Science and engineering research in India (1985–2016): insights from two scientometric databases

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We furnish scientometric data, for science and engineering, of research organizations in India, extracted principally from the Web of Science™ (WoS) database via their InCites™ tool. We classify the data into different granularity levels and address problems in their reliable extraction from publication metadata. We accumulate scientometric measures such as the numbers of publications, citations, and the h-index for the period 1985–2016. We use them to compare research performance in science and engineering, (a) across countries, very briefly, and (b) among Indian research organizations, for which we refine the data to carry out subject-level comparisons. A brief comparison with data from Scopus® and SciVal© is also included.

Keywords: Data structure, *h*-index, India, research performance, scientometry.

ADVANCES in data science and search engines have led to the development of curated data sets of research publications and their citations. Examples of such databases include PubMed, Scopus® and Web of Science™ (WoS). These databases can be used to compare the research output, quantified, e.g. by the number of publications and their citations, of universities all over the world. Bibliographic data are extracted from these archived databases by using search tools. The statistics obtained from these data are used in library and information sciences for quantitative analyses of the academic literature and to study the impact of research organizations and their studies on a given field.

Garfield[1] envisioned this emerging interdisciplinary subject, termed scientometry or bibliometry, in the 1950s. With the rise of computers and the internet, scientometry has experienced a renaissance and it is now used as an input for science policy, to complement qualitative analyses, based on reviews by peers and experts. An overview of metrics and indices that are used by experts in scientometry are provided[2,3].

Scientometric measures are used in ranking the research performance of academic organizations. Major international university ranking systems include Quacquarelli Symonds (QS) World University Rankings, Times Higher Education (THE) World University Rankings, and Academic Ranking of World Universities (ARWU). The methods used by these organizations are described on their respective websites[4–6]. All of them use, to different degrees, data from scientometric databases.

Studies have compared research trends from different countries[7,8]. Similar studies in the Indian context were carried out[9–11] along with subject-specific discussions[12–15]. We extend and update these works by using the InCites™ tool[16]. We concentrate on general trends and do not analyse data for any specific organization. However, we include a brief comparison of some results from WoS, InCites™, Scopus® and SciVal©.

In the next section we review different aspects of the data obtained from InCites™, like subject-wise classification schemes and the labelling of organizations. We use the Essential Science Indicators (ESI) schema, which catalogues only science and engineering articles. The following section details our different comparative studies. Initially we juxtapose India with other top nations in science and engineering research, with data from the last three decades. Next, we confine ourselves to India and list organizations that have shown top research performances in science and engineering. Because of the wide disparity of citation trends in different fields, we group our data into nine categories and consider 6 major branches of engineering. We use data-visualization schemes that constructively highlight and compare the research performances of top Indian institutes, universities, and laboratories. Next a brief account of the validation of our results by comparing with a few earlier studies is presented. In the concluding section, we discuss our results briefly.

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Materials and methods

In this study we use InCites™ (ref. 16) (Clarivate Analytics product), a search tool that provides aggregate citation statistics for a set of search results from the WoS citation database. We restrict ourselves to science and engineering. The reason for this restriction is two-fold: it is very difficult to assess performances in other fields like social science and arts using publications; and the coverage by InCites™, in other fields, is inadequate. InCites™ is accessible by subscription (e.g. at the Indian Institute of Science, Bengaluru) through a web interface. We examine citation data for the period 1985–2016. An equivalent search tool, SciVal©, is available from the Elsevier group and is based on the Scopus® database. Scopus® and SciVal© include more journals than WoS and InCites™. However, SciVal©'s data analytics contain only papers published after 2010.

Data structures

Every published scientific article has a list of metadata, which can be used to classify and aggregate useful scientometric information. Traditionally, metadata have been used by libraries to catalogue books and articles[17]. For a scientific publication, metadata can range from author names to subject classifications. These metadata can be organized in a hierarchical scheme of nested elements that have a parent–child relationship.

Granularity is used to assess the level of structured details encoded in the metadata. The name of the journal, year of publication, and the article title form the lowest level of granularity. The next level of granularity has the affiliation of the author and the country; the final level includes the author name. Note that the higher the level of granularity, the higher the degree of ambiguity in classification, and the difficulty of error correction. Our analysis of the InCites™ data shows that granularity up to the level of affiliation is reliable.

By using the Institute for Scientific Information (ISI)[18] interface, we can search through the WoS database with keywords and pattern-match filters. If we do so when associating papers with institutions, it is important that we know the name variants of institutes. In contrast, InCites™ has a list of organizations, so that any variations, abbreviations or changes in name, over the time period of analysis, are automatically taken into account.

