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MAPPING OF THE RESEARCH OUTPUT ON 'WIRELESS COMMUNICATION (2010 - 2018)': A WEB OF SCIENCE BASED SCIENTOMETRIC EVALUATION

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MAPPING OF THE RESEARCH OUTPUT ON ‘WIRELESS COMMUNICATION (2010 - 2018)’ : A WEB OF SCIENCE BASED SCIENTOMETRIC EVALUATION

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Abstract

The present study aimed at examining the quantitative and qualitative aspects of literature output on Wireless Communication as available and indexed in Web of Science database covering a nine year period i.e from 2010 to 2018. A total of 8482 records were downloaded from Web of Science core collection database. The downloaded records, in txt format, were exported to Bibexcel software for analyzing the data for certain quantitative and qualitative indicators. MS Excel programme was used to do all the necessary calculations and preparation of cross tables with Pivot Table options. The findings were presented under the major heads as basic metrics, author metrics, quality metrics, institution and publisher metrics, future metrics and geo metrics.

The findings reveal that there is a gradual growth of publications on WLC during the study period. An exponential growth pattern was found. The Relative Growth Rate shows a decreasing trend and the Doubling time shows an increasing trend. Rather than single authored publications, multi-authored publications are more in numbers. The authors preferred to work in very small / small teams. The Degree of collaboration kept on growing throughout the study period. The researchers in WLC preferred to publish their research findings in the form of Journal articles. English is the preferred language of publications among the WLC researchers. China and USA lead the world in WLC research followed by India in the third place. Intra-county collaboration was found to be more in numbers than inter-country collaboration in WLC research output. The journals publishing research papers

in WLC research do not fall in Bradford's law of scattering. The time series analysis shows that the growth of WLC research output will be in better prospects in the years to come.

Keywords: Scientometrics, Wireless Communication, Web of Science, author metrics, geo metrics, Bradford's law

1 INTRODUCTION

Large quantum of research publications are being brought out and added to the existing information heap now-a-days. Such a situation warrants quantitative and qualitative analysis of the literature being published through metric studies. Such studies help to identify the research performance, emerging research areas, collaboration pattern, citing and cited relationship, quality of publishing documents, journal and channel. Scientometric analysis has received an adequate attention and it has been widely applied to evaluate the research activities of the scientists and the growth of literature. It aims to integrate the cognitive or intellectual structure of research with a view to appraise the relations among the authors, institutions, journal articles and as a means of assisting the peer review procedure. Scientometric analysis of literature in various disciplines has been carried out by using primary or secondary sources to examine the quantitative aspects of literature growth in a particular field of knowledge. Quantitative measurement of publications, citations and other Scientometric parameters have been largely applied and used in evaluating scientific research.

Scientometric has become a more powerful instrument of science policy worldwide. It determines the way to prioritize the project funding and assessment of institutional priorities, perspectives, and capacity at a great extent. The Scientometric evaluation of research activities is a valuable method for the development of new scientific and technological knowledge. As a whole, Scientometric becomes a very prospective research field in the general studies of science, providing powerful and effective instruments for analyses and evaluations in the sphere of science as a significant accelerator of the economic growth and social prosperity. Results of such research could provide a better sight on the scientific status of researchers in terms of the type and number of research articles they have published. Also the results can help the relevant authorities to develop better policies with active participation in the growth and development of research in national and international arena. So, the researcher has planned to undertake a Scientometric study.

2 STATEMENT OF THE PROBLEM

Every scientific discipline grows in its own pace. Depending on the inevitability and immediate applications, every field of work grows both quantitatively and qualitatively. In the ever-growing field of internet, both computer and communication technologies play a pivotal role. These two tools are the backbone of WWW. Without communication technologies, it is difficult to connect the computers to one another. Communication technologies grow faster. Wireless communication is the most emerging field of communication science. An analysis of reviews collected by the researcher on the Scientometric study of various science subjects with a special reference to physics revealed that no comprehensive metric study on wireless communication has taken up till date by the researchers both at national and global level. So, the researcher wanted to undertake a Scientometric study on the global research output on the topic ‘wireless communication’. Thus, the present research work is entitled as ‘Mapping of the Research Output on ‘Wireless Communication (2010 - 2018)’: A Web of Science based Scientometric Evaluation’.

3 OPERATIONAL DEFINITIONS

3.1 Scientometrics

Nalimov and Mulchenko (1989) defined Scientometrics as ‘the quantitative method which deals with the analysis of science viewed as an information process’.

Beck (1978) defined Scientometrics as ‘a study of the quantitative evaluation and inter comparison of scientific activity, productivity and progress’.

Koenig and Bookstein (1995) defined Scientometrics as “the science of measuring science”.

3.2 Wireless Communication

Communication Systems can be Wired or Wireless and the medium used for communication can be Guided or Unguided. In Wired Communication, the medium is a physical path like Co-axial Cables, Twisted Pair Cables and Optical Fiber Links etc. which guides the signal to propagate from one point to other. Such type of medium is called Guided Medium.

4 REVIEW OF LITERATURE

4.1 Engineering and Technology

Gupta and Dhawan (2018) undertook a study on Scientometric Assessment of Global Publications Output of Three Dimensional (3D) Printing during 2007-16 based on publications as indexed in Scopus database during 2007-16. The study reveals that the global research output in field of 3D printing cumulated to 7309 publication in 10 year during 2007-16. The USA leads the ranking with 32.03% global publications share, followed distantly by China (13.85 % share). Engineering is the most favoured subject in 3D printing research (with 53.76 % publications share). Medical application is the most favoured topic in 3D printing research accounting for the highest number of publications (1401). 3D printing accounts for the highest of publications (393). 'Plastic as a material' is the most used material in 3D printing research accounting for highest number of 575 publications, followed by ceramic (281), titanium (218). About 3644 authors participated in 3D printing research during 2007-16. Out of the total world output in 3D printing research, 62.98 per cent (4603) appeared in journals, 28.96 per cent (2117) in conference proceedings. Only 114 (1.56 % share) cumulated 101 to 973 citations per papers (cumulative total 21996 citations) since their publication during 2007-16, averaging to 192.95 citations per papers. Among the highly cited papers, USA collaborated in the largest number of papers (67 papers).

Batcha (2017) undertook a scientometric study on research Output Analysis on Robotic Technology. Data for this study was collected from the Web of Science database. The period of study is from 1990 to 2016. Totally 3703 institutions resulted out the output of 5316. Among them, top 30 institutions' output is noteworthy. The developed countries like USA, UK and Germany concentrate in the field of robotic technology. Yet Major portion of contribution (36.30%) is from USA. More number of publications among the researchers were in the form of articles which is amounted to be top (67.40%). The language preferred in exchanging research results is English (87.70%) followed by German. The prolific authors in the field of robotic technology are highly found from USA. Among them, the contribution by Bloss R is appreciable. The citation counts seem to be high in the year 2015 which has recorded 11,000 citations.

Pattanashetti and Harinarayana (2017) evaluated the research output in the field of mechanical engineering using scientometric indicators. It is a comparative study of India, Japan, and South Korea. The study is restricted to articles indexed in the Science Citation Index – Web of Science for the period 2000 to 2014. Overall, 29% of the total number of articles (for all three countries) has been authored by three authors, followed by 28% with two authors. A total of 2,66,902 articles cited 30,578 articles published by Japan, likewise for South Korea 2,04,393 articles cite 24,494 articles, and 20,836 articles published by India received 1,97,679 citations. The citations per paper rate are highest for India with 9.5 followed by 8.7 for Japan and 8.3 for South Korea. The study suggests the need to increase the pace of Japanese research in mechanical engineering as there is a decline in the number of publications.

Kumar (2016) carried a Scientometric Study of Artificial Neural Networks Research in India Data. For this study data were collected from the Science Citation Index – Expanded (SCI-E) for a period of 24 years from 1991-2014 by giving a single keyword “artificial neural network” in the topic field. This study reveals that India contributed a total of 3411 papers on ANNs research during 1991-2014. China ranked as number one with 7599 (15.5%) publications followed by USA with about the same 15.4% publications. India is ranked number three on the basis of research publications with 7% papers. The total Indian research output of 3411 papers was contributed by 5654 unique authors. There are only 8 authors who have published more than 20 papers during the period of study on ANNs research in India. Ganapati Panda of Indian Institute of Technology, Bhubaneswar is the most prolific author with 42 publications. Research papers on ANNs in India are published in 893 journals and 508 conferences. The 3411 papers appeared in 894 journals published from 44 different countries. However, journals published from top seven countries contributed 92.6% papers. These seven countries are USA, UK, Netherlands, Germany, India, Switzerland and South Korea. The remainder of the output (7.4%) was in journals published from 37 other countries. Highest number of collaborating links was with USA with 88 (2.58%) papers and followed by Canada with 36 (1.06%) papers. There are 92 (2.7%) publications which received more than 50 citations. Out of the total publications on ANNs research, 1119(32.9%) were either conference papers or papers published in journals which are yet to receive their impact factor from Journal Citation Report. 19.2% papers are published in journals with impact factor less than 1, and 25.4% papers are published in journals with impact factor in the range of 1 to 2.

Santha Kumar and Kaliyaperumal (2015) conducted a study on scientometric analysis of mobile technology published on Web of Science database during 2000–2013. Totally 10,638 publications were published in the field. The findings revealed that the average number of publications published per year was 759.86 and the highest number of publications 1495 were published in 2013. Out of total publications, 9037 were produced by multiple authors and 1601 by single authors. Authors from USA have contributed maximum number of publications compared to the other countries and India stood 16th ranking in terms of productivity in this study period. The most prolific author is Kim who contributed 42 publications followed by Kim with 36 publications. Collaboration Index ranges from 3.67 (2000) to 4.57 (2009) with an average of 4.32 per joint authored paper which implies the research team falls between 3 and 5 in the field of mobile technology. University of California System (USA) is the highly contributed institutions with 243 publications followed by University of London (UK) with 149 publications. India contributed lesser no of publications.

Balasubramani, Gopalakrishnan and Gnanasekaran (2014) undertook a scientometric study on Growth of Research Output in Genetic Engineering. For this study, the data were downloaded from the multi discipline citation database ‘Scopus’ and there were 165984 records contributed worldwide over a period of 40 years from 1974-2013. The average number of publications per year was 4149. Maximum number of articles 123239 (74.25%) are published in journals. This is followed by reviews 18329 (11.04%). Research outputs on Genetic Engineering were contributed in 27 major sub-fields. Also the subfields of 1025 publications were unidentified. The subject biochemistry, genetics and molecular biology constituted the highest number of articles i.e. 89756 (54.08%). Among the literatures published worldwide in genetic engineering, 18,208 publications seem to be the joint contribution of two or more countries. USA published maximum number of articles i.e 59877 (36.07%) publications and it holds first place. India holds 8th place with 5354 (3.23%) publications. The researcher concluded that most popular subjects of research are Biochemistry, Genetics, Molecular Medicine, Immunology, Microbiology, Agricultural and Biological Sciences. In order to bring about more balance in future between different subfields of Genetic Engineering, more attention and funding needs to be focused. The lack of fund to the research is a major drawback to the researchers.

Santhanakarthykeyan, Padma, Grace and Ravikrishnan (2014) conducted a research on Scientometric Analysis of Recent Aeronautical Research during 2003–2012. The data for this research is collected from Aeronautical articles indexed in IEEE database Citation Index produced by the Institute of Electrical and Electronics Engineering. At the time of this study (2003 -2012), the IEEE database listed a total of 86 aeronautical unique title journals. The findings of this study revealed that 100 percent of the articles were in English. Maximum number of the articles (36.5%) was contributed by three authors. Out of 86 articles, the highest number i.e. 40 (47.1%) has been contributed by China professionals that is followed with approximately 25.9% by USA authors. The maximum references of 199 (37.4%) was made in the year 2012. Nearly 34.7% of the articles were having references between 10 and 50 while 28% of the articles have references above 50. No references were made for the articles in the year 2007. The collected data indicates that out of 894 articles, 458 (51.23%) articles were cited and 436 (48.77%) were not cited. Out of 458 cited articles those with one citations has the highest number (182; about 40%) and other 60 percent has got citations between 2 to more than 10 times. The average number of citations for 458 cited articles is 3.14, but as a whole for all cited and not cited articles is 1.60 per article. From the data collected, it shows that most of the articles (41.9%) are published by IEEE and 23.3% of the articles are published in AIP journals, 14% of the articles are from BIAI.

Karpagam, Gopalakrishnan, Natarajan and Ramesh Babu (2011) studied the growth pattern of Nanoscience and Nanotechnology literature in India during 1990–2009 (20 years). Data for this study was collected from Scopus database. The finding of this study shows that nearly 22,765 bibliographic records were traced out. Out of 7,59,704 publications, 54.63% of contribution are from USA, China, Japan and Germany. 20.29% of contributions are from USA alone and ranks top in the position. Out of the top 10 countries, India holds 7th rank with its contribution of 3.00% in the field of nanoscience and nanotechnology during the period 1990–2009. Indian publication output in Nanoscience and Nanotechnology during the period 1990–2009 consists of 22,765 records, with an average publication per year as 1,138. Out of the 22,765 published papers, 6,330 (28%) papers did not have any citation and the remaining 72% had one or more citations. Indian Institute of Technology (IIT) produced 1831 papers during the period 2000–2007. Based on the average citations per paper the Journal of Material Chemistry holds the first position (21.658). The contribution of India has increased

greatly in the last 5 years. The field of Nano science and nanotechnology is currently led by USA, China, and Japan.

Nazim and Moin (2008) investigated the scientific output in the field of 'nanotechnology', the aim being to offer an overview of research trends in this field and characterize its most important aspects such as growth of literature, authorship pattern, most productive journals, authors, countries, etc. A total of 2675 articles for the period of 1991-2006 were collected from Web of Science (WoS). The findings of the study revealed that 167 articles were published in each year. English was found the most popular language with 97.5% of the total articles. The literature on nanotechnology was scattered in the journals of 145 subject areas. Among a total of 145 subject areas, it can be seen that the greatest interest in the study of nanotechnology is shown in the area material science multidisciplinary. Collaborative research was found to be common in the field of nanotechnology as 83% of the total articles were contributed by two or more than two authors. The country with the greatest output in terms of research on nanotechnology is the USA (40.56%).

4.2 Wireless Communication

Manickaraj, Rajendran and Elango (2014) conducted a Scientometric study on research output of wireless communication. This study analyzed the research output in Wireless Communication published during the period of 2001 – 2012 based on the bibliographic records extracted from SCOPUS Database. The analysis includes year wise output, language wise distribution, leading contributors (country, institute and author) and most preferred journals. A total of 9565 articles published during this study period. The United States published most of the articles and most of the articles are in English. IEEE Journals preferred by researchers in the field of Wireless Communication.

Arul Dhanakar (2011) investigated the research output of wireless communication. This study analyzed 31882 records covered in two databases i.e COMPENDEX and INSPEC during the period of 1970 – 2009. The study findings revealed that the majority of articles were published in English. Maximum numbers of articles were published by US. Maximum number of article was contributed by multiple authors.

5 AIM OF THE STUDY

To conduct a quantitative study on the research output of Wireless Communication as indexed in Web of Science database (2010-2018)

5.1 OBJECTIVES OF THE STUDY

The major objectives of the present study are :

1. To conduct basic metric analyses on global WLC research productivity in terms of year-wise growth, block-wise growth, documents types, languages etc.
2. To apply various Scientometric indicators on global WLC research productivity to get valid inferences
3. To find out the most prolific authors, institutions, countries, funding agencies and publishers in WLC research output
4. To examine the collaborative research pattern in global WLC research output – author collaboration, country collaboration and institutional collaboration.
5. To weigh the qualitative aspects of global research productivity of WLC – total citations, WOS citations, usage180, usage2013 and h-index.
6. To unearth the prominent research areas and WOS categories in global WLC research output
7. To trace out the authorship pattern of global WLC research output
8. To apply bibliometric laws on global WLC research output and
9. To estimate the future growth of WLC research productivity

6 HYPOTHESES

Keeping the objectives stated above in view, the following hypotheses are formulated and tested with appropriate statistical tools:

1. The global research output on Wireless Communication follows an exponential growth pattern.
2. There is an inverse relationship between Relative Growth Rate and Doubling Time.
3. English is the most preferred language among the researchers in publishing research findings in WLC.
4. There has been an increasing trend in collaborative research during the study period.
5. The journal source of publication of Wireless Communication research output absorbs the predominant place in comparison with other source of publications.
6. The distribution of Wireless Communication research output conform the implications of Bradford's law.
7. The future estimate of WLC research output shows an increasing trend.

7 RESEARCH DESIGN

7.1 Research type

The study undertaken by the researcher is a quantitative study. It is a Scientometric study of research productivity of publications in the field of Wireless Communication indexed in the Web of Science database covering 9 years period from 2010 to 2018.

7.2 Data Base Selection

The necessary data has been downloaded from Web of Science database. Web of Science includes the Science Citation Index (SCI), Social Science Citation Index (SSCI) and Arts & Humanities Citation Index (ACHI). The WoS is an online bibliographic database of around 20,000 journals. The service is provided by Clarivate Analytics (formerly by Thomson Reuters who had taken it from the Institute for Scientific Information (ISI) in Philadelphia). The publications on “Wireless Communication” by the scientists were taken as a source for the present study.

