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Scientometric Study of Superconductivity Research in India from 1989 to 2014

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Abstract

This paper presents scientometric analysis of superconductivity research output in India from 1981 to 2014 and compares it with Global output as reported in Web of Science. The study shows that superconductivity research in India had a steep growth between 1981 and 1988, particularly an abrupt hike in 1987 is noticeable (both Indian and Global) followed by a more or less steady pattern thereafter up to 2014. The Indian growth pattern however differs from Global pattern. A sudden climb was noticed in 1987, which touched the crest in 1991. It started to descend thereafter steadily and troughed in 2003 followed by another steady rise again up to 2014. Indian trend thus shows a dip between 1992 and 2014 unlike Global pattern which was nearly steady over the span. The author productivity pattern only approximately corresponds to Lotka's law. The number of core journals in the subject area is comparatively less as obtainable by employing Bradford's law of scattering.

Keywords: Bradford's Law, Growth of Literature, India, Logistic Model, Lotka's Law, Scientometrics, Superconductivity Research

1. Introduction

Superconductivity is a phenomenon of exactly zero electrical resistance and expulsion of magnetic fields occurring in certain materials when cooled below a critical temperature. It was discovered by Dutch physicist Heike Kamerlingh Onnes in 1911. Like ferromagnetism and atomic spectral lines, superconductivity is a quantum mechanical phenomenon. It is characterized by the Meissner effect, the complete ejection of magnetic field lines from the interior of the superconductor as it transitions into the superconducting state. The occurrence of the Meissner effect indicates that superconductivity cannot be understood simply as the idealization of *perfect conductivity* in classical physics[1]. Superconductivity phenomenon is characterized by complete disappearance of electrical resistance in various solids when they are cooled below a characteristic temperature. This temperature, called the transition temperature, varies for different materials but generally is below 20 K (−253 °C)[2]. The research in this area has a long history of nine decades. A radical change in superconductivity research was observed due to discovery of High Temperature Superconductivity by Bednorz and Muller in 1986.

2. Related Works

Sharma and Sen[3] studied changing pattern of collaboration in Indian superconductivity research. Uzunov[4] conducted study on Superconductivity Research in Bulgaria and found that research in superconductivity related topics is concentrated mainly in two Bulgarian scientific institutions. Arunachalam and Singh[5] conducted an analysis of 130 papers on superconductivity published by Israeli researchers and indexed in Physics Abstracts (1971-1982) and found that Israel does pretty well in this area. Prolific institutions and authors were identified as well as journals most often used, highly cited papers, etc. Many of the papers appeared in high impact international journals, with Physical Review B (26), Journal of Low Temperature Physics (11) and Solid State Communications (10) leading the field. Among the five institutions active in the area, Tel Aviv University (68) accounts for more than half of Israel's publication output. Zhu and Willett[6] studied a bibliometric analysis of the development of Chinese research in superconductivity since the advent of high-temperature superconductivity (HTS) in the mid-Eighties, and to compare Chinese research with that of its international competitors and

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found that Chinese HTS research has grown steadily in importance over the period with a significant increase in peer-recognition, as measured by citations from non-Chinese researchers. Arunachalam and Singh[7] studied a analysis of bibliographic data on 255 randomly chosen documents on superconductivity (1969-1970) and the citations to them in the international literature over the twelve year period 1970-1981, to identify the geographical origin, language, and journal-wise distributions of the papers, the citedness of these papers and the distribution of citations as a time series for the more often cited papers. Barth and Marx[8] analyzed the research field of high-temperature superconductivity to demonstrate the potential of modern databases and search systems for generating meta-information. The alkaline earth (A2) rare earth (RE) cuprite high-temperature superconductors as a typical inorganic compound family and the corresponding literature were analyzed by scientometric methods. Nadel[9] found that, the citation and co-citation data are separate types of information which, under some historical conditions, give differing results. There are a number of bibliometric studies of superconductivity research: Cardona and Marx[12], Chu[10,15] and Garfield[16,17], to mention a few. Cardona and Marx studied the influence of the work of Vitaly Ginzburg, an influential scholar in superconductivity research, and Chu[13,14] discussed communications between Chinese and non-Chinese superconductivity scientists, revealing that the Chinese scientists were less visible compared to non-Chinese scientists. However, there are not many scientometric studies on Indian superconductivity research, though it is a forefront research area. Arunachalam and Singh carried out comparative studies between different nations' contributions to superconductivity that predate the High Temperature Superconductivity era. This paper reports a detailed scientometric analysis of Indian superconductivity research for the period 1989-2014.