Our analysis of these data indicates some possible anomalies. One such instance is multiple entries for a university, e.g. Anna University and Anna University-Chennai, which appear with different citation statistics. The Anna University structure shows that it is a conglomeration of five different universities, one of which is located in Chennai. In such cases, we do not use the superset of all these five universities; hence, we retain Anna University-Chennai and not the group Anna University. By the same token, we exclude Council of Scientific and Industrial Research (CSIR) and Indian Institute of Technology (IIT)-System, as they are also conglomerate entries. Additionally, by our citation analysis we find that the entry for Tata Institute of Fundamental Research (TIFR) does not include National Centre for Biological Sciences (NCBS); so we retain both. InCites™ includes, under TIFR, publications from TIFR, Mumbai, National Centre for Radio Astronomy (NCRA), Pune, TIFR Centre for Interdisciplinary Sciences (TCIS), Hyderabad, TIFR Centre for Applicable Mathematics (TIFR-CAM), Bengaluru, and the International Centre for the Theoretical Studies (ICTS-TIFR), Bengaluru. Similarly, InCites™ publications from AIIMS include all seven campuses, with the parent institution at New Delhi, established in 1956, and the rest of the six institutes, established in 2012. Another conglomerate is Indian Statistical Institute (ISI), with campuses in Kolkata, Delhi and Bangalore. Some organizations, which have undergone some administrative changes in the recent past, like the Institute of Chemical Technology-Mumbai, do not have reliable data entries in the InCites™ database.

The InCites™ handbook[19] indicates that, 'all author affiliations are captured from each publication...'. In the case of multiple authors with the same affiliation, only one publication count is added to the organization. Furthermore, if an author is affiliated with more than one organization, the article and its citations are assigned to all the organizations.

We use the ESI schema for the subject classification of articles. This schema has 22 different research-field classifications that are created by assigning each journal to a subject category[19]. We give a schematic illustration of this classification schema in Figure 1. In the ESI database there is no over counting, i.e. each article is assigned to one and only one category. We re-group these 22 categories into 9 classes as shown in Figure 1.

We use the WoS schema to explore research performance in individual branches of engineering. The WoS schema has 225 categories and encompasses all major engineering branches. However, unlike the ESI schema, here, an article can belong to more than one category and can lead to over counting. Hence, the ESI and the WoS schemas can be incompatible.

The databases we use have documents ranging from research articles to obituaries. To constrain ourselves to research articles, we filter the documents to be among Articles, Proceedings Papers, Reviews, and Book Chapters.

Along with these citation data, we obtain the *h*-index due to Hirsch[20], for quantifying research output. The *h*-index for an author is defined as the maximum value of the integer *h*, such that at least *h* of her/his publications have at least h citations. This index can be generalized to the citations of papers published by organizations. The