7.3 Data collection process

Step 1: Logged on to Web of Science database (In the Department of Library and Information Science, Madurai Kamaraj University, Madurai) on 10th February, 2019.

Step 2: Choose ‘Web of Science Core Collection’ in the ‘select a database option’.

Step 3: The keyword “Wireless Communication” was typed as a search term in the search interface of Web of Science.

Step 4: The ‘Topic’ option was selected which is available to the right of the search box.

Step 5: In the time slot, 2010-2018 was set as the range for the data collection period.

Step 6 : The Search button was clicked.

Step 6: The result was displayed in the screen. The search results include a total of 8482 records.

Step 7: Records were saved in plain text format. At a time 500 records were downloaded.

Step 8: Default data analysis reports was collected for data interpretation.

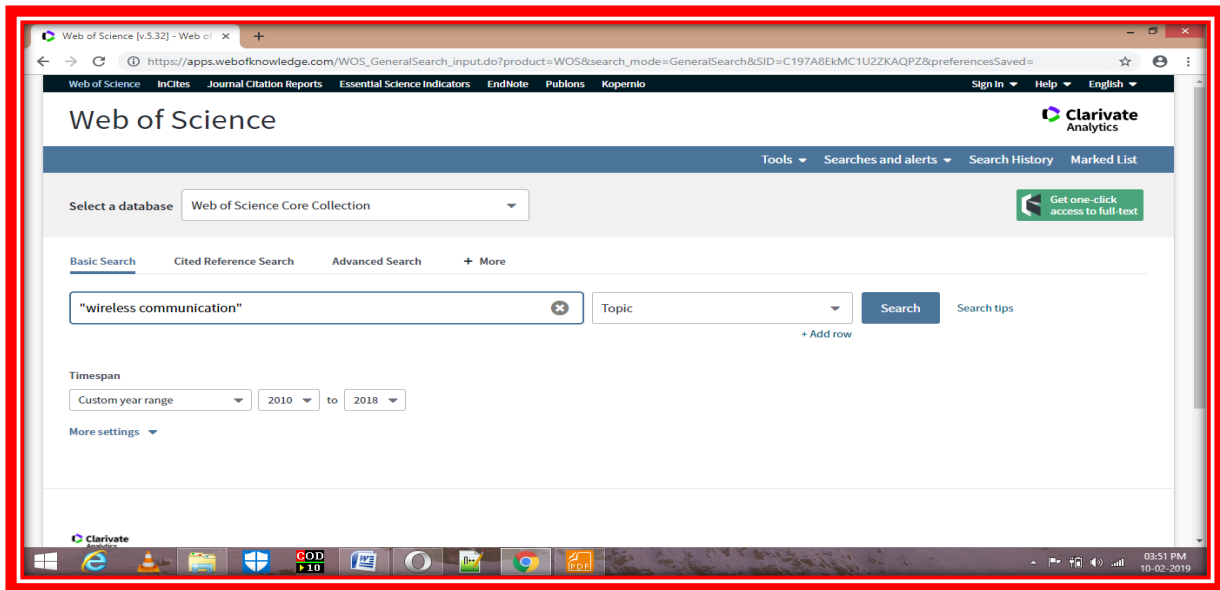


Figure 1: Searching for ‘Wireless Communication’ output in Web of Science Database (Steps 1-4).

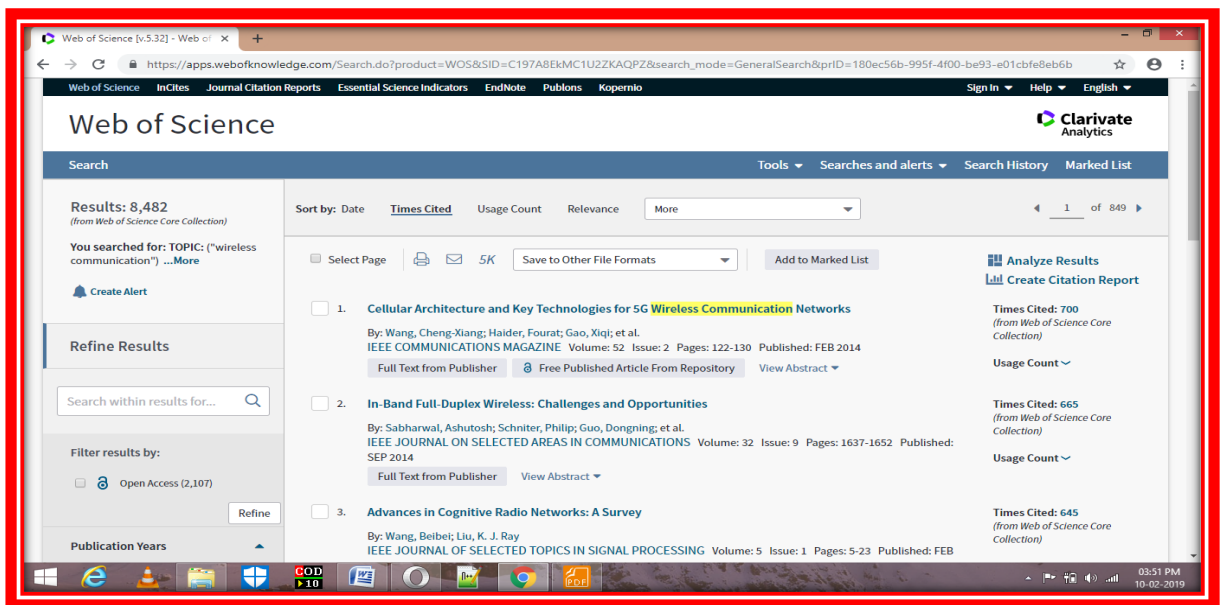


Figure 2: Page Showing result for Wireless communication (Steps 5-6)

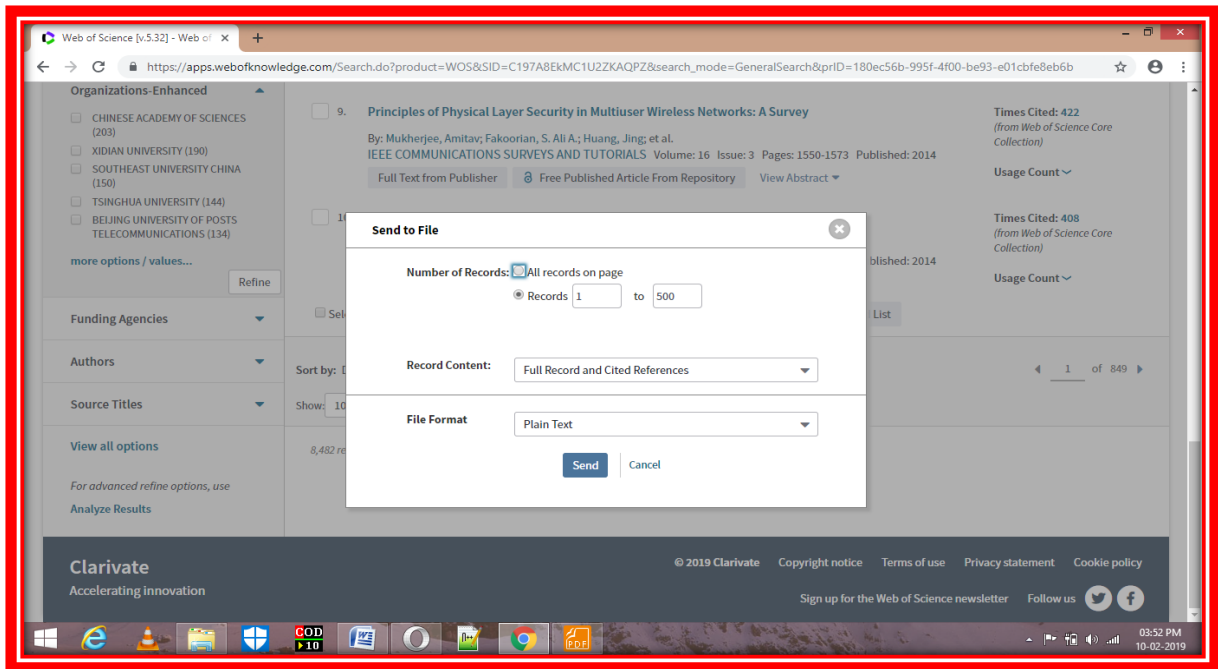


Figure 3 : Saving 500 Records at a time (Step 7)

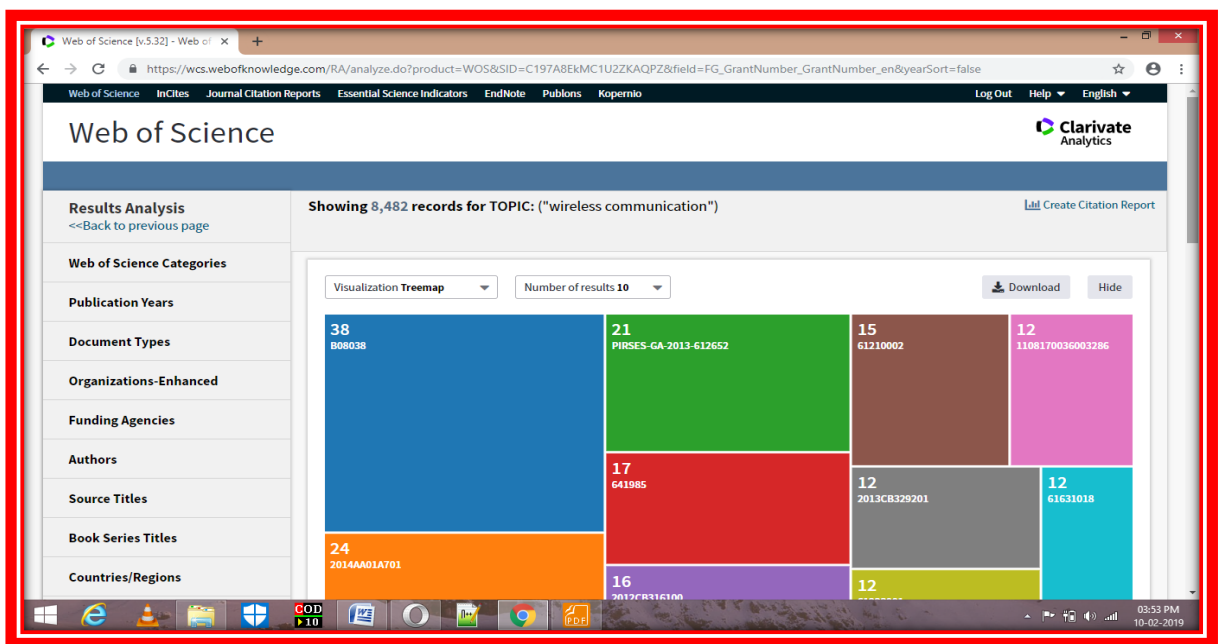


Figure 4: Collection of default data analysis reports (Step 8)

7.4 SCOPES AND LIMITATIONS

The present study has the following limitations with its operating purview.

- The data covered in this study were collected only from the Web of Science database.
- The study is limited to the research publications of 9 years period only (2010 to 2018).

- This study is a Scientometric study of research output in the field of Wireless Communication as depicted only on Web of Science database as on 10th FEB 2019.

8 DATA ANALYSIS AND PRESENTATION

The plain text files (17 in numbers) comprising of 8482 documents on the selected topic was analyzed in the following manner.

- a) The readymade indicators available in the Web of Science database website were downloaded directly by the researcher. Example: Funding bodies, Organizations-enhance, etc.
- b) The data was fed into bibexcel software and a good number of operators were used to draw few tables. Example: h-index of authors, cited references, total citations etc.
- c) Few results either got from WoS database directly or from Bibexcel software, are taken to MS-Excel programme and necessary calculations were done to draw few more interferences. Eg. Time Series Analysis, Relative Growth Rate, Doubling Time, Degree of Collaboration etc.

Apart from the tables, charts and diagrams like pie chart, bar diagram, line diagram and staked cylinders were used to illustrate the interpretation in a visual/graphic pattern.

8.1 CATEGORIZATION OF METRIC INDICATORS

All the Scientometric indicators and other evaluation tools are categorized by the researcher into the following major categories.

- **Basic-metrics** – To conduct year-wise, language-wise and Document type-wise analysis of WLC research output, to know the most used Keywords and the most researched areas, to calculate AGA, AroG, RGR and DT.
- **Quality-Metrics** – To examine the cited references, WoS citations, global citations – overall, year-wise and journal-wise analysis and to investigate U180 and U2013.
- **Author-Metrics** – To examine the prolific authors, year-wise distribution of prolific authors, authorship pattern, degree of collaboration, rate of single authorship, co-authorship pattern, h-index etc.
- **Geo-Metrics** – To examine the most productive countries, year-wise distribution most productive countries and most collaborative countries.
- **Institution-cum-Publisher metrics** – To examine the research productivity of organizations, organizations enhanced, funding bodies and the grant numbers.
- **Future-Metrics and Bradford's Law of Scattering** – To predict the future growth with Time Series Analysis and to test the fitness of Bradford's law in WLC research output.

8.2 BASIC METRICS

8.2.1 YEAR-WISE DISTRIBUTION OF RESEARCH OUTPUT OF WIRELESS COMMUNICATION

Table 1

Year wise distribution of Research output of Wireless Communication

Year	Publication Count	Cumulative Total	%	Cumulative %
2010	516	516	6.08	6.08
2011	601	1117	7.09	13.17
2012	731	1848	8.62	21.79
2013	733	2581	8.64	30.43
2014	818	3399	9.64	40.07
2015	1015	4414	11.96	52.03
2016	1186	5600	13.98	66.01
2017	1347	6947	15.89	81.90
2018	1535	8482	18.10	100.00
Total	8482	-	100	-
Average publications per year				942

Table 1 and Fig. 5 show clearly that during the period 2010 - 2018 a total of 8482 publications were published at Global level. The research productivity in Wireless Communication research shows a gradual growth from 2010 to 2018. The average publication per year was 942.2. The highest number of records i.e 1535 (18.09%) were published in the year 2018 followed by 1347 (15.88%) records in 2017 and 1186 (13.98%) records in 2016 and so on. The least number of records i.e. 516 (6.08%) were published in the year 2010. The growth of publications shows an increasing trend and this shows the popularity of the field.

The cumulative analysis shows that first five years of the study period i.e 2010 to 2014 had contributed 40% (3399) of total global WLC research output and the remaining 4 years i.e. 2015-2018 had contributed the rest of the publications (60%).

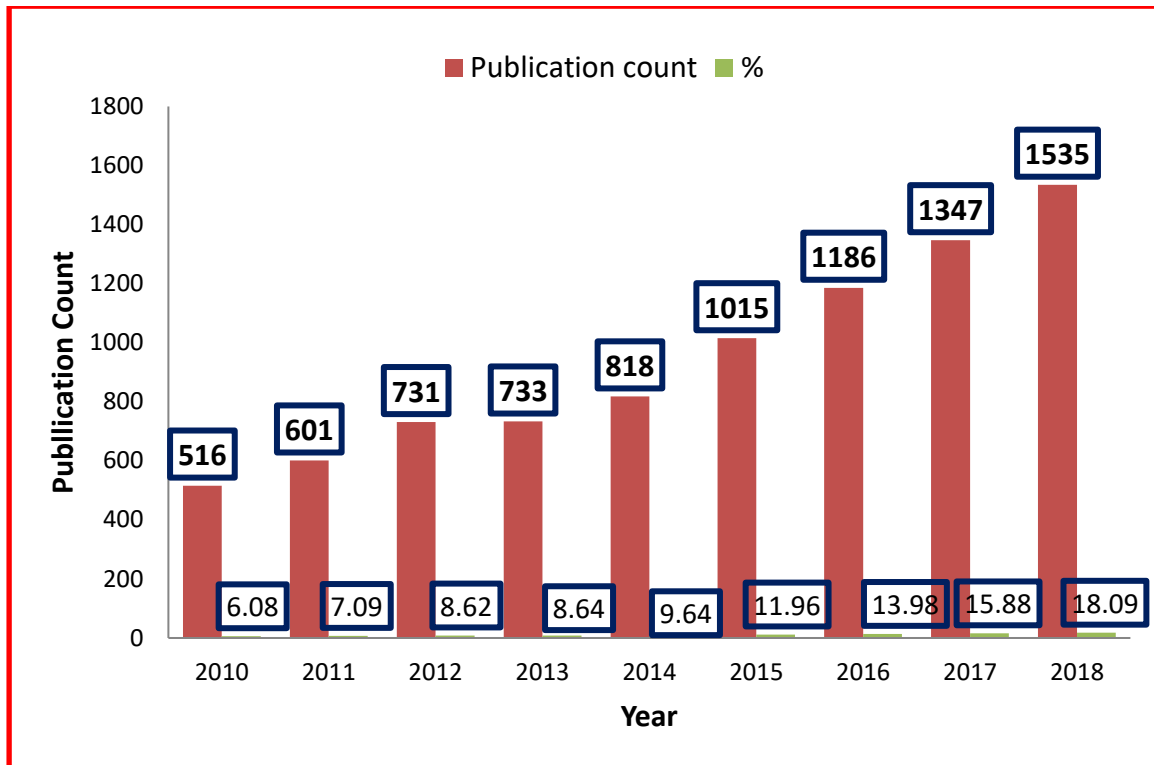


Figure 5: Year wise distribution of Research output of Wireless Communication

8.2.2 BLOCK-WISE ANALYSIS OF GLOBAL WLC RESEARCH OUTPUT

Table 2

Block-wise Analysis of global WLC Research output

Block	Publication Count	Cumulative Total	%	Cumulative %
2010-2012	1848	1848	21.79	21.79
2013-2015	2566	4414	30.25	52.04
2016-2018	4068	8482	47.96	100
Total	8482	100	100	---

Table 2 shows that the percentage of growth of global WLC Research output over the study period in terms of block – years. It shows an increasing growth trend. The number of records has increased from 1848 (21.79%) records in the first block (2010-2012) to 2566 (30.25%) in the second block (2013-2015) and 4068 (47.96%) in the third block (2016-2018). While the first two blocks (6 years from 2010-2015) had contributed 52% of total output, the

remaining 48% of the output was contributed by the researchers in the third block (2016-2018). Thus, third block has been the most productive block in WLC research output.

