metz, Cade. The race to sell quantum computers begins before they really exist. https://www.wired.com/2017/03/race-sell-true-quantum-computers-begins-really-exist/
3. Lardinois, Frederic. D-Wave launches its 5,000 qubit advantage system. https://techcrunch.com/2020/09/29/d-wave-launches-its-5000-qubit-advantage-system/
4. Tilley, Aaron. IBM loads quantum computing onto its cloud. https://www.forbes.com/sites/aarontilley/2017/03/06/ibm-quantum-computing-cloud/#43cf540e77a2
5. Dhawan, S.M., Gupta, B.M., & Bhusan, S. (2018). Global publications output in quantum computing research: A scientometric assessment during 2007-16. Emerging Science Journal 2018, 4(2), DOI:10.28991/ESJ-2018-01147Corpus ID: 70112201
6. Tolcheev, V.O. Scientometric analysis of the current state and prospects of the development of quantum technologies. Autom. Doc. Math. Linguist. 52, 121–133 (2018). https://doi.org/10.3103/S000510551803007
7. Gupta BM, Singh N, Gupta R. International cloud computing literature: A scientometric analysis for 2004-13. Information Studies April and July 2015, 21(2-3), 111-31.
8. Gupta BM, Singh N, Gupta R. Indian cloud computing research: A scientometric assessment of publications output during. 2004.-13. SRELS Journal of Information Management October. 2015, 52(5):315-26.
9. Gupta, B.M. Social cloud research: A scientometrics assessment of global publications output during 2009–18. International Journal of Information

Dissemination and Technology 2019, 9(2), 85-89 Article DOI : 10.5958/2249-5576.2019.00018.9

10. Gupta, B. M. Dhawan S., Gupta Ritu. Mobile cloud computing: A scientometric asessment of global publications output during 2007-16. Journal of Scientometric Research December 2017, 6(3), 186-194.DOI:10.5530/jscires.6.3.26