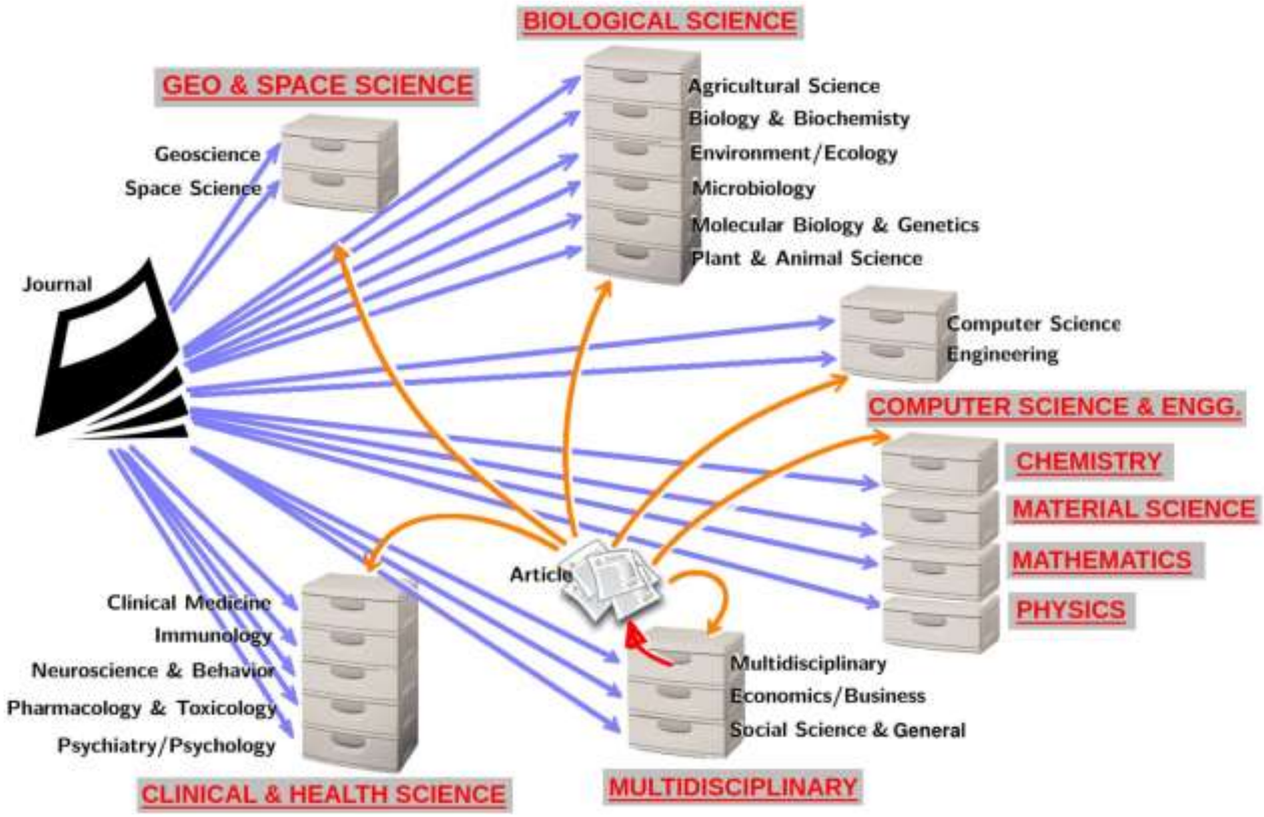


Figure 1. A schematic illustration of the ESI schema: A journal can belong to one of 22 categories. The articles in each journal inherit the category, except ones belonging to the multidisciplinary category; these are reclassified by using references in the article (indicated by orange lines). We re-group these classes into 9 categories (red labels).

h-index depends on both the number of publications and the number of citations. This index is meaningful only for comparisons in the same field, because citation conventions differ widely among different fields. As with any metric that tries to encapsulate the state of a multivariable system in terms of a single number, the *h*-index has shortcomings[21–23]; various alternatives and modifications have been proposed[2,3]. We use the *h*-index because of its simplicity and ease of calculation. We also use the Citation Impact, which is defined as the ratio of the number of citations to the number of publications during 1985–2016. Our definition of Citation Impact is different from that used in the QS World University Rankings[4], where the Citations per paper for the current year is defined as the average number of citations in the current year to articles published in the last five years.

Visualization provides rapid access to data in a format that leads to easy assimilation of trends in a dataset. A human-vision study[24] has shown that our ability to compare geometric properties differs widely; and empirical results indicate a decreasing order of sensitivity for the following: length, area, shades, colour, and angle. Therefore, we use bar charts for comparing most of our data on absolute scales; we use pie charts, or their stacked-donut chart generalizations, for percentages or relative comparisons. Furthermore, in the bar charts we use gradients in shades to contrast the variations in the neighbouring bars effectively.

We have extracted the data presented here from the InCites™ server on 30 March 2017.

Results

We have organized our results into five subsections: (i) country-wise comparison of research output in science and engineering. (ii) Data for the top Indian science and engineering research organizations. (iii) subject-wise-refined data; (iv) A comparison of research outputs of organizations in six common engineering areas, and (v) finally a decadal comparison of data from (iii).

Brief comparison of science-and-engineering research across countries

The multi-bar horizontal chart in Figure 2 shows the number of science and engineering publications (left panel) and the corresponding citation number (right panel) for the top-15 countries, in descending order of publication numbers, for the period 1985–2016.