3. Objectives

The principal objectives of the study are to find:

- Growth pattern of literature from 1981 to 2014,
- Comparative study between Global and Indian growth pattern over the same period,
- Core journals of this subject domain,
- Core authors of this subject domain, and
- Applicability of Bradford's law and Lotka's law.

4. Scope and Methodology

The data for this study was downloaded from the *Web of Science* database. For downloading the data, the search term applied was "Superconduct*" AND Author address= "India". The search term "Superconductivity" consists of the prefixed word stem "Super" and the semantic full word "Conductivity". This may be considered as central keyword of the topic discussed. As indicated by Lancaster, main heading takes care of synonyms, near synonyms and homonyms. Therefore maximum retrieval is expected by using this term. A total of 6415 records spanning for the years 1981 to 2014 were downloaded. Each record contained English language abstract with complete bibliographic data e.g. author, name of journal, author address, affiliation, keywords, cited items etc. The downloaded data was analysed for source items to find out the research trend.

5. Results and Analysis

5.1 Growth of Literature

The no. of Indian and Global research articles published along with corresponding growth rate, fluctuations, percentages, cumulative numbers and % of Indian share of Global output, are presented in Table 1. In all, 6415 articles (Indian) and 179962 articles (Global) were published during this time span. The average Indian share of Global research output is 3.56% over the time span. The abrupt hike in number of papers from 1986 to 1987 is a notable feature. The Indian and Global output galloped seven times (from 14 to 101) and 3.4 times (from 799 to 2699) respectively from 1986 to 1987. Both positive and negative growth rates of Global and Indian research output are observed as presented in Table 1. In case of both Indian and Global output, 19 positive and 14 negative growth rates are observed. Also, the fluctuating trend for Global and Indian contributions are not identical over the entire time span. It is found that Global and Indian growth trends are identical, i.e. both are either positive or negative, for 21 years, ('82, '83, '87, '88, '91-'96, '98, '99, 2001, 2002, 2005-'09, 2012 and 2013) and opposite for 12 years, (1984-'87, '89, '90, '97, 2000, 2003, 2004, 2010, 2011 and 2014). The number of research papers is succeeded by another bracket, which shows the percentage contribution in each year over the total contribution (Global: 179962 and Indian: 6415). Figure 8 shows the comparative study between Global and Indian research contributions during 1981-2014. Also, Figure 5 shows the year-wise variation of Indian share of Global output, which is continuously fluctuating with a marked depression since 2000 to 2007. The lowest number of Global and Indian research articles were published in the years 1982 (731) and 1985 (10) respectively, while the highest number of Global and Indian research articles

were published in the year 1991 (Global: 8050 and Indian: 327). The average Global and Indian fluctuation rates over the entire time span are 10.21% and 26.5% respectively. The average Indian fluctuation is thus 2.5 times higher than Global fluctuation. Figure 9 presents the comparative study between Global and Indian growth % fluctuation since 1981-2014. The total positive fluctuation figures 1130.2 (Indian) and 504.2 (Global), whereas the total negative fluctuation figures -255.6 (Indian) and -167.2 (Global). Hence, the magnitude of Indian positive fluctuation is nearly 5 times larger than Indian negative fluctuation. Also, the magnitude of Global positive fluctuation is nearly 3 times larger than Global negative fluctuation. As total positive fluctuation is higher than total negative fluctuation in both cases, it may be inferred that the overall trend is growth, but not decay. The year-wise variation of Indian and Global output are presented in Figures 1 and 3 respectively, which shows several fluctuations, in particular the fluctuations between 1989 and 1993, 2009 and 2011 are noteworthy. A steep rise in no. of articles in the year 1987 is an aberration in more or less uniform growing trend. The year-wise variation of cumulative no. of Indian and Global output are presented in Figures 2 and 4, which shows a uniform growth represented by nearly straight line. It is thus evident that, in India superconductivity research has been continued since long and at present it is also growing.