8.2.3 YEAR-WISE ANNUAL RATIO OF GROWTH AND ANNUAL GROWTH RATE

Table 3

Annual Ratio of Growth and Annual Growth Rate : Year-wise analysis

Year	Publication Count	ARoG	AGR
2010	516	---	---
2011	601	1.165	0.165
2012	731	1.216	0.216
2013	733	1.003	0.003
2014	818	1.116	0.116
2015	1015	1.241	0.241
2016	1186	1.168	0.168
2017	1347	1.136	0.136
2018	1535	1.140	0.140
Total	8482	-	-

Table 3 shows the Annual Ratio of Growth and Annual Growth Rate.

Annual Ratio of Growth (ARoG)

The Annual Ratio of Growth (ARoG) of global WLC research output shows an oscillation throughout the study period. AroG increased from 1.165 in 2011 to 1.216 in 2012 but decreased to 1.003 in 2013 and again increased to 1.116 in 2014 and 1.241 in 2015. It fluctuates between 1.168 and 1.136 during 2016 and 2017. It reached 1.140 in 2018.

Annual Growth Rate (AGR)

The Annual Growth Rate (AGR) of global WLC research output shows fluctuations in the first four years i.e from 2011 to 2014. But it showed a decreasing trend from 2015 onwards. The AGR which was .24 in 2015 decreased to .16 in 2016 and .14 in 2018. The number of publications is increasing every year but the growth rate is not increasing proportionately. We could see a 24% growth rate in 2015 and 14% growth rate in 2018.

Table 4***Block-wise Analysis: Annual Ratio of Growth and Annual Growth Rate***

Block	Publication Count	AroG	AGR
2010-2012	1848	---	---
2013-2015	2566	1.389	0.389
2016-2018	4068	1.585	0.585
Total	8482	--	

Table 4 shows the ARoG and AGR of WLC research output in three blocks of the study period. Both ARoG and AGR show an increasing trend while the former has increased from 1.38 in the second block to 1.58 in third block, the later has increased from .38 in the second block to .58 in the third block.

8.2.4 RELATIVE GROWTH RATE VS. DOUBLING TIME**Table 5*****Relative Growth Rate and Doubling time: Yearly Analysis***

Year	No. of Records	Cumulative	log W1	log W2	RGR	Doubling Time
2010	516	516	0.00	6.25	6.25	0.11
2011	601	1117	6.25	7.02	0.77	0.90
2012	731	1848	7.02	7.52	0.50	1.38
2013	733	2581	7.52	7.86	0.33	2.07
2014	818	3399	7.86	8.13	0.28	2.52
2015	1015	4414	8.13	8.39	0.26	2.65
2016	1186	5600	8.39	8.63	0.24	2.91
2017	1347	6947	8.63	8.85	0.22	3.22
2018	1535	8482	8.85	9.05	0.20	3.47
Total	8482	-	-	-	-	-

Table 5 shows the Relative Growth Rate and Doubling time of WLC research output.

Relative Growth Rate (RGR)

The relative growth rate of wireless communication research output shows a decreasing trend. RGR got decreased from 0.77 in 2011 to 0.5 in 2012, further decreased to

0.33 in 2013 to 0.28 in 2014 and reached its least of 0.20 in 2018. It means that the growth rate of WLC output is decreasing year by year.

Doubling Time (DT)

The doubling time of WLC research productivity shows an increasing trend. The DT which as just .90 in 2011 increased to 2.07 in 2013, 2.91 in 2016 and 3.47 in 2018. It means that the doubling time is increasing to indicate that it will more years in doubling the literature output.

Table 6

Relative Growth Rate and Doubling time : Block-wise Analysis

Block	Period	no of publications	cum. Total	log1	log2	RGR	Dt
I block	2010-2012	1848	1848	0	7.522	---	---
II	2013-2015	2566	4414	7.522	8.393	0.87	0.79
III	2016-2018	4068	8482	8.393	9.046	0.65	1.06

Table 6 shows the block – wise RGR and Dt of research output on wireless communication during 2010 – 2018. It shows that the RGR decreased from 0.87 in the second block to 0.65 to the third block. And the Dt increased from 0.79 in the second block to 1.06 to the third block.

8.2.5 EXPONENTIAL GROWTH OR LINEAR GROWTH PATTERN

To investigate whether the research output of Wireless Communication follows exponential or linear growth pattern, the researcher had used MS Excel programme to calculate R Squared values for both the patterns of growth.

Figures 6 and 7 reveal the result of the investigation. The R Squared value is 0.9563 for the linear growth model and 0.9851 for the exponential growth model. This shows that the research output on Wireless Communication follows the exponential growth pattern. There is an exponential growth in the research output over the period of 9 years.

Exponential Vs Linear Growth pattern in Wireless Communication Research productivity

Linear Growth

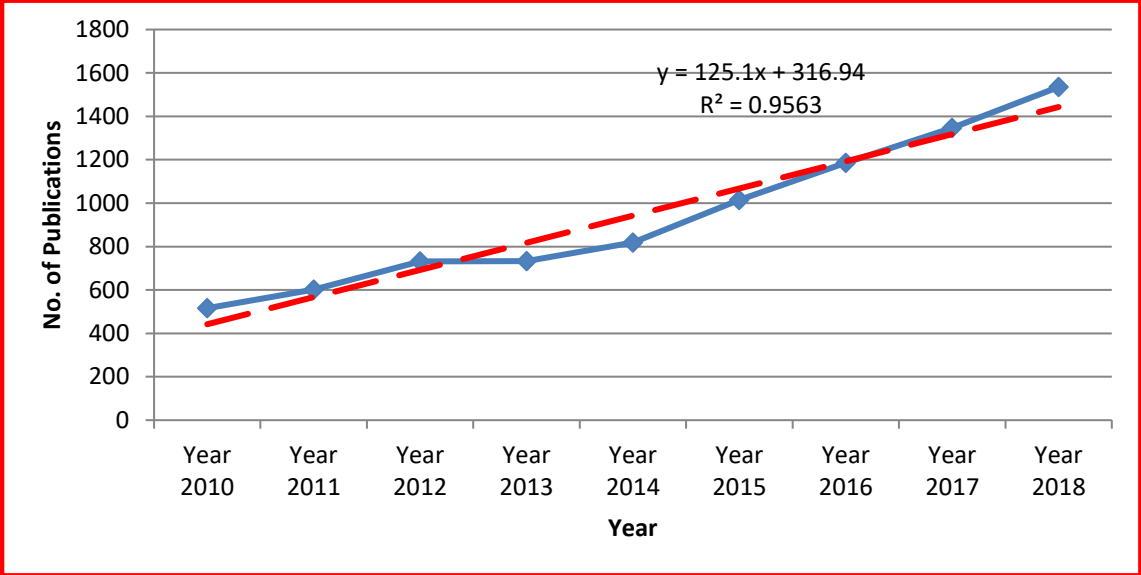


Figure 6: Linear Growth pattern of Wireless Communication Research productivity

Exponential Growth

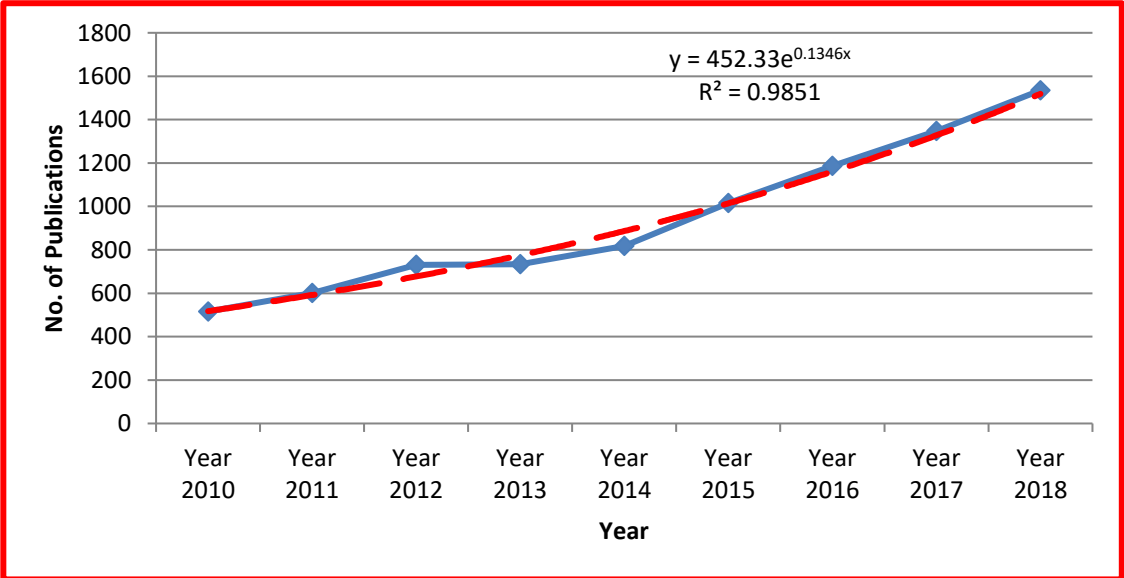


Figure 7 : Exponential Growth pattern of Wireless Communication Research productivity

8.2.6 PUBLICATION TYPE-WISE ANALYSIS

Table 7

Publication Type

Type	No.	%
Journals	8479	99.96
Book in Series	3	0.04
Total	8482	100

Table 7 shows that analysis of research output on wireless communication in terms of publication type. It is clear that 8479 (99.96%) records were published in journals. Only 3 (0.04%) records were published as ‘book in series’

Table 8

Year-wise Analysis of book in Series

Title	Year
Topics in Applied Physics	2015
Advances in Experimental Medicine and Biology	2013
Advances in Computers	2013

Table 8 shows that three records were published in the form of book series. Those are: Topics in Applied Physics published in 2015, Advances in Experimental Medicine and Biology and Advances in Computers both published in 2013.

8.2.7 DOCUMENT TYPE-WISE DISTRIBUTION OF RESEARCH LITERATURE ON WIRELESS COMMUNICATION

Table 9 categorizes the types of documents published in Wireless Communication research output. The research output appeared in 12 types of documents. The maximum number of publications were ‘Articles’ (7990, 94.20%) followed by Proceedings paper (200, 2.36%) and Reviews (197, 2.32%). The Lowest number of records were published in the form of Article: Retracted Publication, Review: Book chapter, Review: Retracted publication and Letter each with 1 (0.01%) count.

Table 9*Document Type-wise distribution of Research Literature on Wireless Communication*

Document Types	Records	% of 8482
Article	7990	94.20
Proceedings Paper	200	2.36
Review	197	2.32
Editorial Material	65	0.77
Meeting Abstract	10	0.12
Correction	9	0.11
News Item	5	0.06
Article; Book Chapter	2	0.02
Article; Retracted Publication	1	0.01
Letter	1	0.01
Review; Book chapter	1	0.01
Review; Retracted publication	1	0.01
Total	8482	100

Table 10*Year-wise document type-wise distribution of WLC Research Output*

Document Type	Year of Publication									Grand Total
	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Article	472	554	707	690	781	961	1102	1279	1444	7990
Article; Proceedings	22	23	11	16	9	24	38	25	32	200
Review	6	13	4	16	16	23	33	32	54	197
Editorial Material	9	9	3	7	9	5	12	8	3	65
Meeting Abstract	2	2	2	1	-	-	1	1	1	10
Correction	3	-	1	1	3	-	-	1	-	9
News Item	1	-	2	-	-	1	-	-	1	5
Article; Book Chapter	-	-	-	2	-	-	-	-	-	2
Article; Retracted	-	-	-	-	-	-	-	1	-	1
Letter	-	-	1	-	-	-	-	-	-	1
Review; Book Chapter	-	-	-	-	-	1	-	-	-	1
Review; Retracted	1	-	-	-	-	-	-	-	-	1
Grand Total	516	601	731	733	818	1015	1186	1347	1535	8482

Table 10 shows the year-wise document type-wise distribution of WLC research output during 2010-2018.

Out of 7990 articles published on WLC, the highest number of 1444 was published in 2018 followed by 1279 in 2017, 1102 in 2016 and 961 in 2015. The number of articles shows an increasing trend. Out of 200 proceedings papers, 30 plus were published in 2016 and 2018, 20-30 were published in 2010, 2011, 2015 and 2017 and the least of 9 were published in 2014.

197 reviews published on WLC research include 54 in 2018, 33 in 2016, 32 in 2017 and 23 in 2015. The editorial materials found a two digit count only in 2016. Out of 12 different types of document types, only four items i.e article, proceedings paper, review and editorial material are found to be published throughout the study period.

8.2.8 LANGUAGE WISE DISTRIBUTION OF GLOBAL WLC RESEARCH OUTPUT

Table 11

Language wise distribution of global WLC Research output

Languages	Records	% of 8482
English	8352	98.467
Chinese	43	0.507
Portuguese	22	0.259
Spanish	21	0.248
German	11	0.130
Turkish	11	0.130
Polish	7	0.083
French	4	0.047
Korean	3	0.035
Malay	3	0.035
Russian	3	0.035
Croatian	1	0.012
Slovenian	1	0.012
Total	8482	100

Table 11 shows the language wise distribution of records published on Wireless Communication. It is clear that maximum number of articles i.e 8352 (98.467%) were published in English language followed by Chinese with 43 (0.507%) articles, Portugues with 22 (0.259%) articles, Spanish with 21(0.248%) articles, German and Turkish each with 11 (0.130%) articles, French with 4 (0.047) articles, Korean, Malay and Russian each with 3 (0.035%) articles. And only 1 (0.012%) article was published in both Crotian and Slovenian languages. This shows the preference of the authors to publish their WLC research findings in English Language than other languages.

Table 12

Year-wise language-wise distribution of WLC research output

Language	Year of Publication									Total
	2010	2011	2012	2013	2014	2015	2016	2017	2018	
English	510	594	722	727	811	994	1158	1326	1510	8352
Chinese	2	2	4	-	3	6	6	10	10	43
Portuguese	-	2	1	1	2	6	6	2	2	22
Spanish	2	-	1	-	2	4	5	4	3	21
German	2	-	1	2	-	1	4		1	11
Turkish	-	-	-	2	-	-	4	2	3	11
Polish	-	3	1	1	-	-	1		1	7
French	-	-	-	-	-	1	1	1	1	4
Korean	-	-	-	-	-	2	-	-	1	3
Malay	-	-	1	-	-	1	-	-	1	3
Russian	-	-	-	-	-	-	-	2	1	3
Croatian	-	-	-	-	-	-	-	-	1	1
Slovenian	-	-	-	-	-	-	1	-	-	1
Grand Total	516	601	731	733	818	1015	1186	1347	1535	8482

Table 12 shows the year-wise language-wise distribution of WLC publications during 2010-2018. Out of 8352 articles published in English, a majority 1510 was published in 2018 followed by 1326 in 2017, 1158 in 2016 and it went on decreasing in the reverse chronology. The English language publications went on increasing throughout the study period. Out of 43 publications in Chinese language, a majority of 10 records were published in 2017 and 2018.

We could see only the publications in English language to appear in all the 9 years. But the good thing is that we could observe the growing number of publications in various languages get published on WLC research output in the recent years especially from 2016 onwards.

Table 13

Document type-wise language-wise distribution of global WLC research output

Document Type	Languages													Total
	Chinese	Croatian	English	French	German	Korean	Malay	Polish	Portuguese	Russian	Slovenian	Spanish	Turkish	
Article	42	1	7868	4	8	3	3	6	20	3	1	20	11	7990
Article; Proceedings Paper	-	-	195	-	2	-	-	-	2	-	-	1	-	200
Review	1	-	195	-	-	-	-	1	-	-	-	-	-	197
Editorial Material	-	-	64	-	1	-	-	-	-	-	-	-	-	65
Meeting Abstract	-	-	10	-	-	-	-	-	-	-	-	-	-	10
Correction	-	-	9	-	-	-	-	-	-	-	-	-	-	9
News Item	-	-	5	-	-	-	-	-	-	-	-	-	-	5
Article; Book Chapter	-	-	2	-	-	-	-	-	-	-	-	-	-	2
Article; Retracted Publication	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Letter	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Review; Book Chapter	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Review; Retracted Publication	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Grand Total	43	1	8352	4	11	3	3	7	22	3	1	21	11	8482

Table 13 shows the document type-wise and language wise analysis of WLC research output during 2010-2018. Out of 8352 records published in English language, a majority of 7868 records were ‘Articles’ followed 195 proceedings papers, 195 reviews, 64 editorial materials and 10 meeting abstracts. Out of 43 records published in Chinese language, 42 were articles and just one was a review. Only proceedings papers, reviews and editorial materials are found in other languages than English and Chinese. But articles were published in all the 13 languages in WLC research output.