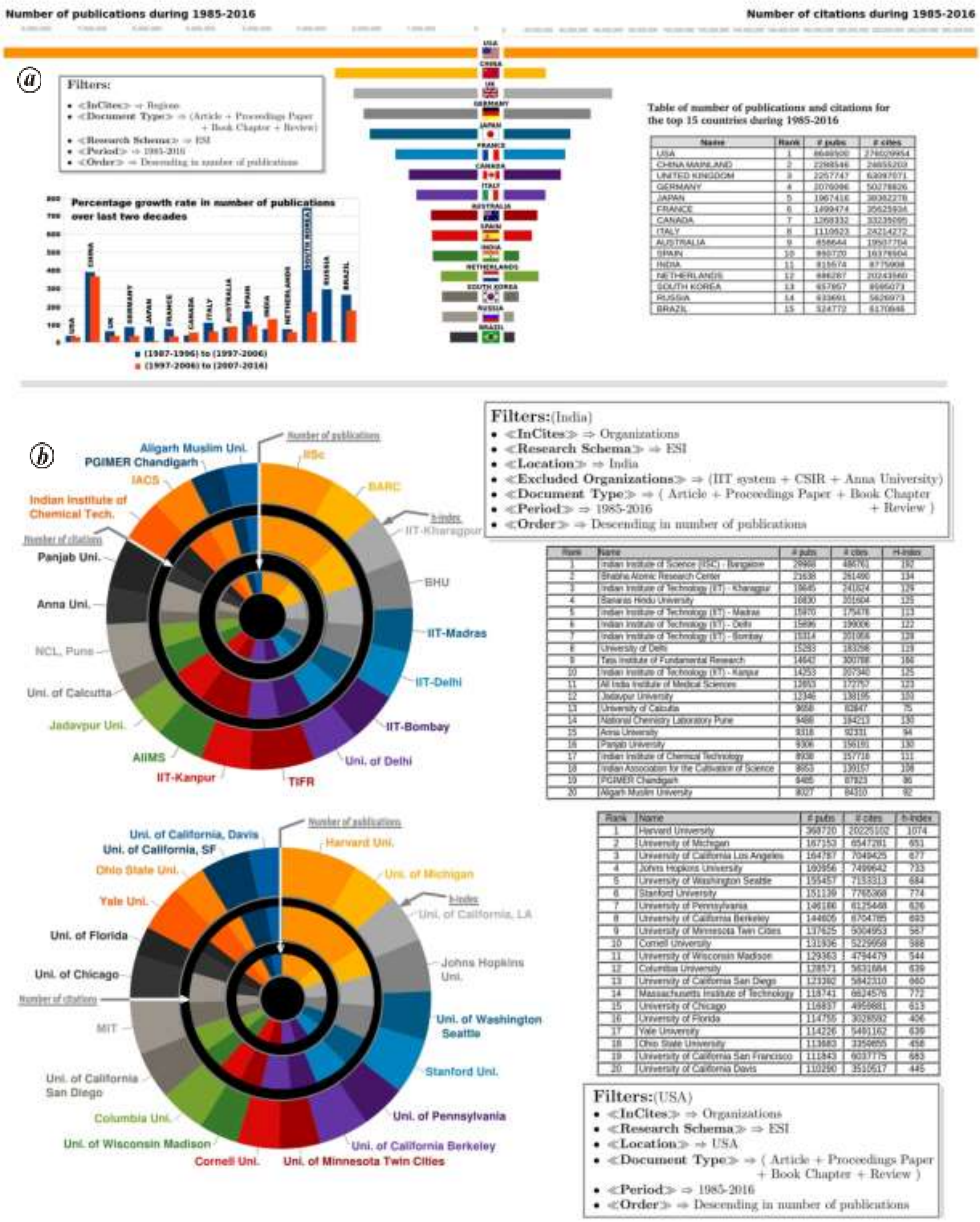


Figure 2. ***a***, A multi-bar-chart comparison of the ESI citation data, from the InCites database, for the top-15 countries (by number of publications). The bar chart in the left panel shows the number of publications, in science and engineering, during 1985–2016; and the corresponding number of citations are shown in the right panel. The numerical data are presented in the inset. The grouped bar chart in the left inset shows the percentage growth in the number of publications over the last three decades. In our calculations for percentage growth rate we use: %GT1 (blue bar) = ((# pubs in 1997–2006 – # pubs in 1987–1996)/(# pubs in 1997–2006)) and %GT2 (red bar) = ((# pubs in 2007–2016 – # pubs in 1997–2006)/(# pubs in 2007–2016)). ***b***, The three stacked donut charts display the *h*-index, the number of citations, and the number of publications for the top-20 Indian (top panel) and USA (bottom panel) science-and-engineering research organizations (in terms of number of publications) for the period 1985–2016. The inner-most donut shows the number of publications, the middle one represents the number of citations, and the outer-most is the *h*-index; the angle of a sector is proportional to the numerical values, which are given in the tables on the right.

The authors have investigated the publication trends for emerging countries[7]. We present a publication-growth comparison for the last three decades in the left inset of Figure 2. Notice that India has a substantially higher growth rate in publications for 2006–2016 (red bar) compared to that in the previous decade (blue bar).

Comparison of top-20 Indian and USA science-and-engineering research organizations

Figure 2 shows a stacked, donut chart of the top-20 Indian (top panel) and USA (bottom panel) research organizations, based on their numbers of publications in science and engineering, during the period 1985–2016. The angles in the colour-coded regions of the inner donut show the percentage of total publications; the outer donut represents the *h*-index; and the number of citations in percent is sandwiched between them.

The table alongside this chart lists the top-20 Indian and USA research organizations. Among the Indian organizations, the Indian Institute of Science (IISc), the five oldest Indian Institutes of Technology, Department of Atomic Energy institutes like the Bhabha Atomic Research Center (BARC) and the TIFR, universities such as Banaras Hindu University (BHU), Delhi, Jadavpur, Panjab, Anna University, and Aligarh Muslim University, medical institutes such as All India Institute of Medical Sciences (AIIMS) and the Postgraduate Institute of Medical Education and Research (PGIMER) Chandigarh, and the Indian Association for the Cultivation of Science (IACS) appear in this list. The top-20 USA research organizations are public and private universities. The *h*-indices of these USA research organizations are about six times greater than those of their Indian counterparts. Given the funding level of universities in the USA, this is not a surprise (data for USA from InCites™, 18 March 2017).

Subject-level comparison of Indian science-and-engineering research organizations

The citation conventions in different fields of research vary vastly. For example, the average number of citations for a paper in mathematics is far lower than, say, its counterpart in biological sciences. Therefore, we compare research organizations in different fields separately, in contrast to the comparison we have made in the previous section. Although the WoS schema has 225 subject categories, we choose the coarser categorization in the ESI schema with 22 categories which we reclassify into nine topics (Figure 1).

In Figure 3, we present data for the top-30 Indian organizations, in terms of number of citations, in their respective fields (data details in the Supplementary Material).

The top-5 Indian research organizations in different subjects, based on the number of citations, are as follows:

Biological sciences: IISc, University of Delhi, BHU, Central Food Technological Research Institute, Indian Agricultural Research Institute.

Chemistry: IISc, Indian Institute of Chemical Technology, National Chemistry Laboratory(NCL), IACS, BARC.

Clinical and health science: AIIMS, PGIMER, Christian Medical College and Hospital (Vellore), BHU, National Institute of Mental Health and Neurosciences.

Computer science and engineering: IISc, IIT-Delhi, IIT-Madras, IIT-Kharagpur, IIT-Kanpur.