The variation of Global superconductivity literature follows almost logistic growth pattern, which is shown in Figure 6. The logistic equation representing the curve of Figure 6 may be written as:

$Y = a/(1 + b*\exp(-c*X))$, where, a=6640.6, b=208.01 and c=0.6868 (1)

The variation of Indian superconductivity literature follows superposition of two curves, i.e. one logistic curve and the other parabolic curve. The combined growth pattern is shown in Figure 7. The logistic equation of the curve of Figure 7 may be written as:

$Y = a/(1 + b*\exp(-c*X))$, where, a=239.8, b=740.2 and c=0.834 (2)

The parabolic equation of the combined curve of Figure 7 may be expressed as:

$Y = 1/(a + b*X + c*X^2)$, where a = -0.0016, b = 0.000556 and c = -0.0000121 (3)

The complete curve of Figure 7 is thus the superposition of curves represented by Equations (2) and (3).

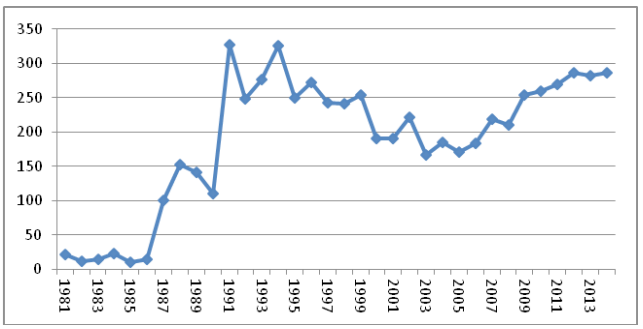

Figure 1. Year-wise variation of Indian superconductivity literature (1981-2014).

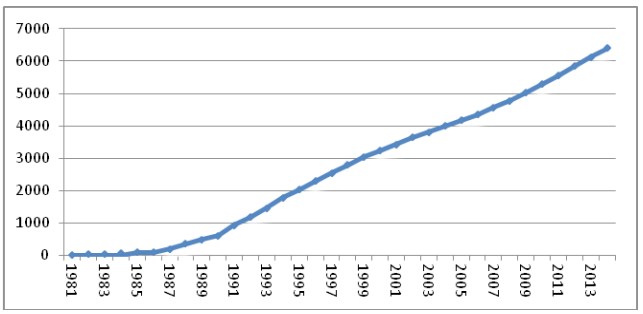

Figure 2. Year-wise variation of Indian superconductivity literature (cumulative).

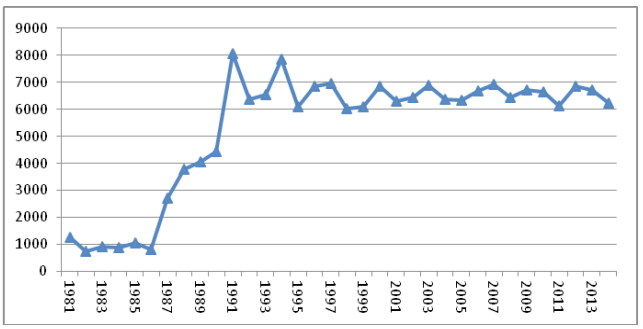

Figure 3. Year-wise variation of Global superconductivity literature (1981-2014).

