A bibliometric analysis of highly cited papers from India in Science Citation Index Expanded

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The aim of the present study is to analyse the highly cited papers from India. The Science Citation Index Expanded database was used to retrieve the related bibliographic records. Grouping and reclassification of institutions with misspellings and variants have been done. The most productive institutions, collaborating partners and Y-index of the contributing authors were examined. Results revealed that all the highly cited papers from India did not receive citations in the early years after publication. Co-authored (or international collaboration) papers received more citation impact than single-authored ones. USA was the preferred collaborative partner for international collaboration. The Indian Institutes of Technology, CSIR organizations, and Indian Institute of Science, Bengaluru were the leading Indian institutions.

Keywords: Bibliometrics, citation impact, highly cited articles, scientometrics, *Y*-index.

HIGHLY cited articles could provide interesting information about the contributors, articles and topics which are influential in the research community during a certain period[1]. Publications receiving 100 or more citations are considered as highly (or top) cited articles[2,3]. India's scientific output has quadrupled since 2000 (refs 4, 5). India became 10th most active publishing country in the journals covered by Science Citation Index Expanded (SCI-EXPANDED) database and 40% increase in research output will be achieved by 2020 over the year 2012 (ref. 6). India is ranked 13th globally in the Nature Index 2014, which shows that the country is among the global leaders in terms of producing high-quality science[7].

Previously, numerous studies have been conducted to identify and examine the highly cited papers in the fields of environmental science[8], adsorption[9], materials science[10], health care science[11], medical education[12] and thermodynamics[13]. Recently, analysing the highly cited articles of a specific country/territory is also of interest among the researches; for example, Russia[14], Taiwan[15] and Canada[16].

The aim of this study is to identify and examine the highly cited research papers from India in the SCI-EXPANDED database from 1900 to 2014. The study covers annual production, most cited articles (≥1,000 citations), contributing institutions and authors, and collaborative countries. A newly developed indicator called *Y*-index is used to evaluate the publication performance of contributing authors.

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Methodology

Bibliographic data for the study has been collected from SCI-EXPANDED of Web of Science (WoS; Thomson Reuters). A search was conducted with the phrase 'India' in the address field and restricted to articles only. Initially, 786,903 articles were identified, which were published between 1900 and 2014 (date of search: 25 November 2015). Then filter to highly cited publications, i.e. articles with TC_{2014} of ≥100 were selected[17,18]. This yielded 4,395 articles which were used for further analysis.

Additionally, indicators C_{2014} (ref. 3) – number of citations received by a paper in the recent year 2014, and C_0 (ref. 19) – number of citations received by a paper in the publication year were used to characterize highly cited Indian papers. Further, $TCPY^3$ – a ratio between total number of citations and number of years since date of publication to 2014 was also used.

In SCI-EXPANDED, the corresponding author is labelled as reprint author and is taken as the corresponding author[3]. In a single-author article, the author is classified as both the first author and the corresponding author. Country in authors, affiliations are checked and grouped manually[3,20–22].

Y-index

The *Y*-index[3,22,23] was employed to examine the publication performance of contributing authors. It has two constants, j (publication intensity) and h (publication

characteristics). It considers both the number of first-author papers (*FP*) and corresponding-author papers (*RP*), defined as

$$j = FP + RP, \tag{1}$$

$$h = \tan^{-1}\left(\frac{RP}{FP}\right). \tag{2}$$

where j is the total number of papers as a first author or a corresponding author. As easy to compare, we can differentiate the publication intensity and characteristics of contributing authors with the *Y*-index. A greater value of j reveals greater number of papers. Also, $h > 0.7854$ indicates more corresponding-author papers; $h = 0.7854$ indicates the same number of first and corresponding-author papers and $0 < h < 0.7854$ indicates more first-authored papers. When $h = 0$, j is the number of first-author papers and when $h = \pi/2$, j is the number of corresponding-author papers.