8.2.9 MOST PROLIFIC JOURNALS (50 and above records)

Table 14

Most Prolific Journals (50 and above records) in WLC Research Output

Name of the journal	No. of records	% of 8482
Wireless personal communications	353	4.16
IEEE access	247	2.91
IEEE transactions on wireless communications	211	2.49
IEEE transactions on vehicular technology	197	2.32
Microwave and optical technology letters	173	2.04
Sensors	157	1.85
IEEE transactions on communications	142	1.67
Eurasip journal on wireless communications and networking	132	1.56
IEEE transactions on antennas and propagation	132	1.56
IEEE antennas and wireless propagation letters	131	1.54
IET communications	128	1.51
IEEE communications letters	104	1.23
IEEE communications magazine	92	1.08
International journal of distributed sensor networks	90	1.06
IEEE journal on selected areas in communications	85	1.00
IEICE transactions on communications	80	0.94
IEEE transactions on signal processing	79	0.93
Wireless communications & mobile computing	79	0.93
Journal of lightwave technology	75	0.88
Electronics letters	72	0.85
IEEE wireless communications	67	0.79
International journal of communication systems	67	0.79
IEEE transactions on mobile computing	66	0.78
Optics express	65	0.77
International journal of antennas and propagation	60	0.71
AEU-international journal of electronics and communications	59	0.70
IEEE transactions on microwave theory and techniques	59	0.70
IET microwaves antennas & propagation	59	0.70
China communications	57	0.67
IEEE sensors journal	57	0.67
KSII transactions on internet and information systems	56	0.66
Wireless networks	55	0.65
IEEE communications surveys and tutorials	54	0.64
Telecommunication systems	50	0.59
Total	3590	42.33

Table 14 shows the most prolific journals which have published => 50 records in WLC research. 1213 journals contributed 8482 records in WLC research output during 2010-2018. It depicts that 3590 records were published in 34 journals. The most productive journal was ‘Wireless personal communications’ with 353 publications followed by IEEE Access with 247 publications and ‘IEEE transactions on wireless communications’ with 211 publications. There are nine journals with 100-200 publications and the remaining 22 journals have published 50-92 records. These 34 records account for 42.33% of total WLC research output 2010-2018.

Table 15

Year-wise distribution of publications in most prolific journals in WLC Research output

Name of the Journal	Year of Publication									Total
	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Wireless personal communications	14	11	21	39	31	58	34	100	45	353
IEEE access	-	-	-	1	4	6	36	64	136	247
IEEE transactions on wireless communications	23	14	27	24	19	17	27	32	28	211
IEEE transactions on vehicular technology	14	12	12	18	18	22	25	28	48	197
Microwave and optical technology letters	19	16	22	23	12	21	20	25	15	173
Sensors	5	3	9	7	16	23	18	27	49	157
IEEE transactions on communications	14	18	16	13	9	14	16	21	21	142
IEEE transactions on antennas and propagation	5	16	11	14	23	8	13	19	23	132
Eurasip journal on wireless communications and networking	14	11	21	11	12	18	17	12	16	132
IEEE antennas and wireless propagation letters	12	13	16	14	13	11	14	28	10	131
IET communications	5	15	15	9	14	12	21	19	18	128
IEEE communications letters	7	8	13	16	10	12	12	8	18	104
IEEE communications magazine	11	9	9	6	13	11	10	11	12	92
International journal of distributed sensor networks	-	2	7	17	18	20	9	12	5	90
IEEE journal on selected areas in communications	2	4	10	9	11	14	14	13	8	85
IEICE transactions on communications	12	12	16	3	9	5	13	6	4	80
Wireless communications & mobile	1	6	2	3	11	8	11	10	27	79

computing										
IEEE transactions on signal processing	9	13	13	10	7	6	7	5	9	79
Journal of lightwave technology	4	2	6	6	11	9	13	3	21	75
Electronics letters	4	5	10	8	8	16	7	7	7	72
IEEE wireless communications	7	7	10	6	5	10	6	9	7	67
International journal of communication systems	3	6	3	4	9	4	11	15	12	67
IEEE transactions on mobile computing	8	7	11	9	10	4	4	5	8	66
Optics express	3	3	6	6	4	8	10	10	15	65
International journal of antennas and propagation	1	-	10	11	17	5	6	4	6	60
IET microwaves antennas & propagation	7	5	2	6	6	1	10	10	12	59
IEEE transactions on microwave theory and techniques	4	6	8	5	8	4	7	10	7	59
AEU-international journal of electronics and communications	2	3	2	-	4	8	8	12	20	59
IEEE sensors journal	1	3	3	3	2	12	13	11	9	57
China communications	2	4	5	1	5	8	12	8	12	57
KSII transactions on internet and information systems	-	5	6	11	7	5	6	9	7	56
Wireless networks	5	5	2	2	9	5	11	11	5	55
IEEE communications surveys and tutorials	-	4	5	3	9	6	12	8	7	54
Telecommunication systems	1	1	3	11	4	5	5	11	9	50
Total	219	249	332	329	368	396	458	583	656	3590

Table 15 shows the year-wise distribution of most prolific journals which have published at least 50 records in WLC research output. Out of 34 most prolific journals, 28 journals had published records throughout the study period. The most prolific journal ‘Wireless personal communications’ has contributed a maximum of 100 records in 2017 and the minimum of 11 records in 2011. ‘IEEE access’, the second most prolific journal, has contributed from 2013 continuously, with a maximum of 136 records in 2018 and minimum of 1 record in 2013. IEEE transactions on wireless communication has contributed the highest number of articles in 2010 (23) and 2012 (17), IEEE transactions on Communications in 2011(18), Wireless personal communications in 2013(39), 2014(31), 2015(58) and 2017(100), IEEE access in 2016 (36) and 2018(136).

8.2.10 KEYWORD ANALYSIS OF GLOBAL WLC RESEARCH OUTPUT

Table 16

Keyword Analysis of global WLC Research output

Keywords	No of Records	% of 8482
Wireless Communication	981	11.57
OFDM	227	2.68
Wireless Sensor Networks	180	2.12
Cognitive Radio	172	2.03
Energy Efficiency	144	1.70
MIMO	136	1.60
Optical Wireless Communication	112	1.32
Security	108	1.27
Channel Estimation	106	1.25
Wireless Sensor Network	99	1.17
Wireless Networks	84	0.99
5G	83	0.98
Outage Probability	80	0.94
Internet of Things	79	0.93
Visible Light Communication	74	0.87
Resource Allocation	71	0.84
Physical Layer Security	66	0.78
Energy Harvesting	64	0.75
Cooperative Communication	63	0.74
Channel Capacity	61	0.72
Smart Grid	59	0.70
Fading Channels	56	0.66
Wireless	56	0.66
Zigbee	55	0.65
Power Control	54	0.64
Wideband	52	0.61
Optimization	52	0.61
CMOS	51	0.60
Power Allocation	50	0.59
Total	3475	40.97

Table 16 and Fig.8 show the most frequently used keywords in WLC research output. 20497 keywords were used in WLC research output during 2010-2018. The term ‘Wireless communication’ appeared in a majority of 981 (11.57%) records followed by the keywords ‘OFDM’ in 227 (2.68%), ‘wireless sensor networks’ in 180 (2.12%) records and ‘cognitive

radio' in 172 (2.03%) records. The table has listed 32 keywords which were used in at least 50 records. These keywords were used in 3475 records which account for 40.97% of total research output on WLC.

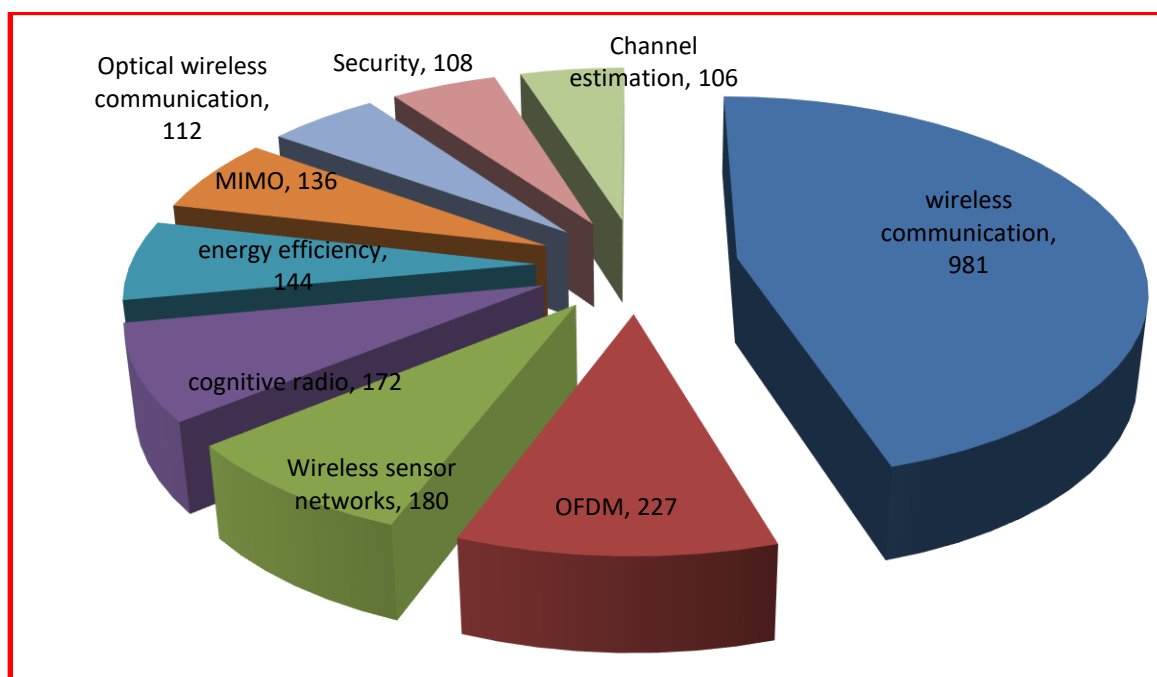


Figure 8: Most frequently keywords WLC research output (>100).

Year-wise distribution of most used Keywords in WLC research output

Table 17

Year-wise distribution of most used Keywords in WLC research output

Keywords	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Wireless Communication	71	67	124	92	89	106	123	133	166	981
OFDM	14	16	16	17	25	25	35	44	35	227
Wireless Sensor Networks	9	11	17	18	16	25	23	25	36	180
Cognitive Radio	12	14	17	12	19	19	21	26	32	172
Energy Efficiency	2	6	6	13	19	17	34	20	27	144
MIMO	9	16	21	13	12	6	19	14	26	136
Optical Wireless Communication	6	5	7	9	9	16	15	20	25	112
Security	7	6	9	9	11	11	24	11	20	108
Channel Estimation	6	12	14	4	9	10	13	14	24	106
Wireless Sensor Network	4	7	9	8	9	16	15	10	21	99
Wireless Networks	6	9	7	9	6	13	14	12	8	84

5G	-	1	-	-	3	3	17	22	37	83
Outage Probability	1	5	5	11	11	6	10	20	11	80
Internet of Things	1	-	-	3	2	13	13	17	30	79
Visible Light Communication	-	1	2	4	4	13	9	14	27	74
Resource Allocation	1	2	6	6	1	5	14	16	20	71
Physical Layer Security	-	-	4	1	4	4	13	17	23	66
Energy Harvesting	-	1	3	6	6	12	11	12	13	64
Cooperative Communication	1	-	3	7	10	12	7	11	12	63
Channel Capacity	2	4	5	8	8	7	11	9	7	61
Orthogonal Frequency Division Multiplexing (OFDM)	1	5	4	6	7	10	7	11	9	60
Smart Grid	-	3	5	10	6	7	9	7	12	59
Fading Channels	7	6	6	4	7	7	5	8	6	56
Wireless	5	5	8	7	6	4	9	4	8	56
Zigbee	1	3	-	7	6	8	12	7	11	55
Power Control	4	5	7	6	4	6	7	7	8	54
Wideband	4	5	1	4	6	2	9	10	11	52
Optimization	3	4	2	1	5	4	11	6	16	52
CMOS	7	4	1	7	4	6	7	10	5	51
Power Allocation	2	1	5	2	4	9	8	8	11	50
Total	185	219	310	298	321	392	528	534	688	3475

Table 17 shows the year-wise analysis of most frequently used keywords in research publications in Wireless Communication. ‘Wireless Communication’ is the most preferred keyword that is used in 166 publications in 2018 followed by 133 records in 2017, 124 records in 2012 and 123 records in 2016. The keyword ‘OFDM’ was the second most used keyword which was used in 44 records in 2017, 35 records in 2016 and 2018 and 23 records in 2016. The Word set ‘Wireless Sensor Networks’ was used in 180 records 36 records were published in 2018 followed by 25 in 2017 and 2016 and 23 in 2016. The fourth most used keyword set ‘Cognitive Radio’ was used in 32 records in 2018, 26 records in 2017 and 21 records in 2016. We could see a progressive increase in the use of these keywords in WLC research output in the recent years.

8.2.11 RANGE OF PAGE NUMBER-WISE ANALYSIS

Table 18

Range of Page Numbers

Range of Page numbers	No. of Records	%	Total pages	%
1-10	4366	51.47	30821	31.97
11 to 20	3553	41.89	49821	51.69
21-30	466	5.49	11222	11.64
31-40	71	0.84	2451	2.54
41-50	15	0.18	663	0.69
51-60	3	0.04	166	0.17
More than 60	8	0.09	1247	1.29
Total	8482	100	96391	100

Table 18 shows the page ranges of WLC research output 2010-2018. It is crystal clear that 93% of papers published in WLC research areas have 1-20 pages. 51.47% (4366) of records have 1-10 pages and 41.89% (3553) of records have 11-20 pages. Only very few papers have (11) have more than 50 pages each. 4366 (51.47%) records have consumed 31.97% (30821) of total pages and 41.89% (3553) of records have consumed 51.69% (49821) of total pages. The average pages per paper is 11.36.

$$\begin{aligned}\text{Average pages per paper} &= \text{total pages} / \text{total papers} \\ &= 96391 / 8482 = 11.36 \text{ pages per paper}\end{aligned}$$

8.2.12 RESEARCH AREAS IN WLC RESEARCH OUTPUT

Table 19

Research Areas in WLC Research Output

Research Areas	Records	% of 8482
Engineering	5126	60.434
Telecommunications	3796	44.754
Computer Science	2252	26.550
Optics	753	8.878
Physics	619	7.298

Instruments Instrumentation	400	4.716
Transportation	325	3.832
Science Technology	289	3.407
Chemistry	266	3.136
Materials Science	231	2.723
Automation Control Systems	189	2.228
Electrochemistry	187	2.205
Mathematics	140	1.651
Operations Research Management Science	62	0.731
Environmental Sciences Ecology	47	0.554
Robotics	46	0.542
Medical Informatics	41	0.483
Energy Fuels	38	0.448
Health Care Sciences Services	32	0.377
Education Educational Research	31	0.365
Business Economics	28	0.330
Life Sciences Biomedicine	27	0.318
Mechanics	27	0.318
Public Environmental Occupational Health	27	0.318
Remote Sensing	26	0.307

Table 19 shows the major areas of research in WLC during 2010-2018. ‘Engineering’ is the major thrust area in WLC research with 5216 records. This domain has contributed 60% of total research output on WLC. It is followed by other two thrust areas namely ‘Telecommunication’ and ‘Computer Science’ with 3796 and 2252 records respectively. While 753 papers were published on ‘Optics’, 619 papers were published on ‘Physics’. Since, the subject is interdisciplinary in nature, we could see a lot of papers published in multiple subject areas.