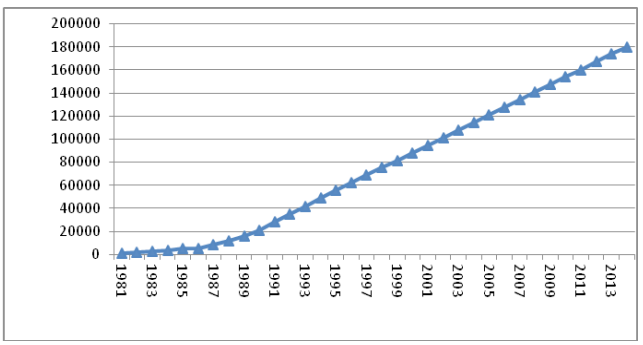

Figure 4. Year-wise variation of Global superconductivity literature (cumulative).

Table 1. Growth of literature of superconductivity (Indian and Global)

Year	Global output (No. & % of papers)	Global growth %	Global output (Cumulative)	Indian output (No. & % of papers)	Indian growth %	Indian output (Cumulative)	% Indian share
1981	1263 (0.7%)		1263	21 (0.33%)		21	1.66
1982	731 (0.41%)	-42.12	1994	11 (0.17%)	-47.62	32	1.50
1983	922 (0.51%)	26.13	2916	15 (0.23%)	36.36	47	1.63
1984	877 (0.49%)	-4.88	3793	23 (0.36%)	53.33	70	2.62
1985	1036 (0.58%)	18.13	4829	10 (0.16%)	-56.52	80	0.97
1986	799 (0.44%)	-22.88	5628	14 (0.22%)	40.00	94	1.75
1987	2699 (1.5%)	237.80	8327	101 (1.57%)	621.43	195	3.74
1988	3783 (2.1%)	40.16	12110	153 (2.39%)	51.49	348	4.04
1989	4045 (2.25%)	6.93	16155	142 (2.21%)	-7.19	490	3.51
1990	4447 (2.47%)	9.94	20602	111 (1.73%)	-21.83	601	2.50
1991	8050 (4.47%)	81.02	28652	327 (5.1%)	194.59	928	4.06
1992	6361 (3.53%)	-20.98	35013	248 (3.87%)	-24.16	1176	3.90
1993	6553 (3.64%)	3.02	41566	277 (4.32%)	11.69	1453	4.23
1994	7841 (4.36%)	19.66	49407	326 (5.08%)	17.69	1779	4.16
1995	6082 (3.38%)	-22.43	55489	250 (3.9%)	-23.31	2029	4.11
1996	6854 (3.81%)	12.69	62343	273 (4.26%)	9.20	2302	3.98
1997	6949 (3.86%)	1.39	69292	243 (3.79%)	-10.99	2545	3.50
1998	6024 (3.35%)	-13.31	75316	241 (3.76%)	-0.82	2786	4.00
1999	6102 (3.39%)	1.29	81418	254 (3.96%)	5.39	3040	4.16
2000	6838 (3.8%)	12.06	88256	191 (2.98%)	-24.80	3231	2.79
2001	6318 (3.51%)	-7.60	94574	190 (2.96%)	-0.52	3421	3.01
2002	6433 (3.57%)	1.82	101007	221 (3.45%)	16.32	3642	3.44
2003	6902 (3.84%)	7.29	107909	167 (2.6%)	-24.43	3809	2.42
2004	6387 (3.55%)	-7.46	114296	185 (2.88%)	10.78	3994	2.90
2005	6348 (3.53%)	-0.61	120644	171 (2.67%)	-7.57	4165	2.69
2006	6670 (3.71%)	5.07	127314	183 (2.85%)	7.02	4348	2.74
2007	6936 (3.85%)	3.99	134250	219 (3.41%)	19.67	4567	3.16
2008	6430 (3.57%)	-7.30	140680	210 (3.27%)	-4.11	4777	3.27
2009	6700 (3.72%)	4.20	147380	254 (3.96%)	20.95	5031	3.79
2010	6637 (3.69%)	-0.94	154017	259 (4.04%)	1.97	5290	3.90
2011	6145 (3.41%)	-7.41	160162	269 (4.19%)	3.86	5559	4.38
2012	6858 (3.81%)	11.60	167020	287 (4.47%)	6.69	5846	4.18
2013	6712 (3.73%)	-2.13	173732	282 (4.4%)	-1.74	6128	4.20
2014	6230 (3.46%)	-7.18	179962	287 (4.47%)	1.77	6415	4.61
All	**179962**			**6415**			**3.56**