Materials science: IISc, IIT-Kharagpur, IIT-Madras, BARC, IIT-Bombay.

Mathematics: ISI, TIFR, IIT-Kanpur, Aligarh Muslim University, IISc.

Multidisciplinary: ISI, AIIMS, University of Delhi, Jawaharlal Nehru University, Christian Medical College and Hospital.

Physics: TIFR, BARC, Panjab University, IISc, Saha Institute of Nuclear Physics.

Geo and Space Science: TIFR, Inter-University Centre for Astronomy and Astrophysics, Physical Research Laboratory, IISc, Indian Institute of Astrophysics.

Comparing branches of engineering

The WoS database provides a refined classification of engineering into 18 different branches. We present data for the six common branches, namely, Aerospace, Civil, Chemical, Computer Science, Electrical and Electronics, and Mechanical Engineering.

Figure 4 shows the top-20 organizations in terms of the number of citations in each of the engineering fields. Publication conventions are different in different branches of engineering. The top five research organizations, based on number of citations, in different branches of engineering are:

Aerospace engineering: IISc, IIT-Kanpur, IIT-Kharagpur, Vikram Sarabhai Space Centre, IIT-Bombay.

Chemical engineering: NCL, University of Mumbai, IIT-Kharagpur, Institute of Chemical Technology, IIT-Delhi.

Civil engineering: IIT-Kharagpur, IIT-Roorkee, IIT-Madras, IIT-Bombay, IISc.

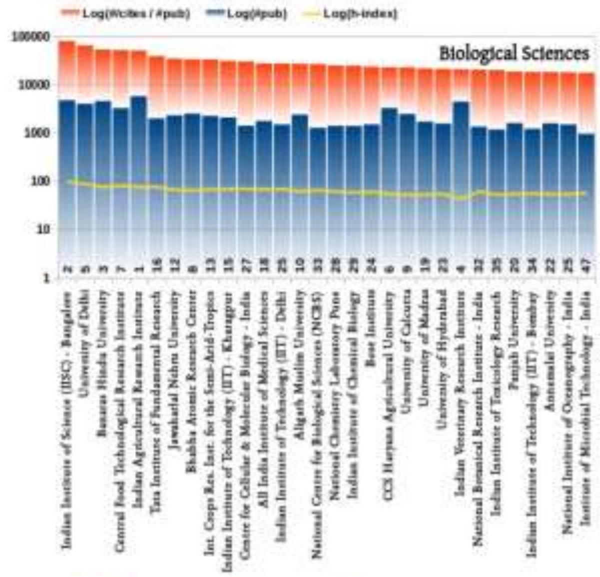
Computer science: IIT-Kanpur, ISI, IISc, IIT-Kharagpur, IIT-Delhi.

Electrical Engineering and Telecommunication: IISc, IIT-Delhi, IIT-Kharagpur, IIT-Bombay, IIT-Madras.

Mechanical engineering: IIT-Madras, IIT-Kharagpur, IIT-Kanpur, IIT-Delhi, IISc.

Decadal comparison of ESI data for Indian science-and-engineering research organizations