Results and discussion

Publication year

A total of 4,395 articles (0.56%) were identified as highly cited ($TC_{2014} \geq 100$) among the 786,903 articles contributed by Indian scientists. In recent years, Ho and his co-researchers have used the indicator citations per publication ($CPP = TC_{year}/TP$) by decades[3,24]. Figure 1 shows that the highly cited papers from India were published during 1940s–2000s. Most of the highly cited articles (87%) were published between 1990 and 2010. The highest number of highly cited papers was published in the 2000s with 55% of total articles and lowest was during 1940s and 1960s, where only one paper received more than 100 citations. There was no highly cited paper during 1950s. In general, peak of highly cited articles was found in the 1990s[9,13,22,25]. The 1940s with only one highly cited article had the highest *CPP* of 231, which can be attributed to the article entitled 'velocity of sound in liquids and chemical constitution' by Rao[26] with $TC_{2014} = 231$ published in 1941. This is also the India's earliest highly cited research paper.

Collaboration pattern

Figure 2 shows the collaboration pattern of India's highly cited papers with their citations per paper. It can be observed from the figure that internationally collaborative highly cited papers from India received more citations than any other highly cited papers. This is in agreement with an earlier study[27]. Similarly, publications with a first author and/or corresponding author from another country tend to receive more citations than those with a first author and/or corresponding author from an Indian institution. Similar kind of trend has been observed in Taiwanese highly cited papers[15]. More than 46% of India's highly cited papers were published with international collaboration. It is higher than the articles (35%) published in international journals[28].

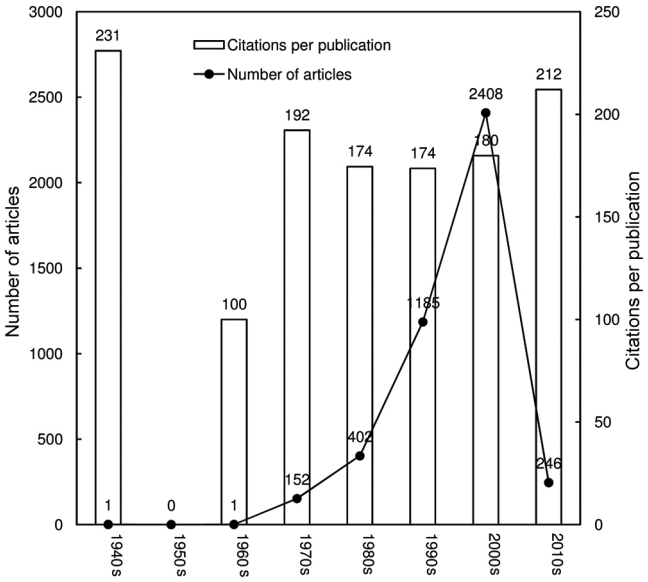

Figure 1. Number of articles and citations per publication by decades.

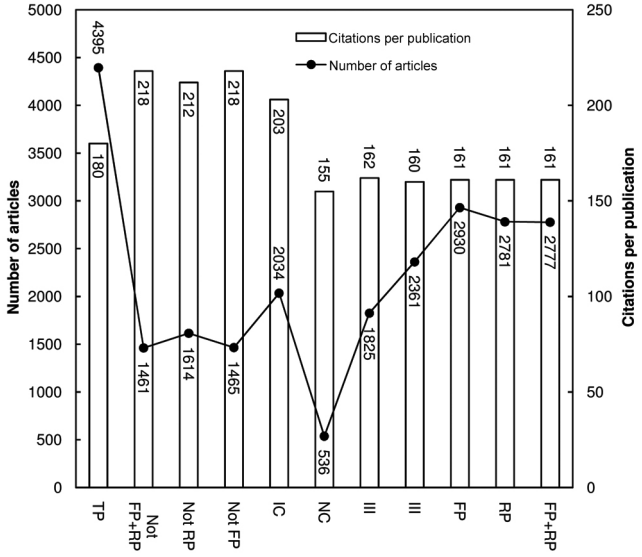

Figure 2. Citations and papers by type of collaboration and authorship. *TP*, All papers; Not *FP* + *RP*, Both first and corresponding authors are not from India; Not *RP*, Corresponding author is not from India; Not *FP*, First author is not from India; IC, Internationally collaborative papers; NC, Nationally collaborative papers; III, Institutionally-independent papers from India; II, Independent papers from India; *FP*, First author is from India; *RP*: corresponding author is from India; *FP* + *RP*: Both first and corresponding authors are from India.