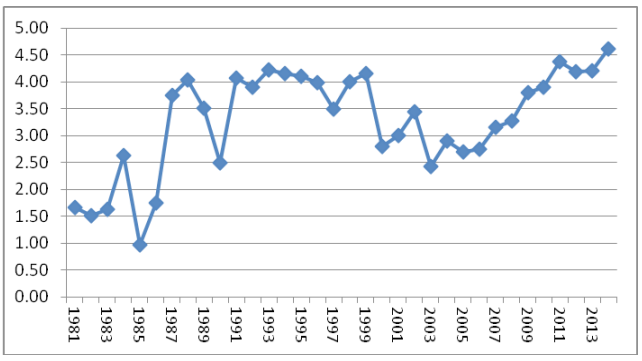

Figure 5. Year-wise variation of Indian share of Global superconductivity research.

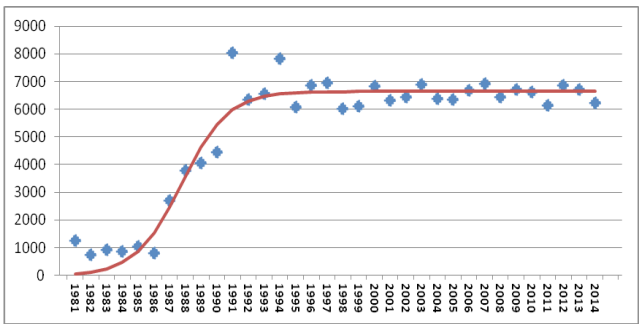

Figure 6. Variation of Global superconductivity literature almost follows logistic growth pattern.

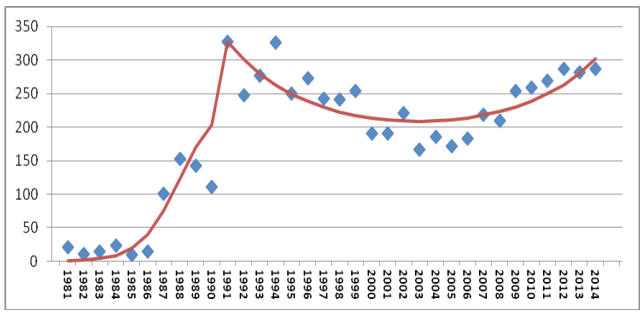

Figure 7. Variation of Indian superconductivity literature follows logistic and parabolic growth patterns at different phases.

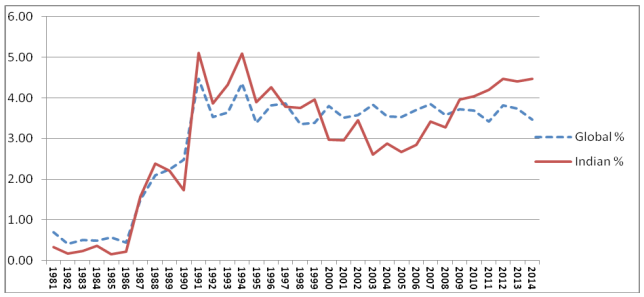

Figure 8. Comparative study between Global and Indian % research contribution since 1981-2014.