In this section we examine the research output, from each of the last three decades, of the top-10 research organizations that we have considered previously (Figure 5).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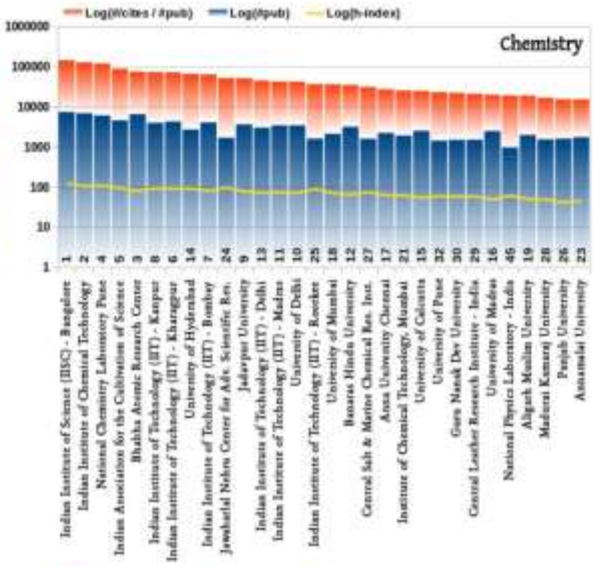
Biological Sciences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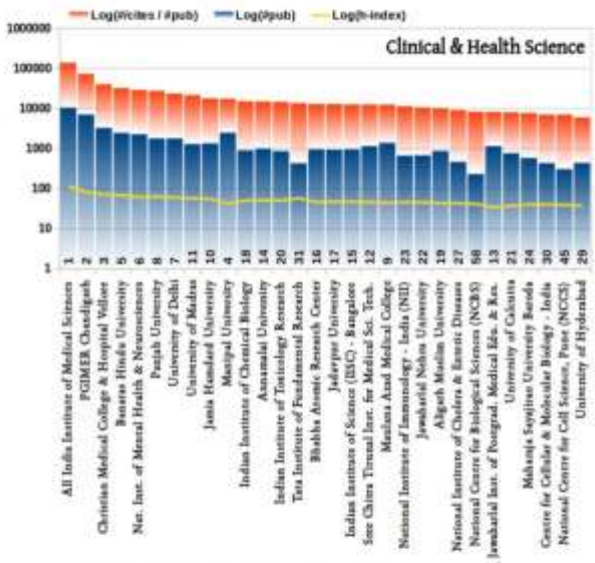
Chemistry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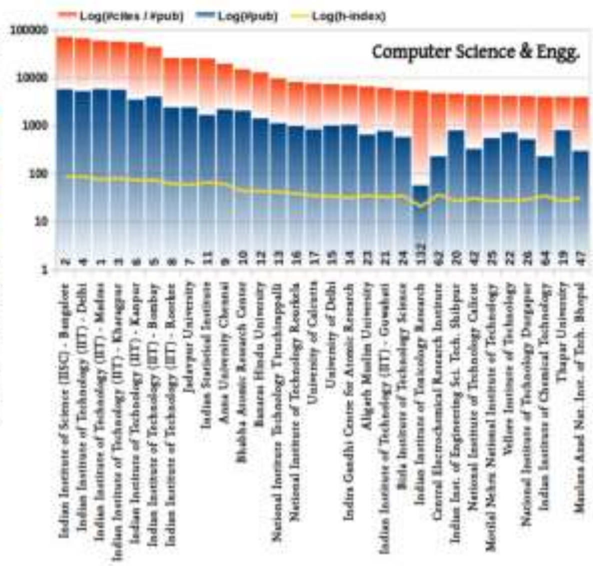
Clinical & Health Science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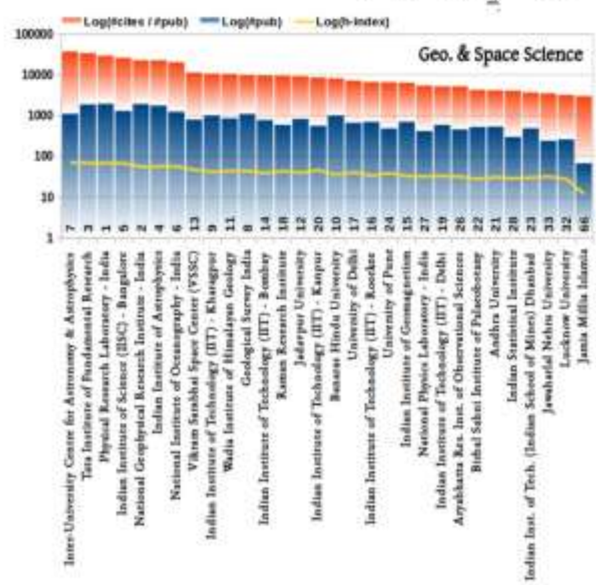
Computer Science & Engg.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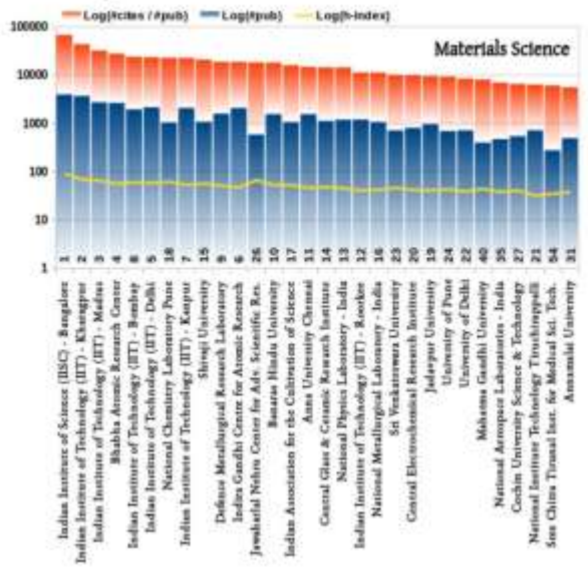
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Materials Science