Table 20

Year-wise publication output on prolific research areas

Research Areas	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
Engineering	34	43	48	44	49	54	68	78	91	5126
Telecommunications	7	1	0	6	9	9	4	0	0	3796
	23	25	32	34	37	41	50	63	69	
	7	8	7	7	7	3	8	4	5	

Computer Science	12	14	16	18	20	27	32	36	45	2252
	3	8	9	4	3	0	9	8	8	
Optics	41	34	62	66	78	99	12	11	14	753
							0	1	2	
Physics	30	49	46	50	54	10	98	83	10	619
						1			8	
Instruments & Instrumentation	23	24	31	28	29	56	55	66	88	400
Transportation	22	20	31	26	31	36	43	46	70	325
Science & Technology - Other Topics	6	10	6	19	30	38	57	57	63	286
Chemistry	7	12	18	13	23	39	30	40	84	266
Materials Science	14	17	11	7	20	30	29	40	63	231
Automation & Control Systems	13	14	18	23	7	18	26	35	35	189
Electrochemistry	8	7	13	10	20	25	21	30	53	187
Mathematics	7	10	15	19	20	16	16	19	18	140
Operations Research & Management Science	8	6	11	4	2	6	13	4	8	62
Environmental Sciences & Ecology	2	3	2	4	8	9	4	5	10	47
Robotics	5	2	1	4	4	4	10	7	9	46
Medical Informatics	3	3	10	2	4	5	5	4	5	41
Energy & Fuels	1	1		5	3	3	8	6	11	38
Health Care Sciences & Services	1	-	8	3	5	4	4	2	5	32
Education & Educational Research	2	6	-	2	5	4	6	3	3	31
Business & Economics	5	1	1	3	1	6	3	4	4	28
Mechanics	1	1	2	6	2	7	5	3		27
Public, Environmental & Occupational Health	2	1	1	3	5	2	3	4	6	27
Life Sciences & Biomedicine - Other Topics	3	4	3	2	2	4	6	-	3	27
Remote Sensing	1	4	2	1	3	4	3	4	4	26
Biotechnology & Applied Microbiology	1	-	-	-	1	1	3	10	9	25

Table 20 shows the year-wise publication output on prolific research areas. It is made clear that out of 5126 publications on 'Engineering' in WLC research output, a majority of 910 papers were published in 2018 followed by 780 in 2017, 684 in 2016 and 549 in 2015. This thrust area is gaining popularity over the years continuously. The same growth rate is seen in other two thrust areas of research namely Telecommunication and computer Science wherein the number of papers published since 2010 kept on increasing throughout the study period. It is good to see that WLC research at the global level has become more inter-

disciplinary and the subject is researched in many angles and directions by researchers from many scientific and non-scientific fields of studies.

8.2.13 WOS CATEGORIES

Table 21

WOS Categories of WLC Research Output

Web of Science Categories	No of records	% of 8482
Engineering, Electrical & Electronic	4692	55.32
Telecommunications	3796	44.75
Computer Science, Information Systems	1593	18.78
Optics	753	8.88
Physics, Applied	475	5.60
Computer Science, Hardware & Architecture	475	5.60
Instruments & Instrumentation	400	4.72
Transportation Science & Technology	318	3.75
Computer Science, Theory & Methods	249	2.94
Computer Science, Interdisciplinary Applications	237	2.79
Engineering, Multidisciplinary	198	2.33
Materials Science, Multidisciplinary	197	2.32
Chemistry, Analytical	192	2.26
Automation & Control Systems	189	2.23
Electrochemistry	187	2.20
Computer Science, Software Engineering	175	2.06
Multidisciplinary Sciences	149	1.76
Computer Science, Artificial Intelligence	136	1.60
Nanoscience & Nanotechnology	121	1.43
Engineering, Civil	109	1.29
Physics, Multidisciplinary	83	0.98
Mathematics, Applied	73	0.86
Engineering, Mechanical	72	0.85
Operations Research & Management Science	62	0.73
Chemistry, Multidisciplinary	55	0.65
Mathematics, Interdisciplinary Applications	53	0.63
Engineering, Biomedical	53	0.63

Table 21 lists the Web of Science categories of wireless Communication research. This categorization is done by WoS database. It clearly shows that the highest number 4692 (55.32%) papers in WLC were published in the high priority research area namely ‘Engineering, Electrical and Electronic’ followed by the research area ‘Telecommunications’ with 3796 (44.75%) records and ‘Computer Science, Information System’ with 1593 (18.78%) records. While 753 papers were published in the research area ‘Optics’, 475 each were published in ‘Applied Physics’ and ‘Computer Science, hardware and Architecture’ and 400 records in ‘Instruments and Instrumentation’. There are 10 research areas which have contributed 100-200 records, 3 research areas which have contributed 200-320 records and 7 research areas with 50-100 contributions on WLC research during 2010-2018.

8.3 QUALITY METRICS

8.3.1 RANGE OF CITED REFERENCES

Table 22

Range of cited references in WLC Research output

Range of cited references	No. of Records	%	Total Cited References	%
0-10	809	9.54	5757	2.32
11 to 20	2495	29.42	39456	15.91
21-30	2423	28.57	61130	24.66
31-40	1379	16.26	48188	19.44
41-50	673	7.93	30081	12.13
51-100	520	6.13	33853	13.65
More than 100	181	2.13	29469	11.89
No information	2	0.02	0	0
Total	8482	100	247934	100

Table 22 shows the range of cited references found in 8482 records published in WLC research output during 2010-2018. A majority of 2495 records (29.42%) have 11-20 cited references closely followed by 2423 (28.57%) records with 21-30 cited references. While 1379 records (16.26%) have 31-40 cited references, 809 (9.54%) records have less than 11 cited references. Thus, it seems to have 11-30 cited references as the ideal number.

Surprisingly, 181 records have more than 100 cited references while 673 records have 41-50 cited references.

An analysis of total cited references shows that 61130 (24.66%) cited references were included in 2423 records followed by 48188 cited references in 1379 papers and 39456 cited references in 2495 records. A total of 247934 cited references were found in 8482 papers with an average cited reference of 29.23 per paper.

Year-wise range of cited references

Table 23

Year-wise range of cited references in WLC Research output

Range of cited references	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
0-10	85	85	102	77	81	105	93	100	81	809
11 to 20	185	204	240	237	247	334	342	374	332	2495
21to 30	133	157	207	205	249	278	317	386	491	2423
31 to 40	57	78	95	115	133	152	191	243	315	1379
41 to 50	27	38	48	47	44	63	115	130	161	673
51 to 100	27	31	34	41	45	63	101	75	103	520
More than 100	2	8	5	10	19	20	27	39	51	181
Total	516	601	731	732	818	1015	1186	1347	1534	8482

Table 23 shows the year-wise distribution of range of cited references in WLC research output. The highest number of 105 and 102 papers with 0-10 cited references were published in 2015 and 2012 respectively. A majority of papers with 11-20 cited references were published in 2017(374) and 2016(342). The years 2018 (491) and 2017(386) had seen the highest number of records with 21-30 cited references while we could see that highest number of records with 31-40 cited references were published in 2018 (315) and 2017(243). Maximum of 161 and 130 records have 41-50 cited references in 2018 and 2017 respectively while the highest number of 103 and 101 records have 51-100 cited references in 2018 and 2016. As far as the publications with more than 100 cited references, year 2018 had seen 51 records and the year 2017 had seen 39 records.

8.3.2 RANGE OF WEB OF SCIENCE CORE COLLECTION TIMES CITED

Table 24

Range of Web of Science core collection times cited

Range of Web of Science core collection times cited	No. of Records	%	Total Web of Science core collection times cited	%
0-10	6665	78.58	15421	17.83
11 to 20	841	9.92	12317	14.24
21-30	348	4.10	8749	10.11
31-40	197	2.32	6937	8.02
41-50	115	1.36	5258	6.08
51-100	201	2.37	14161	16.37
More than 100	115	1.36	23658	27.35
Total	8482	100	86501	100

Table 4.24 shows the range of Web of Science core collection times cited in respect of WLC research output 2010-2018. 'Web of science Core collection times cited' means the citations received for an article in other journals which are indexed and available in Web of Science core collection. It is depicted that 8482 articles were cited 86501 times. Majority of articles i.e. 6665 (78.58%) received 0-10 citations and the total number of citations received by them are 15421. It is followed by 841 (9.92%) records which received 11-20 citations each with a total citation count of 12317 and 348 (4.10%) records which got 21-30 citations each with a total citation count of 8749. While 201 records received 51-100 citations each with a total citation count of 14161, 115 records received more than 100 citations with a total citation count of 23658. Though the number of records which have received more than 50 citations (316) is less, the total citations received by those records constitute 44% of total citations received in WLC research output.

It is noteworthy to note that 78.58% of the records received 17.83% of total citations while 1.36% of total records and 2.37% of total records received 27.35% and 16.37 % of total citations in WLC research output 2010-2018.

Range of Web of Science core collection times cited: Year-wise distribution

Table 25

Range of Web of Science core collection times cited : Year-wise distribution

Range of Web of Science core collection times cited	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
0-10	30	36	44	47	56	75	97	12	15	6665
11 to 20	82	94	12	11	10	12	12	67	8	841
21 to 30	41	44	65	42	53	47	37	18	1	348
31 to 40	28	28	26	35	22	32	18	7	1	197
41 to 50	16	16	23	19	17	15	9	0	0	115
51 to 100	32	37	35	30	29	20	14	4	0	201
More than 100	14	21	14	19	20	14	11	2	0	115
Total	516	601	731	733	818	1015	1186	1347	1535	8482

Table 25 shows the year-wise distribution of 'range of Web of Science core collection times cited' for WLC research output 2010-2018. Out of 6665 records with 0-10 citations, a majority of 1525 records were published in 2018 followed by 1249 in 2017 and 976 in 2016. Out of 841 records with 11-20 citations, the highest number of 128 records was published in 2015 followed by 123 in 2012 and 121 in 2016. As far as the records with more than 100 citations, a majority of 21 documents were published in 2011 followed by 20 records in 2014 and 19 records in 2013. It is clear from the above analysis that the records published in the recent years 2016-2018 received comparatively less number of citations and the records which were published in the middle ages 2012-2015 received more citations.

8.3.3 RANGE OF TOTAL TIMES CITED COUNT

Table 26

Range of Total times cited count

Range of Total times cited count	No. of Records	%	Total of Total times cited count	%
0-10	6663	78.20	15616	17.23
11 to 20	836	9.86	12285	13.56
21-30	362	4.27	9117	10.06
31-40	198	2.33	8398	9.27
41-50	125	1.47	5676	6.26
51-100	210	2.48	14932	16.48
More than 100	118	1.39	24587	27.13
Total	8482	100	90611	100

Total times cited count means citations obtained for a document in Web of Science Core Collection, BIOSIS Citation Index, Chinese Science Citation Database, Data Citation Index, Russian Science Citation Index and SciELO Citation Index taken together.

Table 26 shows the number of citations received by the papers published in WRC as indexed in Web of Science database covering a 9 year period. A total of 90611 citations were received for 8482 documents. A majority of 6633 (78.20%) records have received just 0-10 citations. It is followed by 836 papers which have received 11-20 citations and 362 with 21-30 citations and 198 papers with 31-40 citations. While 125 papers have received 41-50 citations, 210 papers have got 51-100 citations. 118 papers have received more than 100 citations.

It is noteworthy to note that 78.2% of the records received 17.23% of total citations while 1.39% of total records and 2.48% of total records received 27.13% and 16.48% of total citations in WLC research output 2010-2018.

Average number of citations per paper

The average number of citations per paper is calculated by dividing the total number of citations by the total number of papers.

Average Citation Per Paper = total Citations received / No. of Publications

$$= 90611 / 8482 = 10.69$$

Range of Total times cited count: Yearly output

Table 27

Range of Total times cited count: Yearly output

Range of Total times cited count	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
0-10	301	352	443	471	567	756	972	1246	1525	6633
11 to 20	79	101	113	108	107	129	124	68	7	836
21to 30	42	43	74	47	53	46	37	18	2	362
31 to 40	27	24	27	38	21	33	18	9	1	198
41 to 50	20	21	23	18	19	14	10	0	0	125
51 to 100	33	39	36	32	30	22	14	4	0	210
More than 100	14	21	15	19	21	15	11	2	0	118
Total	516	601	731	733	818	1015	1186	1347	1535	8482

Table 27 shows the year-wise distribution of number of total times cited for 8482 papers published on WLC during 2010-2018. Out of 6633 papers with 0-10 total times cited, a majority of 1525 were published in 2018 followed by 1246 in 2017 and 972 in 2016. It is understood that the documents published in 2018 would have received only less number of citations and they may get more citations in the day to come. Out of 836 documents with 11-20 total times cited, a majority of 129 were published in 2015 followed by 124 in 2016 and 113 in 2012. The documents which were published in earlier period of the study had received more total times cited than the recent publications. Most of the documents which have received more than 40 total times cited were published in 2010, 2011 and 2013. Out of 118 documents which have received more than 100 total times cited, a majority was published in 2014(2) followed by 2013(19).

Average number of citations per year

The average number of citations per year is calculated by dividing the total number of citations by the number of years the author or journal has been publishing papers.

Average Number of citations per year = Total number of citations / No. of Years

$$= 90611 / 9 = 10068$$

8.3.4 USAGE180

Table 28

Usage180 of WLC research output

Range of usage	No. of Records	%	Total of usage180	%
0-10	8283	97.65	8760	68.34
11 to 20	145	1.71	2048	15.99
21-30	26	0.31	656	5.12
31-40	13	0.15	453	3.54
41-50	5	0.06	215	1.66
51-60	5	0.06	273	2.13
61-70	2	0.02	130	1.01
More than 70	3	0.04	276	2.15
Total	8482	100	12811	100

Table 28 shows the range of times the WLC research output has been used in the last 180 days from the date of downloading the data. It shows that 8283 (97.65%) records were used 0 - 10 times in the last 180 days. It is followed by 145 records with 11-20 times of usage and 26 papers with 21-30 times of usage. Only 2 papers were used 61-70 times while three papers were used more than 70 times. The total analysis shows that 8482 papers on WLC published between 2010 and 2018 were used 12811 times in the last 180 days.

Average usage180 per day = total of usage 180/total number of documents

$$= 12811/8482 = 1.51 \text{ times}$$

8.3.5 USAGE 2013

Table 29 shows the range of times the WLC research output has been used since 2013. It shows that 5975 (70.44%) records were used 0 - 10 times since 2013. It is followed by 1487 records with 11-20 times of usage and 448 papers with 21-30 times of usage. While 225 papers were used 31-40 times, 167 records were used 51-100 times. Only 14 and 13 papers

were used 6151-200 and more than 200 times since 2013. The total analysis shows that 8482 papers on WLC published between 2010 and 2018 were used 94208 times since 2013.

Average usage₂₀₁₃ per day = total of usage₂₀₁₃/total number of documents

$$= 94208/8482 = 11.11 \text{ times}$$

Table 29

Usage 2013 of WLC research output

Range of usage	No. of Records	%	Total of usage ₂₀₁₃	%
0-10	5975	70.44	23631	25.08
11 to 20	1487	17.53	21503	22.83
21-30	448	5.28	11127	11.81
31-40	225	2.65	7858	8.34
41-50	111	1.31	4945	5.25
51-100	167	1.97	11856	12.58
101-150	42	0.50	4775	5.07
151-200	14	0.17	2507	2.66
More than 200	13	0.15	6006	6.38
Total	8482	100	94208	100.00

8.4 AUTHOR METRICS

8.4.1 Authorship Pattern

Table 30

Authorship Pattern

No of Authors	No. of records	% of 8482	No. of authors	% of 32338
Sing Author	418	4.93	418	1.29
Two Authors	1774	20.91	3548	5.49
Three Authors	2140	25.23	6420	6.62
Four Authors	1789	21.09	7156	5.53
5	1141	13.45	5705	3.53
6	609	7.18	3654	1.88

7	258	3.04	1806	0.80
8	123	1.45	984	0.38
9	76	0.90	684	0.24
10	47	0.55	470	0.15
11	33	0.39	363	0.10
12	20	0.24	240	0.061
13	14	0.17	182	0.043
14	11	0.13	154	0.034
15	7	0.083	105	0.022
16	5	0.059	80	0.015
17	4	0.047	68	0.012
19	3	0.035	57	0.009
20	2	0.024	40	0.006
21	1	0.012	21	0.003
22	2	0.024	44	0.006
24	2	0.024	48	0.006
25	1	0.012	25	0.003
30	1	0.012	30	0.003
36	1	0.012	36	0.003
Total	8482	100	32338	26.23

Table 30 shows the authorship pattern of WLC Research output. 8482 records were contributed by 32338 authors. The majority of 2140 (25.23%) articles were published in three authorship pattern with the contribution of 6.62% of authors followed by 1789 (21.09) articles in four authors style with 5.53% of authors, 1774 (20.91%) articles in two authors style with 5.49% of authors and 1141 (13.45) articles were published in five authors style with 3.53% of authors. Only one article was published with the highest number of author contribution i.e 36 authors.

Average Author per Paper = total authors / total documents

$$= 32338 / 8482 = 3.81 \text{ author per paper}$$

Average Article per Author = total papers / total authors

$$= 8482 / 32338 = 0.26 \text{ article per author}$$

Year-wise Authorship Pattern

Table 31

Year-wise Authorship Pattern

No of authors	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
1	34	33	48	37	33	47	57	69	60	418
2	134	150	153	138	180	217	248	265	289	1774
3	135	167	192	211	217	263	289	297	369	2140
4	92	114	151	178	160	224	240	305	325	1789
5	61	71	90	88	118	129	161	198	225	1141
6	27	30	56	39	55	74	96	103	129	609
7	18	16	14	19	29	29	30	43	60	258
8	4	7	11	5	4	12	28	24	28	123
9	3	6	4	4	6	11	15	17	10	76
10	3	3	3	3	3	2	7	13	10	47
11	-	2	1	3	4	1	5	6	11	33
12	2	1	3	2	-	1	1	1	9	20
13	1	-	2	1	2	2	1	1	4	14
14	1	-	1	2	3	-	2	1	1	11
15	-	-	1	1	1	1	2	-	1	7
16	-	-	-	1	2	1	-	-	1	5
17	-	1	-	-	-	-	2	-	1	4
19	1	-	1	-	-	1	-	-	-	3
20	-	-	-	-	-	-	1	-	1	2
21	-	-	-	-	-	-	-	1	-	1
22	-	-	-	-	1	-	1	-	-	2
24	-	-	-	-	-	-	-	2	-	2
25	-	-	-	1	-	-	-	-	-	1
30	-	-	-	-	-	-	-	-	1	1
36	-	-	-	-	-	-	-	1	-	1
Total	516	601	731	733	818	1015	1186	1347	1535	8482

Table 31 shows the year-wise authorship pattern of total research output. Single author contributions were the most in 2017 (69) and the least in 2011 and 2014 (33). The highest number of joint author publications were found in 2018(289) and the least was found in 2010(134). Three author contributions were the most in 2018(369) and the least in 2010(2010). Among the four author publications, the most were in the year 2018 (325) and the least were in the year 2010(92). Five, six and seven authored publications were found to

be maximum in 2018 with 225, 129 and 60 records respectively. The papers with 25, 30 and 36 authors were published in 2013, 2018 and 2017 respectively.