In total, there were 2,361 (54%) nationally collaborative articles and 2,034 (46%) internationally collaborative articles with 138 countries. Table 1 shows the frequently collaborating countries with the number of first-author and corresponding-author articles. Share of publications of these countries ranged between 2.3% and 27%. Almost one-third of the highly cited articles (27%) were collaborative publications with authors originating from USA. This result is in agreement with the earlier studies, e.g. Taiwanese highly cited papers[15] and China's chemical engineering publications[29]. Similarly, USA had most of the first-author and corresponding-author articles, which indicates that the country has a USA leadership role in collaborative partnership with India. The United Kingdom and Germany are the second and third top collaborative partners of India with 10% of the total publications. The top five collaborative partners (USA, UK, Germany, France and Japan) belong to the G7 countries. Of the top 21 countries, only 4 (China, Japan, South Korea and Taiwan) belong to the Asian region, which indicates that Indian authors willing to collaborate frequently with authors from outside Asia.

Leading institutions and authors

During the analysis, it was observed that there were some institutions with identical names and misspellings. Hence, a thorough reclassification and grouping of institutions has been done (e.g. Jawaharlal Nehru Ctr Adv Sci Res, Jawharlal Nehru Ctr Adv Sci Res and JNCASR).

In total, 1,821 (41% of 4395 articles) were single-institution articles, and 2,574 (59%) were inter-institution collaborative articles, including 540 (12%) nationally collaborative articles and 2,034 (46%) internationally collaborative articles. Table 2 shows the characteristics of the top 12 Indian institutions having more than 80 highly cited papers. More than 36% of highly cited papers were contributed by the top three leading institutions: Indian Institutes of Technology (IITs) with 622 (14%) highly cited papers, CSIR organizations with 565 (13%) highly cited papers, and the Indian Institute of Science (IISc), Bengaluru with 395 papers (9.0%). Research organizations such as Tata Institute of Fundamental Research (TIFR) and Bhabha Atomic Research Centre (BARC), Mumbai were ranked fourth and fifth in terms of number of publications respectively. Similarly, research institutions had self-reliance including CSIR organizations, Jawaharlal Nehru Centre for Advanced Scientific and Research (JNCASR) Bengaluru, and Indian Association for the Cultivation of Science (IACS), Kolkata, which independently published more than 75% of their publications. Some institutions like the IITs, CSIR organizations, IACS, and the Indian Institute of Chemical Technology, Hyderabad both first-author and corresponding-author articles in more than 70% of their publications, whereas these institutions had lower percentage of internationally collaborative publications. This revealed the self-reliance of these institutions. On the other hand, some institutions showed high dependence on international collaborations, e.g. Punjab University, Chandigarh, TIFR and BARC. However, a bias appeared because the Indian Institute of Technology and the CSIR have branches in many different cities[30].

A total of 2,466 authors contributed 4,395 highly cited Indian papers. Generally, the number of contributing authors is greater than the total number of articles. In total, 3,916 articles had information on both the first and corresponding authors in WoS, these were further analysed using the *Y*-index. Figure 3 shows information about the *Y*-index for the top 38 authors ($j \geq 12$); and these 38 authors can be considered as the major contributors to the world scientific fraternity. Each dot represents a *Y*-index (j, h). The publication intensity constant j reveals the number of first-author and corresponding-author papers. Further, Figure 3 can be used as a tool, especially in differentiating the number of first-author and corresponding-author papers. For example, h of C. Namasivayam (Bharathiar University in Tamil Nadu), B. C. Ranu (IACS), J. S. Yadav (CSIR) and R. N. Goyal (IISc) was 0.7854, but their j values differed – 26, 22, 22 and 20 respectively. In another example, the j value of T. Pal