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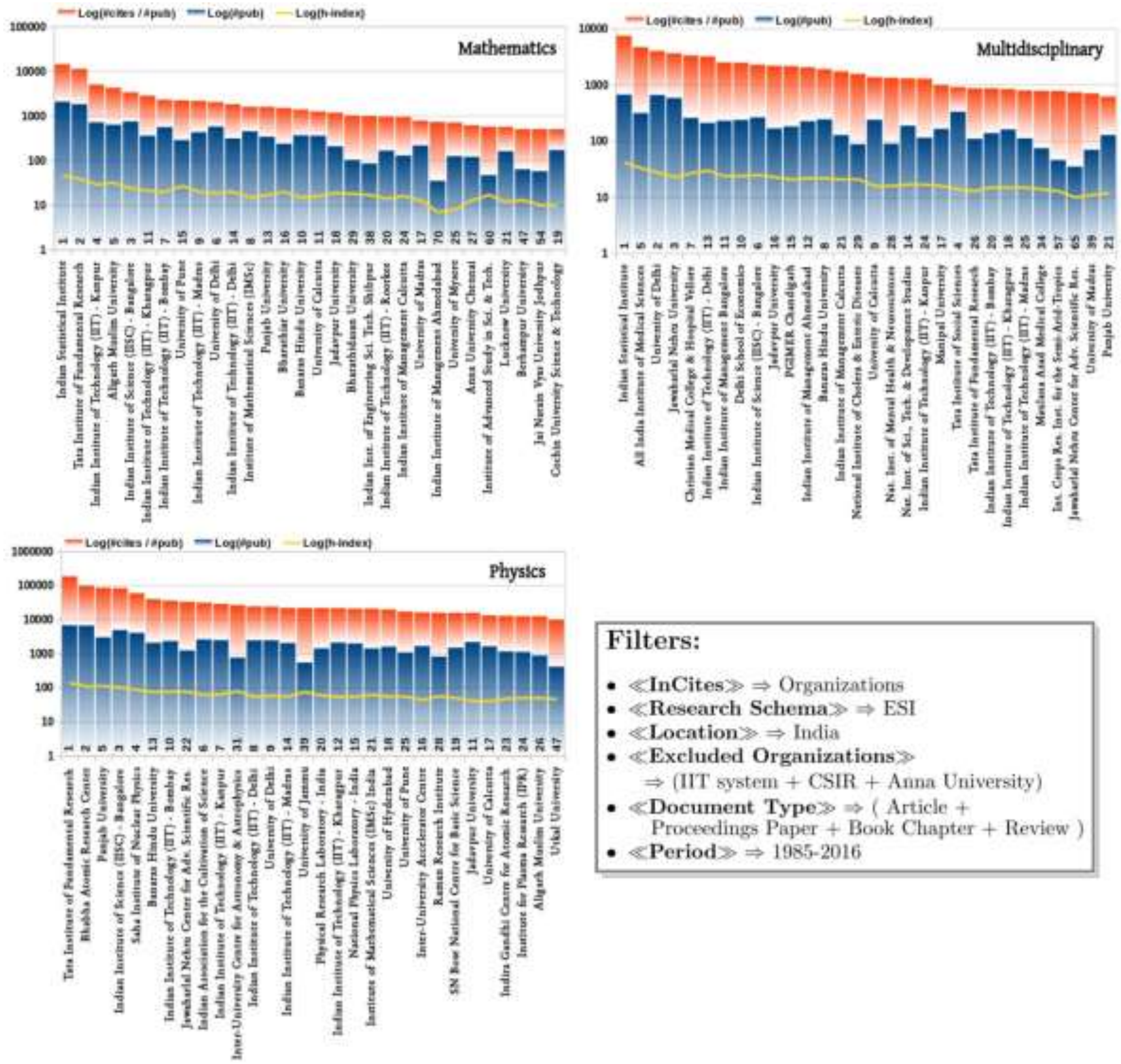

Figure 3. Stacked bar charts for different subject groups of the top-30 Indian science-and-engineering research organizations (in terms of number of citations). The heights of the blue bars indicate $\log_{10}$ of the number of publications and those of the red bars stand for $\log_{10}$ of the Citation impact. Thus, the total height represents $\log_{10}$ of the total number of citations. The yellow line is the plot of $\log_{10}$ of the *h*-index from organizations. The number in black at the bottom of each bar indicate the ranking of the corresponding organization in terms of number of publications.

Validation of data

To validate our analysis, we compare our data with other studies[14,25]. We calculate residuals and the root mean square (rms) of the residual variance in percentage for the data as follows. If X_i and X_i' are the numbers of publications for the *i*th organization in the two different datasets; then the corresponding residuals are $r_i = X_i - \bar{X}_i$ and $r_i' = X_i' - \bar{X}_i$, where $\bar{X}_i = (x_i + x_i')/2$. Then the percentage residual variance for the *i*th organization is

$$\sigma_i = 100 \times (r_i - r_i')/\bar{X}_i \text{ and } \sigma_{\text{rms}} = \frac{1}{N}\sqrt{\sum_{i=1}^{N} \sigma_i^2}.$$

In another study[14], the authors compare the publication outputs of different Indian research organizations in the field of Chemical Engineering for the period 2000–04, by using the WoS database. Our comparison of data from InCites™ with data from another study[14], with the same search parameters, led to an rms residual variance in the number of publications of 14.21%. In contrast to the ESI classification that we use, which is based on a subject-wise grouping of journals, the other classification scheme[14] uses the affiliation of authors to 'chemical engineering' in the address field.