8.4.2 SIZE OF THE RESEARCH TEAM

Table 32

Size of the Research Teams in WLC Research Output

Research team Size	No. of authors involved	No. of papers	%
Solo	1	418	4.93
Duet	2	1774	20.91
Very Small	3-4	3929	46.32
Small	5-10	2254	26.57
Medium	11 - 25	105	1.24
Large	> 25	2	0.02
Total		8482	100.00

Table 32 shows the size of the research teams that produced 8482 documents in WLC research during 2010-2018. It is evident that very small teams are very effective in the publication of research output in WLC. It has produced 3929 (46.325) records. It is followed by small research teams which have produced 2254 (26.57%) records. While medium sized teams have produced 105 records, large teams comprising of more than 25 authors have produced just 2 papers. Thus, it is made clear that very small teams consisting of 3-4 authors and small teams consisting of 5-10 authors are active in WLC research productivity.

8.4.3 MOST PROLIFIC AUTHORS (25 and > 25 records)

Table 33

Most prolific authors (=> 25 records)

Author	no of publications	Cumulative publications	% of 897	% of 8482
Liu Y	61	61	6.80	0.72
Zhang Y	47	108	5.24	0.55
Kim J	43	151	4.80	0.51
Li Y	41	192	4.57	0.48
Wang J	37	229	4.12	0.44
Wang L	37	266	4.12	0.44
Hanzo L	36	302	4.01	0.42
Wang Y	35	337	3.90	0.41

Haas H	35	372	3.90	0.41
Zhang L	34	406	3.80	0.40
Zhang R	33	439	3.68	0.39
Li J	33	472	3.68	0.39
Zhang J	32	504	3.57	0.38
Li L	32	536	3.57	0.38
Lee J	32	568	3.57	0.38
Alouini MS	32	600	3.57	0.38
Wang CX	31	631	3.46	0.37
Wang Q	29	660	3.23	0.34
Wang K	27	687	3.01	0.32
Wang H	27	714	3.01	0.32
Kim S	27	741	3.01	0.32
Liu L	27	768	3.01	0.32
Wang W	26	794	2.90	0.31
Kim H	26	820	2.90	0.31
Liu J	26	846	2.90	0.31
Islam MT	26	872	2.90	0.31
Chen Y	25	897	2.79	0.29
Total	897	---	100	10.58

Table 33 shows the most prolific authors of global research output on WLC. Out of total records in WLC research output, 10.58% (897) of records were contributed by 27 most prolific authors who have contributed 25 – 61 records. Liu Y is the most productive author with 61 records followed by Zhang Y in the second place with 47 records and Kim J in the third place with 43 records.

Year-wise Research Productivity of most prolific authors (=> 25 records)

Table 34

Year-wise Research Productivity of most prolific authors (=> 25 records)

Author	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Liu Y	1	4	4	2	5	9	12	10	14	61
Zhang Y	1	2	1	3	7	9	5	8	11	47
Kim J	7	2	5	1	4	5	3	8	8	43
Li Y	2	1	1	1	3	11	5	6	11	41
Wang J	2	1	3	-	3	5	5	9	9	37
Wang L	-	2	6	3	2	6	4	6	8	37
Hanzo L	2	1	2	3	3	5	9	3	8	36
Wang Y	1	3	-	4	4	5	2	6	10	35

Haas H	2	5	5	4	2	4	4	7	2	35
Zhang L	-	1	1	2	2	4	3	10	11	34
Zhang R	1	1	3	4	2	6	4	5	7	33
Li J	1	3	3	-	-	4	8	7	7	33
Zhang J	2	2	4	5	3	4	2	8	2	32
Li L	1	1	1	6	2	6	9	5	1	32
Lee J	2	1	4	5	3	3	3	8	3	32
Alouini MS	1	1	1	1	2	5	6	9	6	32
Wang CX	2	-	-	2	3	2	8	8	6	31
Wang Q	1	2	4	2	6	3	4	4	3	29
Wang K	2	3	5	1	1	1	3	6	5	27
Wang H	1	2	1	1	2	2	4	6	8	27
Kim S	2	3	4	1	2	2	1	8	4	27
Liu L	1	1	3	3	2	2	4	5	6	27
Wang W	1	1	1	1	5	5	4	4	4	26
Kim H	1	1	2	3	4	1	4	6	4	26
Liu J	3	3	2	3	2	1	5	3	4	26
Islam MT	1	2	1	3	1	7	5	3	3	26
Chen Y	-	1	3	3	-	3	1	6	8	25
Total	41	50	70	67	75	120	127	174	173	897

Table 34 shows the year-wise distribution of most prolific authors who have contributed at least 25 papers in global research output on WLC. Out of 27 most prolific authors 20 authors have contributed papers in all 9 years (2010-2018). The most prolific author ‘Liu Y’ has contributed in all years continuously, with a maximum of 14 records in 2018 and minimum of 1 record in 2010. ‘Zhang Y’, second most prolific author, has also contributed in all years, with a maximum of 11 records 2018 and minimum of 1 record in 2010.’ Kim J’, third most prolific author has contributed papers in all years, with maximum of 8 records in 2017, 2018 and minimum of 1 record in 2103. It is seen that most of the authors have published their maximum papers in 2017 and 2018.

8.4.4 Most collaborative authors

Table 35

Most collaborative authors

First author	Second author	No of records
Wang K	Nirmalathas A	15
Wang K	Lim C	15
Nirmalathas A	Lim C	15
Lim C	Skafidas E	14

Nirmalathas A	Skafidas E	14
Wang K	Skafidas E	14
Chow CW	Yeh CH	13
Gong C	Xu ZY	12
Nistazakis HE	Tombras GS	11
Brandl P	Zimmermann H	11
Naser-Moghadasi M	Sadeghzadeh RA	9
Naser-Moghadasi M	Virdee BS	9
Alam T	Islam MT	9
Virdee BS	Limiti E	9
Maunder RG	Al-Hashimi BM	8
Xu J	Zhang R	8
Al-Hashimi BM	Hanzo L	8
Zeng Y	Zhang R	8
Sadeghzadeh RA	Virdee BS	8
Maunder RG	Hanzo L	8
Wang JB	Chen M	8
Van Torre P	Rogier H	8
Zhang ZY	Zuo SL	7
Wang JY	Chen M	7
Joseph W	Martens L	7
Alibakhshi-Kenari M	Naser-Moghadasi M	7
Du XJ	Guizani M	7
Jha KR	Singh G	7
Jukic T	Zimmermann H	7
Zheng SL	Chi H	7
Jin XF	Zhang XM	7

Table 35 reveals the most prolific collaborative authors in WLC research output. Three pairs of authors viz., Wang K and Nirmalathas A, Wang K and Lim C & Nirmalathas A and Lim C have collaborated and produced 15 papers each. These three pairs were the most prolific collaborative authors. It is followed by three other pairs which have contributed 14 papers each and one pair (Chow CW and Yeh CH) with 13 papers and one pair (Gong C and Xu ZY) with 12 records. There are two pairs with 11 papers each, 4 pairs with 9 papers each and 8 pairs with 8 papers each. There are nine pairs of authors who have published 7 papers each in WLC research output.

8.4.5 CO-AUTHORSHIP INDEX

Table 36

Co-authorship Index

Year	Single Author	CAI	Two Authors	CAI	More than Two Authors	CAI	Total
2010	34	133.71	134	124.17	348	90.94	516
2011	33	111.42	150	119.33	418	93.79	601
2012	48	133.24	153	100.07	530	97.77	731
2013	37	102.43	138	90.02	558	102.65	733
2014	33	81.86	180	105.21	605	99.74	818
2015	47	93.96	217	102.22	751	99.77	1015
2016	57	97.52	248	99.98	881	100.17	1186
2017	69	103.94	265	94.06	1013	101.41	1347
2018	60	79.32	289	90.02	1186	104.19	1535
Total	418	-	1774	-	6290	-	8482

Table 36 shows the Co-Authorship Index of WLC research output during 2010-2018. The CAI of single author contribution shows a fluctuating trend. It was 133.71 in 2010 and got reduced to 111.42 in 2011 but raised to 133.24 in 2012 and finally reached its lowest score of 79.32 in 2018. The CAI of joint authors showed a decreasing trend. It got reduced from 124.17 in 2010 to 105.21 in 2014, 99.98 in 2016 and further to 90.02 in 2018. The CAI of more than two authors showed an increasing trend. The CAI which was just 90.94 in 2010 rose to 97.77 in 2012, 102.65 in 2013 and 104.19 in 2018. This depicts that apart from single author and joint author contributions, the contributions of more than 2 author style is dominating in WLC research output during 2010-2018.

8.4.6 DEGREE OF COLLABORATION AND RATE OF SINGLE AUTHORSHIP

Table 37

Degree of Collaboration and Rate of Single Authorship

Year	Total	Single Authored Papers	Multi-authored papers	DC	RSA
2010	516	34	482	0.93	0.07
2011	601	33	568	0.95	0.05
2012	731	48	683	0.93	0.07
2013	733	37	696	0.95	0.05
2014	818	33	785	0.96	0.04
2015	1015	47	968	0.95	0.05
2016	1186	57	1129	0.95	0.05
2017	1347	69	1278	0.95	0.05
2018	1535	60	1475	0.96	0.04

Table 37 and Fig. 9 show the year-wise and overall degree of collaboration and rate of single authorship of WLC research output. It is clearly visible that the degree of collaboration ranged from 0.93 to 0.96. The DC was the least during 2010 and 2012 (0.93) and it was the highest during 2014 and 2018 (0.96). It was found medium (0.95) in the remaining five years. The overall DC is 0.95 indicating that 95% of total research output in Wireless Communication is contributed in collaborative mode.

The Rate of single Authorship (RSA) also shows the same degree of oscillation. RSA was high in 2010 and 2012 (0.07), low in 2014 and 2018 (0.04) and medium (0.05) in remaining 5 years.

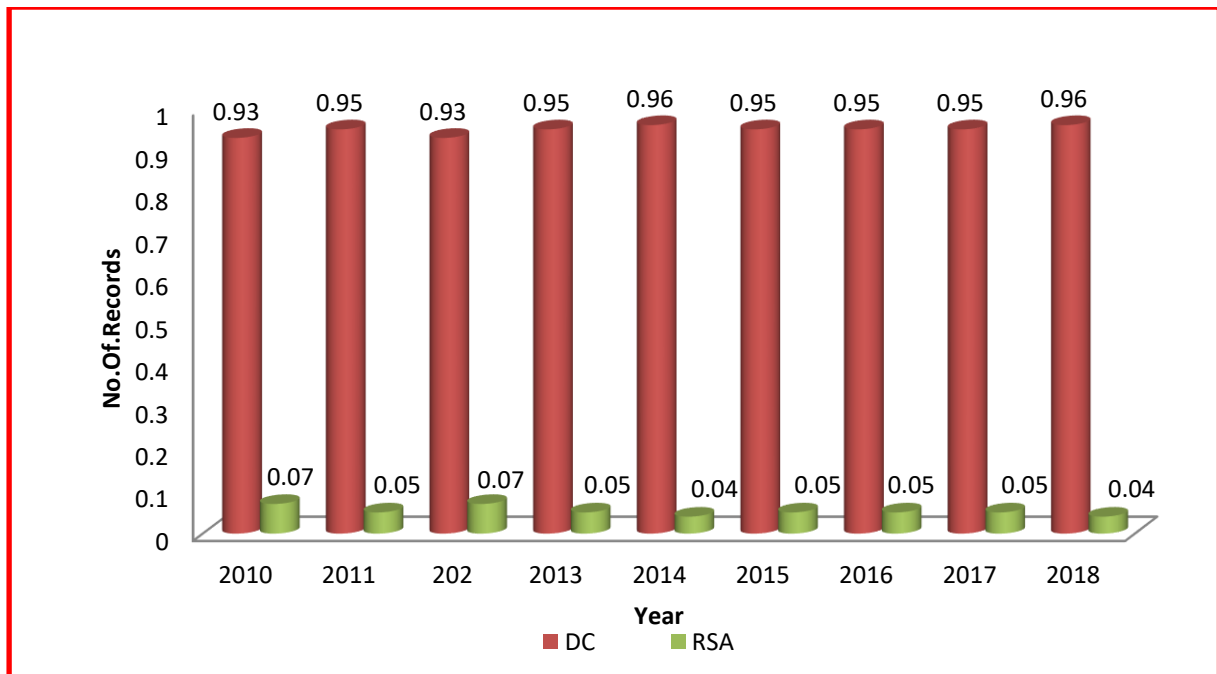


Figure 9: Degree of Collaboration and Rate of Single Authorship

8.4.7 H-INDEX OF PROLIFIC AUTHORS

Table 38

h-index of prolific authors

h-index	Author	Citation sum within h-core	All citations	All articles
24	Haas H	2869	2960	35
20	Zhang R	1811	1893	33
14	Liu Y	539	681	61

14	Di Renzo M	1110	1122	16
13	Heath RW	1427	1456	18
13	Kim J	572	645	43
12	Hanzo L	605	678	36
12	Wang CX	1160	1208	31
12	Choi J	668	685	20
11	Li L	645	712	32
11	Zhang Y	261	360	47
10	Wang L	298	374	37
10	Xu J	381	412	22
10	Alouini MS	338	401	32
10	Wang Q	294	349	29
10	Li Y	560	638	41
10	Shen XM	415	419	13
10	Han Z	424	459	22
10	Lee J	444	482	32

Tables 38 show the prolific authors with the h-index. Haas H tops the table with the h-index of 24 with 2869 citations with h-score and 2960 all citations for his 35 articles, followed by Zhang R with the h-index of 20 for 33 articles. Liu Y and di Renzo M have the h-index of 14 each for their 61 and 16 records respectively. There are two authors with the h-index of 13 and three authors with the h-index of 12 each. While two authors have the h-index of 11 each, there are 8 authors having the h-index of 10 each for their varied number of publications.

8.5 GEO-METRICS

8.5.1 COUNTRY WISE DISTRIBUTION OF RESEARCH OUTPUT

Table 39

Country wise distribution of Research output

Country	No of records	% of 8482
Peoples R China	4206	49.59
USA	2441	28.78
India	1227	14.47
South Korea	1134	13.37
Taiwan	756	8.91
UK	728	8.58
Japan	636	7.50
Canada	572	6.74
Germany	461	5.44
France	437	5.15
Spain	401	4.73

Italy	392	4.62
Australia	303	3.57
Turkey	300	3.54
Malaysia	282	3.32
Pakistan	252	2.97
Brazil	247	2.91
Saudi Arabia	240	2.83
Sweden	226	2.66
Iran	221	2.61
Singapore	192	2.26
Greece	162	1.91
Belgium	143	1.69
Egypt	140	1.65
Finland	130	1.53
Portugal	129	1.52
Netherlands	108	1.27
Switzerland	101	1.19

Table 39 and Fig. 10 show the most productive countries which have made contributions to the study. The list has only those countries which have contributed more than 100 publications. People R China is topped in the list with 4206 (49.56%) publications. It indicates that nearly 50% of publications in Wireless Communication research were published by People R China during the study period (2010-2018). It is followed by USA with 2441 (28.78%) publications, India with 1227 (14.47%) publications and South Korea with 1134 (13.37%) publications. It is good to note that India is in the third rank in the world WLC research output during 2010-2018. There are four countries with more than 500 but less than 800 publications and there are 6 countries with 300-500 publications. While six countries have published 200-300 papers, eight countries have published 100-200 papers.