Table 1. Collaborating countries

Country	*TP*	*TP* rank (%)	*FP* rank (%)	*RP* rank (%)
USA	1185	1 (27)	1 (15)	1 (14)
UK	460	2 (10)	2 (3.5)	2 (3.1)
Germany	450	3 (10)	3 (2.3)	3 (2.3)
France	384	4 (8.7)	4 (1.7)	5 (1.6)
Japan	308	5 (7.0)	4 (1.7)	4 (1.7)
China	278	6 (6.3)	12 (0.41)	11 (0.44)
Russia	218	7 (5.0)	11 (0.43)	11 (0.44)
Italy	217	8 (4.9)	8 (0.75)	8 (0.87)
Canada	205	9 (4.7)	6 (1.3)	6 (1.3)
Switzerland	197	10 (4.5)	7 (1.2)	7 (1.2)
Brazil	193	11 (4.4)	27 (0.091)	28 (0.073)
Australia	191	12 (4.3)	9 (0.50)	10 (0.48)
South Korea	189	13 (4.3)	10 (0.48)	9 (0.51)
The Netherlands	177	14 (4.0)	18 (0.25)	17 (0.29)
Sweden	155	15 (3.5)	14 (0.36)	14 (0.36)
Poland	153	16 (3.5)	31 (0.046)	31 (0.048)
Spain	150	17 (3.4)	15 (0.32)	13 (0.39)
Taiwan	119	18 (2.7)	27 (0.091)	26 (0.10)
Czech Republic	110	19 (2.5)	29 (0.068)	28 (0.073)
Israel	108	20 (2.5)	20 (0.23)	18 (0.24)
Mexico	102	21 (2.3)	31 (0.046)	31 (0.048)
Other countries (117)	2076			
Total	7625*			

TP, Total number of papers collaborative with India; *FP*, Number of first-author papers; *RP*, Number of corresponding-author papers; N/A, Not available. *As 2,034 papers were contributed by authors from more than one country, this number exceeds the total number of publications (4,395).

Table 2. Characteristics of the top 12 institutions (*TP* > 80)

Rank	Institution	*TP* (%[a])	*III* (%[b])	IC (%[b])	*NC* (%[b])	*II* (%[b])	*INC* (%[b])	*FP* (%[b])	*RP* (%[b])
1	Indian Institutes of Technology	659 (15)	437 (66)	222 (34)	106 (16)	331 (50)	328 (50)	485 (74)	473 (72)
2	National Chemical Laboratory	565 (13)	419 (74)	146 (26)	105 (19)	314 (56)	251 (44)	406 (72)	402 (71)
3	Indian Institute of Science	395 (9.0)	235 (59)	160 (41)	88 (22)	147 (37)	248 (63)	249 (63)	223 (56)
4	Tata Institute Fundamental Research	285 (6.5)	91 (32)	194 (68)	18 (6.3)	73 (26)	212 (74)	119 (42)	114 (40)
5	Bhabha Atomic Research Centre	151 (3.4)	51 (34)	100 (66)	17 (11)	34 (23)	117 (77)	52 (34)	47 (31)
6	University of Delhi	115 (2.6)	49 (43)	66 (57)	20 (17)	29 (25)	86 (75)	46 (40)	47 (41)
7	Punjab University	114 (2.6)	16 (14)	98 (86)	5 (4.4)	11 (10)	103 (90)	20 (18)	19 (17)
8	Banaras Hindu University	108 (2.5)	43 (40)	65 (60)	10 (9.3)	33 (31)	75 (69)	48 (44)	45 (42)
9	All India Institute of Medical Sciences	100 (2.3)	36 (36)	64 (64)	13 (13)	23 (23)	77 (77)	34 (34)	30 (30)
10	Jawaharlal Nehru Centre for Advanced Scientific Research	96 (2.2)	74 (77)	22 (23)	49 (51)	25 (26)	71 (74)	53 (55)	52 (54)
11	University of Hyderabad	88 (2.0)	53 (60)	35 (40)	11 (13)	42 (48)	46 (52)	64 (73)	58 (66)
12	Indian Association for the Cultivation of Science	84 (1.9)	68 (81)	16 (19)	10 (12)	58 (69)	26 (31)	67 (80)	65 (77)

TP, Total number of highly cited Indian articles; *III*, Number of India-independent articles; *IC*, Number of internationally collaborative articles; *NC*, Number of nationally collaborative articles; II, Number of institutionally independent articles; *INC*, Number of institutionally collaborative articles; *FP*, Number of first-author articles; *RP*, Number of corresponding-author articles.
%[a] Percentage of highly cited articles among the total highly cited articles from India
%[b] Percentage of highly cited articles among the total highly cited articles from an institution.