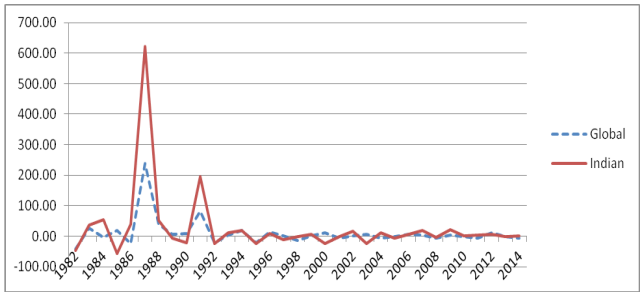

Figure 9. Comparative study between Global and Indian growth % fluctuation since 1981-2014.

5.2 Author Productivity and Lotka's Law

Lotka's law describes the publication frequencies by different authors in a given subject area. It states that the number of authors making contributions is about $1/n^2$ of those making one; and the proportion of all contributors, that make a single contribution, is about 60 percent. This means that out of all the authors in a given field, 60 percent will have just one publication, and 15 percent will have two publications ($1/2^2$ times of 60). Seven percent authors will have three publications ($1/3^2$ times of 60), and so on. According to Lotka's law of scientific productivity, only six percent of the authors in a field will produce more than 10 articles. Lotka's law, when applied to large bodies of literature over a fairly long period of time, can be accurate in general, but not statistically exact.

The general form of Lotka's law can be expressed as $y=c/xn$ where y=percentage of authors, x=number of articles published by an author, c is a constant and –n=slope of the log-log plot. In this study, 11953 authors contributed 6415 articles; on an average 1.9 (~2) authors per articles. Among 11953 authors, 6045 authors (50.6%) contributed only one article; 2009 authors (31.3%) contributed two articles; 1019 (15.8%) authors contributed three articles and 1579 (24.6%) authors contributed four articles. Hence the author productivity in case of Indian superconductivity research does not conform to Lotka's law. The notable point here is that the number of authors contributing four papers is greater than that contributing three papers. In general, the number of authors contributing a single paper account for nearly 60% of all authors. The log-log plot of cumulative number of authors and their cumulative number of papers is presented in Figure 10 that gives an approximate straight line which is not in exact confirmation with Lotka's law.

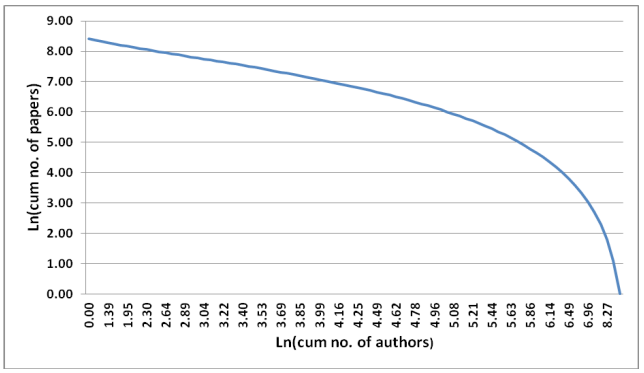

Figure 10. Ln-Ln plot of cumulative number of authors vs. papers.

The ranking of contributing authors along with the list of top authors who contributed more than 100 articles are presented in Table 2.

Table 2. Top ranked 34 authors contributed more than 50 papers

Rank	Authors	No. of articles contributed
1	Awana VPS	242
2	Gupta LC	166
3	Narlikar AV	162
4	Ramakrishnan S	155
5	Rao CNR	144
6	Mallik SK	133
7	Vijayaraghavan R	123
8	Yakhmi JV	122
9	Grover AK	115
10	Nagarajan R	112
11	Pinto R	110
12	Chaddah P, Kishan H	108 (each)
13	Syamaprasad U	100