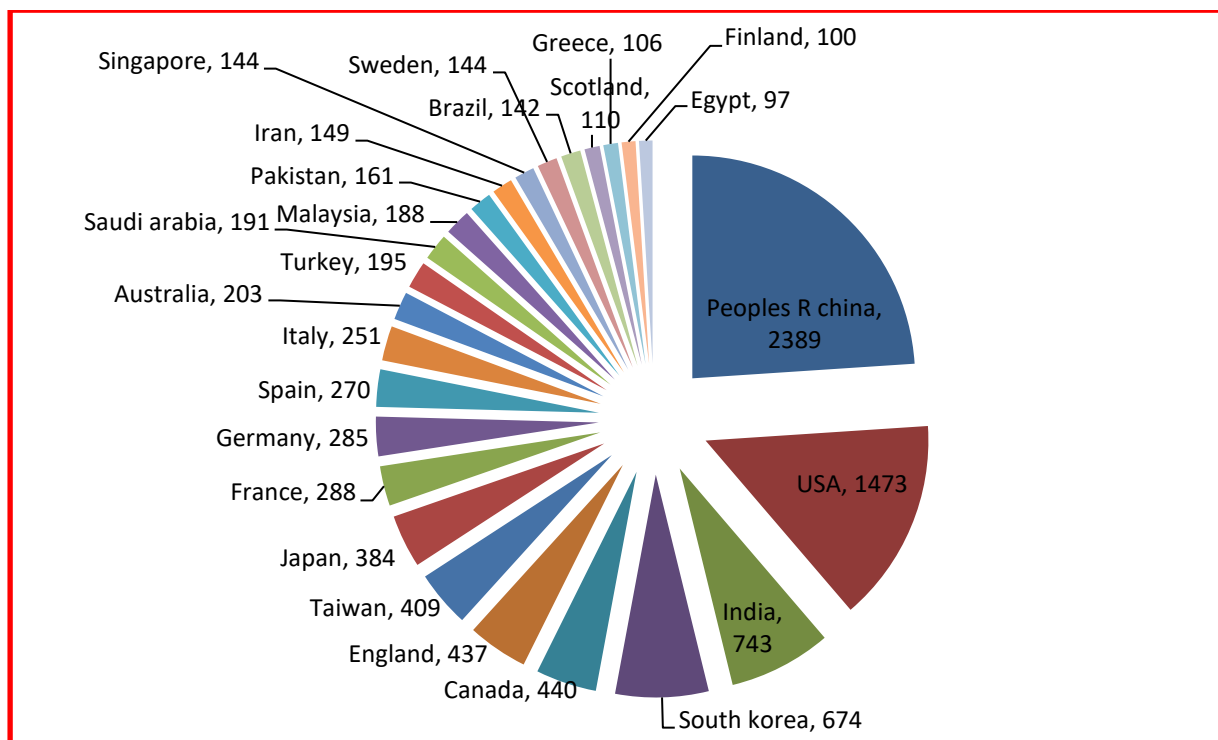


Figure 10: Country wise distribution of Research output

Year-wise Country-wise Distribution of WLC Research Output

Table 40

Year-wise Country-wise Distribution of WLC Research Output

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Peoples R China	101	150	221	294	361	476	650	846	1107	4206
USA	212	236	264	194	243	287	337	344	324	2441
India	14	38	36	65	94	182	192	310	296	1227
South Korea	94	88	109	147	115	136	119	152	174	1134
Taiwan	66	100	101	99	97	89	64	63	77	756
UK	47	53	54	57	75	62	126	120	134	728
Japan	40	44	77	63	71	71	90	92	88	636
Canada	50	56	49	50	45	64	90	71	97	572
Germany	42	59	28	46	44	46	64	65	67	461
France	29	44	42	37	38	43	70	78	56	437
Spain	22	28	28	47	53	50	52	56	65	401
Italy	37	26	32	29	25	34	47	68	94	392
Australia	17	23	30	26	38	35	46	33	55	303
Turkey	10	20	21	33	17	23	53	57	66	300
Malaysia	13	6	15	24	34	58	40	46	46	282
Pakistan	1	1	2	7	19	23	32	54	113	252
Brazil	9	7	17	19	29	24	49	40	53	247

Saudi Arabia	1	13	18	19	27	29	34	39	60	240
Sweden	10	7	21	13	22	25	43	29	56	226
Iran	10	11	22	16	28	24	29	38	43	221
Singapore	16	13	13	10	15	31	35	19	40	192
Greece	9	14	21	24	16	16	32	19	11	162
Belgium	23	5	13	11	14	7	15	24	31	143
Egypt	4	10	7	11	16	20	18	20	34	140
Finland	13	8	10	11	16	13	17	21	21	130
Portugal	11	10	12	8	6	22	10	27	23	129
Netherlands	8	9	21	9	10	11	7	15	18	108
Switzerland	9	13	7	5	11	15	7	22	12	101

Table 40 shows year-wise distribution of the research output of top 28 countries in WLC research output 2010-2018. Out of 4206 publications of Peoples R China, a majority of 1107 were published in 2018 followed by 846 in 2017, 650 in 2016 and 476 in 2015 and the least number of 101 in 2010. Talking about USA, it has produced the highest number of 344 papers in 2017 followed by 337 in 2016, 324 in 2018 and the least of 194 in 2013. India, which has produced 1227 publications, altogether, has published a maximum of 310 papers in 2017 followed by 296 in 2018. The number of publications of India has increased from a mere 14 in 2010 to 65 in 2013, 94 in 2014, 182 in 2015 and 192 in 2016.

8.5.2 ACTIVITY INDEX OF MOST PROLIFIC COUNTRIES

Table 41

Activity Index of most prolific countries

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018
Peoples R China	39.47	50.33	60.97	80.89	89.00	94.57	110.52	126.66	145.43
USA	142.76	136.45	125.49	91.97	103.22	98.25	98.74	88.74	73.34
India	18.76	43.71	34.04	61.30	79.44	123.95	111.91	159.09	133.30
South Korea	136.26	109.52	111.53	150.00	105.15	100.22	75.05	84.40	84.79
Taiwan	143.51	186.68	155.02	151.53	133.04	98.38	60.54	52.47	56.28
UK	106.12	102.75	86.07	90.60	106.83	71.17	123.78	103.80	101.71
Japan	103.38	97.64	140.48	114.62	115.76	93.29	101.20	91.09	76.46
Canada	143.69	138.17	99.40	101.15	81.58	93.50	112.53	78.16	93.71
Germany	149.76	180.62	70.48	115.47	98.97	83.39	99.29	88.79	80.31
France	109.09	142.10	111.52	97.97	90.17	82.23	114.56	112.39	70.81
Spain	90.18	98.55	81.02	135.63	137.05	104.20	92.74	87.94	89.57
Italy	155.15	93.61	94.72	85.61	66.13	72.48	85.75	109.23	132.50

Australia	92.23	107.13	114.88	99.29	130.04	96.53	108.57	68.58	100.30
Turkey	54.79	94.09	81.22	127.29	58.76	64.07	126.35	119.64	121.57
Malaysia	75.78	30.03	61.72	98.48	125.02	171.87	101.44	102.72	90.14
Pakistan	6.52	5.60	9.21	32.14	78.18	76.27	90.82	134.93	247.78
Brazil	59.90	40.00	79.86	89.01	121.74	81.20	141.88	101.97	118.57
Saudi Arabia	6.85	76.45	87.02	91.61	116.65	100.98	101.32	102.33	138.14
Sweden	72.73	43.71	107.82	66.56	100.94	92.44	136.07	80.80	136.92
Iran	74.38	70.25	115.51	83.78	131.37	90.75	93.85	108.27	107.51
Singapore	136.98	95.56	78.56	60.27	81.01	134.93	130.37	62.31	115.12
Greece	91.32	121.97	150.41	171.43	102.41	82.53	141.27	73.85	37.52
Belgium	264.39	49.35	105.48	89.01	101.52	40.91	75.02	105.68	119.79
Egypt	46.97	100.81	58.02	90.92	118.51	119.38	91.95	89.96	134.20
Finland	164.38	86.85	89.26	97.91	127.62	83.57	93.52	101.72	89.26
Portugal	140.17	109.40	107.94	71.76	48.23	142.52	55.44	131.80	98.52
Netherlands	121.76	117.61	225.62	96.43	96.01	85.11	46.35	87.46	92.10
Switzerland	146.48	181.65	80.42	57.29	112.93	124.11	49.57	137.16	65.65

Table 41 shows the Activity Index of most prolific countries. It reveals that the Activity Index of People R China is high i.e 145.43 in 2018 followed by 126.66 and 110.52 in 2017 and 2016 respectively. USA is second with the Activity Index of 142.76, 136.45 and 125.49 in 2010, 2011 and 2012 respectively. It is followed by India with the highest activity Index of 159.09 in 2017 followed by 133.30 in 2018 and 123.95 in 2015. This shows that India is becoming more active in terms of its contributions in total WLC research output in the recent years.

8.5.3 MOST COLLABORATIVE COUNTRIES

Table 42

Most collaborative countries

Country1	Country1	No of records
Peoples R China	Peoples R China	2791
USA	USA	1881
South Korea	South Korea	740
India	India	668
Taiwan	Taiwan	564
Peoples R China	USA	517
Japan	Japan	463
Germany	Germany	301
UK	UK	265

Italy	Italy	239
Peoples R China	UK	232
USA	Peoples R China	232
France	France	213
Spain	Spain	194
Canada	Canada	180
Brazil	Brazil	170
UK	Peoples R China	145
South Korea	USA	140
Australia	Australia	139
Turkey	Turkey	132
Sweden	Sweden	124
Peoples R China	Canada	124
Pakistan	Pakistan	124
Malaysia	Malaysia	120
USA	South Korea	114
Portugal	Portugal	110
Iran	Iran	93
Peoples R China	Australia	87
Greece	Greece	87
Belgium	Belgium	81
Mexico	Mexico	75
Peoples R China	South Korea	73
Peoples R China	Singapore	72
Peoples R China	Taiwan	67
Singapore	Singapore	65
Egypt	Egypt	64
Serbia	Serbia	62
Canada	USA	62
Saudi Arabia	Saudi Arabia	58

Table 42 shows the most collaborating countries in terms of publishing papers in Wireless Communication research. China and China partnered together and produced the highest number of 2791 papers followed by USA and USA partnering to produce 1881 papers. While South Korea and South Korea have produced 740 papers, India and India have produce 668 papers and Taiwan and Taiwan have produced 564 papers. This shows the growth of intra-country collaborative research performance of the researchers. The researchers in the field of WLC want to work with the researchers of the same country than those from other countries. This kind of intra-country collaboration is more visible in the case of Japan, Germany, UK, Italy, France, Spain, Canada and the like countries too. Among the inter-country collaboration, we could see China and USA partnering to produce 517 records followed by China and UK with 232 papers and USA and China with 232 records.

8.6 INSTITUTIONS AND PUBLISHERS METRICS

8.6.1 MOST PROLIFIC ORGANIZATIONS IN WLC RESEARCH PRODUCTIVITY

Table 43

Most Prolific Organizations in WLC Research Productivity

Institution	No of records	% of 8482
Xidian Univ	234	2.76
Tsinghua Univ	176	2.08
Southeast Univ	165	1.95
Beijing Univ Posts & Telecommun	151	1.78
Univ Elect Sci & Technol China	143	1.69
Chinese Acad Sci	139	1.64
Beijing Jiaotong Univ	97	1.14
Zhejiang Univ	91	1.07
Shanghai Jiao Tong Univ	85	1.00
Natl Chiao Tung Univ	85	1.00
Nanyang Technol Univ	73	0.86
Univ British Columbia	72	0.85
City Univ Hong Kong	71	0.84
Natl Taiwan Univ	70	0.83
Georgia Inst Technol	70	0.83
Nanjing Univ Posts & Telecommun	69	0.81
Korea Adv Inst Sci & Technol	66	0.78
Huazhong Univ Sci & Technol	63	0.74
Natl Univ Singapore	63	0.74
Univ Kebangsaan Malaysia	61	0.72
King Saud Univ	61	0.72
Harbin Inst Technol	61	0.72
Natl Inst Technol	60	0.71
Univ Ghent	60	0.71
Univ Southampton	56	0.66
Univ Illinois	55	0.65
Hong Kong Univ Sci & Technol	55	0.65
Islamic Azad Univ	55	0.65
Univ Edinburgh	53	0.63
Indian Inst Technol	51	0.60
Total	2611	30.81

Table 43 shows the institutes that have contributed more than 50 publications on Wireless Communication research during 2010-2018. ‘Xidian University’ topped the list with 234 (2.76%) publications followed by Tsinghua University with 176 (2.08%) publications and Southeast University with 165 (1.95%) publications. Out of the total publications (8482), 2611(30.81%) publications were contributed by 30 most prolific institutions. There are three institutes with 130-151 records and there are 24 institutes which have published 51-100 papers.

8.6.2 GRANT-NUMBER-WISE DISTRIBUTION OF RESEARCH OUTPUT IN WLC

Table 44

Grant-number-wise distribution of Research output in WLC

Grant Numbers	records	%
B08038	38	0.448
2014AA01A701	24	0.283
PIRSES-GA-2013-612652	21	0.248
641985	17	0.200
2012CB316100	16	0.189
61210002	15	0.177
1108170036003286	12	0.141
2013CB329201	12	0.141
61223001	12	0.141
61631018	12	0.141
EP/K008757/1	12	0.141
EP/L020009/1	12	0.141
2013AA013603	11	0.130
2014AA01A706	11	0.130
2014AA01A707	11	0.130
61222105	11	0.130
CNS-1443917	11	0.130

2014AA01A704	10	0.118
2014B010119001	10	0.118
61372034	10	0.118
ECCS-1405121	10	0.118
EP/J016640/1	10	0.118
MOST-103-2221-E-009-030-MY3	10	0.118
QYZDY-SSW-JSC003	10	0.118
U1334202	10	0.118

Table 44 shows the grant numbers under which assistance was provided for carrying out research and publishing papers in WLC. The highest number of 38 papers was granted assistance under B08038 followed by 24 papers granted assistance by 2014AA01A701 and 21 papers granted assistance by PIRSES-GA-2013-612652. While 6 grants have given assistance to 12 papers each, 5 grants have given assistance to 11 papers each and 8 grants have given assistance to 10 papers each.

8.6.3 MOST PROLIFIC PUBLISHERS IN GLOBAL WLC RESEARCH OUTPUT (=>50 publications)

Table 45

Most prolific Publishers in global WLC research output (=>50 publications)

Publisher	No. of Records	% of 6498	% of 8482
IEEE-INST Electrical Electronics Engineers Inc	2705	41.63	31.90
Springer	737	11.34	8.69
Elsevier Science Bv	383	5.90	4.52
INST Engineering Technology-Iet	328	5.05	3.87
Wiley-Blackwell	294	4.53	3.47
IEICE-INST Electronics Information Communications	182	2.80	2.15
Wiley	143	2.20	1.69
Optical Soc Amer	141	2.17	1.66
MDPI AG	140	2.16	1.65
Pergamon-Elsevier Science Ltd	140	2.16	1.65
Springer International Publishing Ag	135	2.08	1.59
IEEE Computer Soc	123	1.89	1.45
MDPI	120	1.85	1.42
Hindawi Publishing Corporation	112	1.72	1.32
Taylor & Francis Ltd	108	1.66	1.27
Elsevier Gmbh, Urban & Fischer Verlag	98	1.51	1.16

Elsevier Sci Ltd	84	1.29	0.99
IOP Publishing Ltd	71	1.09	0.84
Science Press	67	1.03	0.79
Hindawi Ltd	58	0.89	0.68
China Inst Communications	57	0.88	0.67
KSII-KOR Soc Internet Information	56	0.86	0.66
Cambridge Univ Press	56	0.86	0.66
Nature Publishing Group	55	0.85	0.65
Science & Engineering Research Support Soc	53	0.82	0.62
Wiley-Hindawi	52	0.80	0.61
Total	6498	100	76.61

Table 45 shows the most prolific publishers who have published more than 50 papers in WLC research output. It clearly reveals that 6498 (76.61%) records were published by 26 most prolific publishers. The most productive publisher was ‘IEEE-INST Electrical Electronics Engineers Inc’ with 2707 (31.90%) publications followed by ‘Springer’ with 737 (8.69%) publications, ‘Elsevier Science Bv’ with 383 (4.52%) publications and ‘INST Engineering Technology-IET’ with 328 records. While Wiley-Blackwell had published 294 papers, 10 other publishers have published 100-190 papers and 11 other publishers have published 50-100 researchers in WLC during 2010-2018.

Year-wise research productivity of prolific Publishers (=>50 publications)

Table 46

Year-wise research productivity of prolific Publishers (=>50 publications)

Publisher	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
IEEE-INST Electrical Electronics Engineers Inc	19	23	26	22	26	26	35	39	51	2705
	6	3	4	5	3	4	1	6	3	
Springer	36	32	44	82	67	0	86	4	6	737
Elsevier Science Bv	16	22	24	36	29	52	56	69	79	383
INST Engineering Technology-Iet	18	28	30	27	35	36	47	55	52	328
Wiley-Blackwell	11	40	36	43	48	57	54	5	-	294
IEICE-INST Electronics Information Communications Eng	19	18	30	10	22	19	23	26	15	182
Wiley	6	3	2	1	2	3	6	62	58	143
Optical Soc Amer	6	7	11	14	12	17	21	20	33	141
MDPI AG	11	11	9	8	15	21	21	15	29	140
Pergamon-Elsevier Science Ltd	3	4	9	11	16	26	28	37	6	140

Springer International Publishing											
Ag	6	10	26	19	16	18	19	13	8	135	
IEEE Computer Soc	11	15	19	14	18	16	10	8	12	123	
MDPI									10		
	2	-	-	-	2	3	5	6	2	120	
Hindawi Publishing Corporation	7	3	18	26	43	15	-	-	-	112	
Taylor & Francis Ltd	7	4	11	16	14	17	12	14	13	108	
Elsevier Gmbh, Urban & Fischer											
Verlag	3	4	4	2	17	9	15	20	24	98	
Elsevier Sci Ltd	4	6	7	10	12	3	12	20	10	84	
IOP Publishing Ltd	3	6	7	2	9	6	12	13	13	71	
Science Press	3	4	2	5	7	3	13	19	11	67	
Hindawi Ltd	1	-	1	3	3	2	16	15	17	58	
China Inst Communications	2	4	5	1	5	8	12	8	12	57	
KSII-KOR Soc Internet											
Information	-	5	2	5	7	4	13	12	8	56	
Cambridge Univ Press	-	5	6	11	7	5	6	9	7	56	
Nature Publishing Group	1	1	-	1	7	9	10	13	13	55	
Science & Engineering Research											
Support Soc	-	-	-	-	-	13	22	14	4	53	
Wiley-Hindawi	1	-	-	-	1	-	4	14	32	52	
Total	373	425	567	572	677	736	874	1057	1177	6498	

Table 46 shows the year-wise distribution of most productive publishers who have published more than 50 records in WLC research output. Out of 26 most prolific publishers, 17 publishers published research papers throughout the study period. The most prolific publisher ‘IEEE-INST Electrical Electronics Engineers Inc’ has contributed all years (2010-2018), with a maximum of 513 publications in 2018 and the minimum of 196 publications in 2010. ‘Springer’, the second most prolific publisher, has published all the 9 years, with a maximum of 174 publications in 2017 and minimum of 1 publication in 2011. There are two publishers who have not published any paper in the recent years. For example, Wiley Blackwell has not published any papers in 2018 while Hindawi Publishing Corporation has not published any paper on WLC from 2016 to 2018.