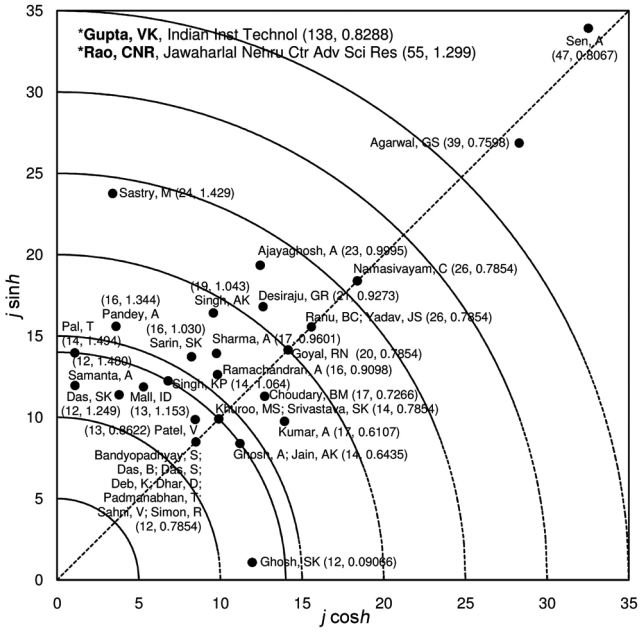

Figure 3. *Y*-index of the top 38 authors with the greatest *j* values ($j \geq 12$).

(IISc), K. P. Singh (Industrial Toxicology Research Centre, Uttar Pradesh), M. S. Khuroo (Sher-i-Kashmir Institute of Medical Sciences, Kashmir), S. K. Srivastava (Indian Institute of Management), A. Ghosh (JNCASR), and A. K. Jain (IISc) was 14, but their *h* values differed – 1.494, 1.064, 0.7854, 0.7854, 0.6435 and 0.6435 respectively. Pal had greater proportion of corresponding-author articles to first-author articles than Singh ($h = 1.064$); Khuroo and Srivastava published the same number of first- and corresponding-author articles ($h = 0.7854$); and Ghosh and Jain published greater proportion of first-author articles to corresponding-author articles ($h = 0.6435$). The leaders in Indian scientific output were V. K. Gupta (IIT Roorkee) with $j = 138$ and C. N. R. Rao (JNCASR) with $j = 55$. Gupta was also evaluated using the *Y*-index as one of the top authors in adsorption research field[9]. Both the authors are doing research in the field of chemistry. In addition, S. K. Ghosh (IIT Maharashtra) published greater proportion of first-author articles to corresponding-author articles with $h = 0.09066$. There is a bias in the analysis of authorship when different authors have the same name, or the authors use different names and spellings in their articles[31]. Another potential arises when an author moves from one affiliation to another[32] and renaming of the institutions over the period. For example, C. N. R. Rao moved from IIT Kanpur to IISc and then to JNCASR. The University of Roorkee was renamed as Indian Institute of Technology Roorkee in the year 2001. In this study, we improved the analysis by merging the institutions.

Leading papers

Table 3 reveals information on the top 27 papers which have received more than 1,000 citations. These can be considered as classic papers contributed by Indian scientists. Among them, 17 papers were published in the 2000s, 6 in the 1990s, 3 in the 2010s, and 1 in the 1980s. Among these 27 papers, only 3 had the first author (including two single-authored papers) from India and there was no corresponding author from India. The earliest classic paper was published in 1987 and the most recent one in 2012. There was no particular pattern in the four indicators TC_{2014}, C_{2014}, C_0, and *TCPY* among the classic papers. For example, there was no citation in the publication year for the top cited paper[33]. However, this paper