5.3 Core Journals and Bradford's Law

In all, there are 402 journals, which published 5712 articles. The scatter of articles over journals is studied using Bradford's law to identify the 'core' journals. Figure 11 shows Bradford plot, where cumulative number of articles is plotted against the journal's rank. The division of 5712 articles into equal zones retaining 1904 articles in each zone suggests that the corresponding Bradford's ratio of number of journals involved as follows: 4 : 21 : 376. This ratio can be rewritten as: 4*(1 : 5 : 94), or, 4*(1: 5: 4*(5)^2). The number of journals in core and allied regions is in consonance with the well-known Bradford's pattern, i.e. k*(1 : n : n^2), where k is the Bradford multiplier. But the number of alien journals is not as per Bradford's pattern. An additional multiplier '4' comes here with '5' for alien journals. In this study, k = 4 and n = 5. The numbers of core, allied and alien journals in Indian superconductivity research are thus 4, 21 and 377 respectively. The notable feature is that the articles are highly concentrated in a few core journals. The numbers of core and allied journals are thus very low compared to alien journals. The list of core and allied journals, i.e. top 25 journals is given in Table 3. A look through Table 3 instantly reveals that of the 25 journals in all, only three are Indian, and remaining 22 journals are published from abroad. The Figure 11 presents journal-rank vs. cumulative no. of articles plot, which shows an approximate straight line indicating deviation from Bradford's law.

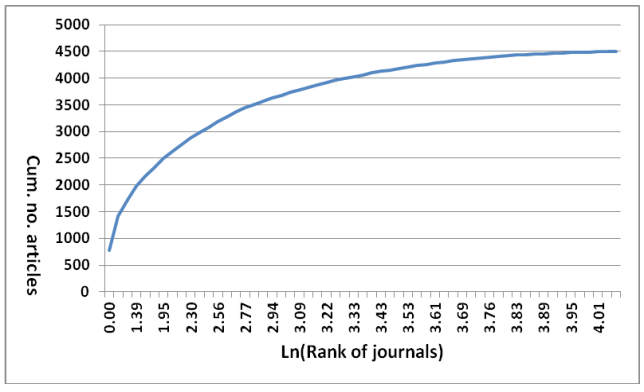

Figure 11. Journal-rank vs. cumulative no. of articles plot.

Table 3. The top 26 ranked journal of superconductivity

Rank	Source Titles	All
1	Physica C	782
2	Physical Review B	627
3	Solid State Communications	307
5	Superconductor Science Technology	261
6	Journal of Physics Condensed Matter	182
7	Bulletin of Materials Science (Indian)	178
8	Journal of Applied Physics	158
9	Pramana Journal of Physics (Indian)	136
10	Journal of Superconductivity and Novel Magnetism	119
11	Indian Journal of Pure Applied Physics (Indian)	117
12	Journal of Superconductivity	104
13	Physica B Condensed Matter	103
14	Modern Physics Letters B	100
15	International Journal of Modern Physics B	96
16	Physical Review Letters	85
17	Journal of Alloys And Compounds	74
18	Applied Physics Letters	66
19	IEEE Transactions on Applied Supercon-ductivity	61
20	Journal of Physics and Chemistry of Solids	56
21	Materials Research Bulletin	55
22	Journal of Magnetism And Magnetic Materials	53
23	Materials Letters	49
24	Journal of Materials Science Letters	47
25	Review of Scientific Instruments	45

6. Conclusion

This study dealing with Indian superconductivity research as reported in Web of Science shows that superconductivity research in India is slow but steady. The research has shown a steady growth from 1982 to 1986, an sudden hike in 1987 (both Indian and Global) followed by a more or less Global steady pattern thereafter up to the year 2014. The Indian growth pattern however

differs from Global pattern. A sudden climb was noticed in 1987, which touched the crest in 1991. It started to descend thereafter steadily and troughed in 2003 followed by another steady rise again up to 2014. Indian trend thus shows a bowl-like pattern (Figure 7) since 1992 to 2014 unlike Global pattern which was nearly steady over the span. It is a peculiarity in Indian superconductivity research trend. The author productivity pattern is not in proximity with Lotka's law. The number of core journals of this subject area is comparatively less as obtained by employing Bradford's law of scattering.

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