8.6.4 Top 25 Funding Agencies in WLC Research

Table 47

Top 25 Funding Agencies in WLC Research

Funding Agencies	Records	% of
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		8482
National Natural Science Foundation of China	950	11.20
National Science Foundation of China	345	4.07
National Science Foundation	309	3.64
Fundamental Research Funds for the Central Universities	274	3.23
National Basic Research Program of China	110	1.30
Engineering and Physical Sciences Research Council	98	1.16
China Postdoctoral Science Foundation	95	1.12
NSFC	88	1.04
111 Project	52	0.61
U S National Science Foundation	52	0.61
Ministry Of Education Science And Technology	41	0.48
European Commission	40	0.47
National Science Council Taiwan	38	0.45
Program For New Century Excellent Talents In University	36	0.42
Beijing Natural Science Foundation	35	0.41
CNPQ	35	0.41
European Union	35	0.41
National High Technology Research and Development Program of China	34	0.40
Natural Sciences and Engineering Research Council of Canada	34	0.40
Total	2701	31.84

Table 47 shows the top 19 funding agencies that have funded for the research projects in Wireless Communication research during the study period of 2010-2018. National Natural Science Foundation of China funded 950 records (11.20 %) followed by National Science Foundation of China with 345 records (4.07%) and National Science Foundation with 309 records (3.64%). While Fundamental Research Funds for the Central Universities has funded 274 records, National Basic Research Program of China has funded 110 records. Other 14 funding agencies have contributed 34-98 records. These 19 agencies have funded 31.84% of total WLC research output during 2010-2018.

8.7 FUTURE-METRICS AND BRADFORD'S LAW OF SCATTERING

8.7.1 TIME SERIES ANALYSIS

Table 48

Time series analysis: Global WLC research output

Sl. No	Year	X	Y	X	XY	X²
1	2010	0	516	-3.5	-1806	12.25

2	2011	1	601	-2.5	-1502.5	6.25
3	2012	2	731	-1.5	-1096.5	2.25
4	2013	3	733	-0.5	-366.5	0.25
5	2014	4	818	0	0	0
6	2015	5	1015	0.5	507.5	0.25
7	2016	6	1186	1.5	1779	2.25
8	2017	7	1347	2.5	3367.5	6.25
9	2018	8	1535	3.5	5372.5	12.25
Total	-	36	8482	0	6255	42

$y=a+bx$	
$a=\Sigma Y/N$	942.4444
$b=\Sigma XY/\Sigma X^2$	148.9286

2025	3176.37
2030	3921.02
2040	5410.30
2050	6899.59

Table 48 shows the projected output of the research publications in Wireless Communication. It is estimated that the number of documents in Wireless Communication research will reach 3176 in 2025, 3921 in 2030, 5410 in 2040 and 6900 in 2050, if the present trend continues.

Table 49

Time series analysis: single author publications in global WLC research output

Sl. No	Year	X	Y	X	XY	X ²
1	2010	0	34	-3.5	-119	12.25
2	2011	1	33	-2.5	-82.5	6.25
3	2012	2	48	-1.5	-72	2.25
4	2013	3	37	-0.5	-18.5	0.25
5	2014	4	33	0	0	0
6	2015	5	47	0.5	23.5	0.25
7	2016	6	57	1.5	85.5	2.25
8	2017	7	69	2.5	172.5	6.25
9	2018	8	60	3.5	210	12.25
Total	-	36	418	0	199.5	42

$y=a+bx$	
$a=\Sigma Y/N$	46.44444
$b=\Sigma XY/\Sigma X^2$	4.75

2025	117.69
2030	141.44
2040	188.94
2050	236.44

Table 49 shows the Time Series Analysis (TSA) of single author publications in global WLC research output. It clearly depicts that projected output of the research publications in Wireless Communication in terms of single authorship pattern. The number of contribution of single authors will reach 118 in 2025, 141 in 2030, 188 in 2040 and 236 in 2050, if the present trend continues.

8.7.2 BRADFORD'S LAW OF SCATTERING

Bradford's law serves as a general guideline to librarians in determining the number of core journals in any given field. It states that journals in a single field can be divided into three zones, each zone containing the same number of articles (Bibliometric Laws, 2012):

- a) Core journals on the given subject, relatively few in number that produces approximately one-third of all the articles.
- b) A second zone, containing the same number of articles as the first, but a greater number of journals.
- c) A third zone, containing the same number of articles as the second, but a still greater number of journals.

The mathematical relationship of the number of journals in the core to the first zone is a constant 'n' and the second zone of relationship is n^2 . Bradford expressed this relationship as 1:n:n².

Table 50

Application of Bradford's Law of Scattering for WLC research output

Zone	No. of Journals	%	No. of Articles	%	Bradford Multiplier
One	42	3.40	2826	33.32	---
Two	88	7.13	2823	33.28	2.10
Three	1104	89.47	2833	33.40	12.55

Total	1234	100	8482	100	14.64 (Mean = 7.32)
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It is observed from the Table 4.50 that there are 42 journals in the nucleus and these are the most productive journals devoted to Wireless Communication, sharing 3.40% of total journals. The next zone is represented by 88 journals which share 7.13% of total journals, and the last zone is represented by 1104 journals which share 89.47% of total journals. Each zone has approximately one-third of the total articles.

In Bradford's law, the 8482 articles were divided into three zones. The Bradford's multiplier factor was arrived at by dividing journal titles of a zone by its preceding zone. The basis for choosing the three zones was that the percentage error in distribution of articles, among the three zones should be the tests possible. In the present data set, 42 journals covered 2826 articles, next 88 journals covered 2823 article and next 1104 journals covered 2833 articles. According to Bradford zones, thus identified in the form 1: n: n². in the present study, the relationship of each zone is 42:88:1104 :: 1:2.10:26.29. Here, 1 represents the number of periodicals in the nucleus and n= 7.32 is a multiplier. The mean value of multipliers is 7.32.

Therefore, 1: n: n² :: 1: 1 X 7.32 : 1 X 53.58

$$= 1:7:54/1234$$

$$= 62 (1+7+54)$$

$$\text{Percentage of Error} = \frac{1234-62*100}{1234}$$

$$= \frac{-4966}{1234}$$

$$= -4.02\%$$

Theoretical value (1:7:54) stands very far from the observed value (1:2.10:26.29) and -40.2% of error is quite significant. Hence, the research output on WLC (2010-2018) does not follow the Bradford's Law of scattering.

9 TENABILITY OF HYPOTHESES

Hypothesis One : The global research output on Wireless Communication follows an exponential growth pattern.

The R Squared value is 0.9563 for the linear growth model and 0.9851 for the exponential growth model. This shows that the research output on Wireless Communication follows the exponential growth pattern. There is an exponential growth in the research output over the period of 9 years (Figures 4.2 and 4.3). Thus, the hypothesis is accepted.

Hypothesis Two : There is an inverse relationship between Relative Growth Rate and Doubling Time.

The relative growth rate of wireless communication research output shows a decreasing trend. The doubling time of WLC research productivity shows an increasing trend (Table 4.5). Thus, the hypothesis is accepted.

Hypothesis Three : English is the most preferred language among the researchers in publishing research findings in WLC.

The maximum number of articles i.e 8352 (98.467%) were published in English language (Table 4.11). Thus, the hypothesis is accepted.

Hypothesis Four : There has been an increasing trend in collaborative research during the study period.

The degree of collaboration ranged from 0.93 to 0.96. The DC was the least during 2010 and 2012 (0.93) and it was the highest during 2014 and 2018 (0.96) (Table 4.37). Thus, the hypothesis is accepted.

Hypothesis Five : The article form of publication in Wireless Communication research output absorbs the predominant place in comparison with other type of publications.

The maximum number of publications were 'Articles' (7990, 94.20%) in WLC research output (Table 4.9). Thus, the hypothesis is accepted.

Hypothesis Six : The distribution of Wireless Communication research output conforms the Bradford's law of Scattering.

Theoretical value (1:7:54) stands very far from the observed value (1:2.10:26.29) and -40.2% of error is quite significant. Hence, the research output on WLC (2010-2018) does not follow the Bradford's Law of scattering (Table 4.50). Thus, the hypothesis is rejected.

Hypothesis Seven : The future estimate of WLC research output shows an increasing trend.

Projected output of the research publications in Wireless Communication is estimated that the number of documents in Wireless Communication research will reach 3176 in 2025, 3921 in 2030, 5410 in 2040 and 6900 in 2050, if the present trend continues (Table 4.48). Time Series Analysis (TSA) of single author publications in global WLC research output depicts the number of contribution of single authors will reach 118 in 2025, 141 in 2030, 188 in 2040 and 236 in 2050, if the present trend continues (Table 4.49). The hypothesis is, thus, accepted.

10 SUGGESTIONS

10.1 Findings' Specific Suggestions

The following suggestions are made by the researcher in the context of above findings.

- Two of the total 8482 records are retracted publications. The researchers should work in the environment which ensure academic and research integrity. They should follow the research ethics scrupulously. Without getting caught in the act of plagiarism, giving due credit to the original ideas, the publications are to be prepared.
- Compared to journal articles, conference publications are less in WLC research output. These days, lot of conferences are being conducted throughout the world. The conference organizers should bring out the conference proceedings to increase the visibility of the researchers.
- As journal articles are the most preferred form of communication among the researchers of WLC, the researchers should be educated on the form, content, style and presentation of journal articles with the art and science of undertaking the same. The mechanism and tools available for article preparation and checking may be brought to the notice of the researchers.
- Compared to English, the research publications on WLC is comparatively very less. The researchers may be motivated to publish papers in their regional language also. Full paper may be published in the regional language and the abstract may be made available in English too.
- The libraries which are interested to build their e-resource collection on WLC may look for the most prolific journals enlisted in this research work. Before subscribing the journals on WLC, the nucleus or core journals should be considered by the selection committee.

- The keywords which were frequently used may be compiled and kept ready in the library and the same may be communicated among the budding scientists in WLC which may give them a lead to find out the most emerging areas of research. And searching for information using these keywords will bring forth the required results.
- The ideal paper number is around 12. The researchers in the WLC field may be directed to draft their findings within this page range for their immediate acceptance and universal alignment.
- The most active research areas / thrust areas in the field of WLC may be circulated among the researchers to update them on the hot areas and topics. At the same time, the less touched areas / upcoming research fields in WLC may also be communicated to alert the researchers to take up some initiatives in those emerging areas.
- As it is evident, multi-disciplinary and inter-disciplinary research is very much welcomed in the field of WLC. The researchers should be encouraged to think in broader perspectives, to work in wider areas so as to unearth the research areas of WLC from different viewpoints.
- It is found that a good number of articles don't have cited references. The researchers should be directed to include suitable references in their research papers. The journal or book or conference editors should insist the contributors to include the list of references in their papers before they are accepted for publication.
- The research papers with highest number of citations, the most influencing research communications in WLC field may be purchased / downloaded and made available to all the researchers.
- Rather than single author contributions, multi-authored and joint-authored contributions are more. Thus, the researchers may be motivated to work in collaboration with others.
- Very small and small research teams are popular in WLC research. So, the researchers should be encouraged to work in teams. The team may either consist of likeminded researchers thinking about a specific piece of work or a heterogeneous group consisting of researchers viewing WLC from different perspectives.
- The papers written by the most prolific authors may be compiled and circulated among the researchers. The budding scientists in the field of WLC will be motivated and they will get an insight into the way of writing research papers in the most acceptable form.

- The most cited items and the most influencing research papers in the field of WLC may be made available in open source platforms to propagate their importance and inevitability.
- The developed countries in the field of WLC may build open source resource centres exclusively for developing countries. A kind of knowledge sharing may be developed over such programmes.
- Researchers' exchange programme may be implemented. The countries which are not developed in their WLC research programmes, may be sent on an academic and research visits to developed countries for a stipulated period to learn the recent advancements.
- International / National research cell may be formed to assist the budding scientists to get necessary technical assistance in conducting research on WLC.
- An online forum of eminent scientists on WLC research may be formed to provide online guidance and assistance to the required researchers so as to promote the research interests and publications on WLC.
- Enough lab infrastructure facilities should be developed in developing countries to provide enough ambiances for the researchers to conduct their research studies in the best possible manner.
- The most prolific publishers on WLC research areas may come forward to bring out whole / a part of their publications on open source platforms.
- The budding scientists should make a note of funding agencies which are ready to sanction funds to promote research in WLC. They should apply for research funds on various emerging areas and carry out their research work effectively.

10.2 General Suggestions

The following general suggestions are given by the researcher to promote the quantity and quality of research on WLC.

- Necessary Research Circles may be created in WLC research institutions enabling the researchers work in teams to produce collaborative papers.
- Collaborative Research Funding may be instantiated. More funds will be allocated to the WLC researches being undertaken by the research teams of small and medium sizes rather than that by the individuals.

- The researchers on WLC studies may be directed to publish their findings on the most productive journals the journals with high citations / h-index/ impact factor to increase their visibility.
- A good number of open access online journals and databases may be initiated in WLC research studies.
- The researchers may be suggested to publish their research findings in English language since the documents which are published and cited most are in English.
- A national level network of institutions carrying out research in WLC studies may be formed to promote domestic collaborative research efforts.
- The investments, infrastructures and facilities to access international databases should be provided to the institutions which are lagging behind, to accelerate their research activities and to collaborate with other active institutions at national and international level.
- Indian institutions should be encouraged to undertake international level R & D projects to improve the international collaboration and to increase the visibility of their research findings.
- The directory of WLC institutions and the most productive researchers in the WLC research may be created state-wise and made available in public domains.
- National Information Centre for WLC may be created to maintain a national level database on the subject with a decentralized input and centralized output mode.
- Both the central and state governments should allocate sufficient funds for undertaking R & D activities in WLC research.
- Mini, Micro and Major level projects may be granted to the teaching and researching professionals.
- Both short term and long term proposals may be invited from the interested researchers for carrying out research in WLC and related areas.
- Recognitions in terms of awards, rewards, extra grants, concessions may be provided to the institutions / individual researchers who make a great breakthrough in WLC research studies.
- National and international level conferences and seminars may be organized in India to kindle the interest of young researchers to publish their research papers in WLC studies.
- Libraries and information centres should provide alert services, SDI services and new arrivals services to the scientists working on WLC research to keep them updated in the field.

11 DIRECTIONS FOR FURTHER RESEARCH

The present research may be furthered by the future researchers in the following directions.

1. Scientometric analysis of research output on 'Indian contributions in Wireless Communication' Research output.
2. Scientometric analysis of research output of 'SAARC Countries on Wireless Communication'.
3. Scientometric analysis of research output of 'G-7 / ASEAN Countries on Wireless Communication'.
4. Scientometric analysis of research output of 'Asian Tigers' on Wireless Communication'.
5. Scientometric analysis of research output of Women Contributors on Wireless Communication'.
6. Scientometric analysis of research output of Asian Vs. American or Asian Vs. African, Asian Vs European countries on Wireless Communication'.
7. Scientometric analysis of research output of on wireless Communication as available in open access databases and directories like DOAJ, Paperity etc.
8. Scientometric analysis of research output on Wireless Communication as indexed in Scopus Database.
9. Scientometric analysis of research output on Wireless Communication as indexed in Indian Citation Index.
10. Scientometric analysis of research output on Wireless Communication as indexed in Engineering Village.

12 CONCLUSION

The libraries which are located in research institutions involved in WLC research should mobilize both print and e-resources required by the researchers. The researchers should be provided with both traditional and modern online library services to enable them get the latest updates on WLC research both in India and other countries. The libraries should make use of all the web 2.0 and social media tools to reach the scientists working on WLC with right information at right time. Good ICT infrastructure, wi-fi enabled library campus, in-built institutional repositories, RFID based library routines, customer oriented programmes, service minded qualified LIS professions and the active management support are the requisites to make the library contribute their best in grooming WLC research output.

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