had received more than 1,000 citations in 2014. Similarly, publications of Desiraju[34], Yusuf *et al.*[35] and Deb[36] had no citation in the publication year. Among the 27 papers, 13 were published in high-impact journals: four in the *New England Journal of Medicine* (impact factor $IF_{2014} = 55.873$), three each in *Lancet* ($IF_{2014} = 45.217$) and *Nature* ($IF_{2014} = 41.456$), one in the *Nature Nanotechnology* ($IF_{2014} = 34.048$), and two in *Science* ($IF_{2014} = 33.611$). As expected, papers published in high impact factor journals accrued more citations. The top cited paper dealt with genetic algorithms[33] and had all the authors from India. Only two papers were published with single author[34,36]. Majority of the leading papers (10) were published in the field of medicine, e.g. Cohen *et al.*[37], Granger *et al.*[38] and Haynes *et al.*[39]. Others deal with physics[40], chemistry[41] and materials science[42].

Conclusion

This bibliometric analysis of highly cited papers from India yields some interesting results. Highly cited papers did not receive citations in the early years. The increasing number of highly cited Indian papers is mainly due to increasing trend in the international collaboration. Most of the internationally collaborated highly cited papers from India were contributed with the authors from USA. Research networks headed by the IITs, CSIR organizations and IISc dominated Indian science. Evaluation by *Y*-index showed that V. K. Gupta and C. N. R. Rao made the greatest contribution to the highly cited articles from India. The article by Deb *et al.*[33] published in 2002, ranked first by two indicators of citations in recent years and citations since publication to 2014, and may be India's most influential publication in the international context. It is evidenced from the most cited articles that high-impact journals receive more citations than low-impact journals: 13 out of 27 most cited articles were published in high-impact journals with $IF_{2014} > 30$. Furthermore, this study suggests that misspelling and variants of institution names should be verified and corrected in any bibliometric study based on bibliographic records retrieved from WoS.

Table 3. Twenty-seven most cited articles ($TC_{2014} > 1000$)

Rank (TC_{2014})	Rank (C_{2014})	Rank (C_0)	Rank (*TCPY*)	Reference
1 (5947)	1 (1101)	2116 (0)	5 (457)	33
2 (3744)	863 (24)	5 (118)	6 (416)	43
3 (2932)	2975 (7)	21 (53)	17 (195)	47
4 (2689)	13 (330)	358 (7)	16 (224)	42
5 (2455)	5 (581)	80 (24)	7 (409)	45
6 (2293)	2975 (7)	28 (46)	32 (135)	46
7 (2044)	2 (932)	4 (123)	1 (681)	40
8 (1978)	173 (63)	174 (13)	40 (116)	47
9 (1899)	17 (247)	758 (3)	83 (67.8)	41
10 (1877)	15 (307)	98 (19)	19 (171)	48
11 (1865)	14 (325)	29 (45)	11 (311)	49
12 (1635)	80 (95)	231 (10)	31 (136)	50
13 (1596)	4 (596)	19 (54)	8 (399)	37
14 (1572)	38 (142)	142 (15)	26 (157)	51
15 (1413)	27 (172)	1388 (1)	50 (88.3)	52
16 (1265)	32 (157)	1388 (1)	55 (84.3)	53
17 (1201)	10 (442)	82 (23)	12 (300)	38
18 (1198)	75 (98)	758 (3)	38 (120)	54
19 (1178)	414 (38)	2116 (0)	144 (49.1)	34
20 (1163)	24 (199)	192 (12)	21 (166)	55
21 (1140)	21 (222)	10 (72)	18 (190)	39
22 (1128)	53 (120)	611 (4)	73 (70.5)	56
23 (1090)	2257 (11)	358 (7)	102 (57.4)	57
24 (1042)	64 (107)	2116 (0)	69 (74.4)	35
25 (1014)	18 (236)	63 (27)	29 (145)	58
26 (1012)	16 (249)	358 (7)	20 (169)	59
27 (1004)	43 (138)	2116 (0)	86 (66.9)	36

TC_{2014}, Number of citations since publication to the end of 2014; C_{2014}, Number of citations in 2014; C_0, Number of citations in the publication year; *TCPY*, TC_{2014} per year.

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