A similar comparison of our data with other data[25] gave an rms residual variance for the number of publications of 4.94%. Here publications across all fields are

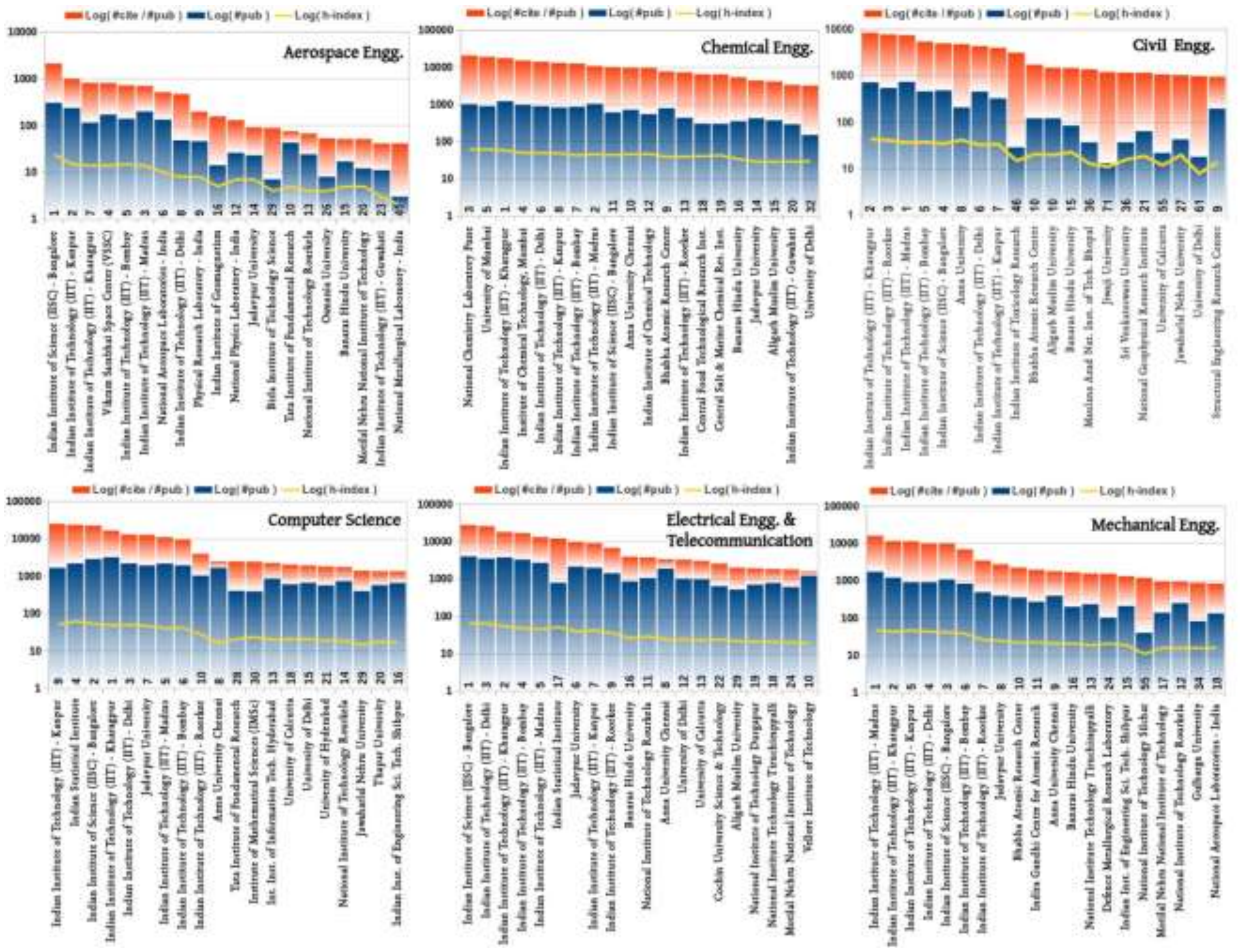

Figure 4. Stacked bar chart for different engineering fields of top-20 Indian organizations (in terms of number of citations) are shown. The height of the blue bars indicate the $\log_{10}$ of the number of publications and that of red bars stand for the $\log_{10}$ of the Citation impact. Thus, the total height represents the $\log_{10}$ of the number of citations. The yellow line is the plot of the $\log_{10}$ of the *h*-index. The number in black at the bottom of each bar indicate the ranking of the corresponding organization in terms of number of publications.

considered over the 5-year period 2007–2011. It must be noted that the Scopus® database, which is used in the other study[25], is more extensive than WoS, as Scopus® includes more journals than does WoS.

InCites™ uses data from WoS; similarly, SciVal© is a tool based on data from Scopus®; it 'covers around 20,000 peer-reviewed journals and 5.5 million conference papers'[26]. InCites™ for the same period, 2011–2016 covers only around 4.7 million conference papers. The plots in Figure 6 show a comparison of publication data from the SciVal and InCites™ tools. InCites™ data when compared to SciVal underestimates the number of publications on average by approximately 79%, and drops to around 70% for India. Hence the results presented in this article provide a lower bound for India's performance. The key expediency of using InCites™ in our work is the longer period of coverage, dating back to 1985. In comparison, the SciVal catalogue is available only up to 2011. This wide range of coverage (1985–2016) enables us to exhibit the trend data, which complement the data from the ranking systems (based only on 5-year data) by providing the change in performance at a coarse, 5-year time scale. For most of the fields the cumulative citation statistics takes about five years to stabilize[27]; hence, a decadal comparison highlights the change in performance of the organizations over time.

Conclusion and discussions

We have presented citation data extracted from the InCites™ database to compare quantitatively the research performances across countries and science-and-engineering research organizations in India. In particular, we have briefly listed the relative research performances among the top-15 countries across all fields of science and

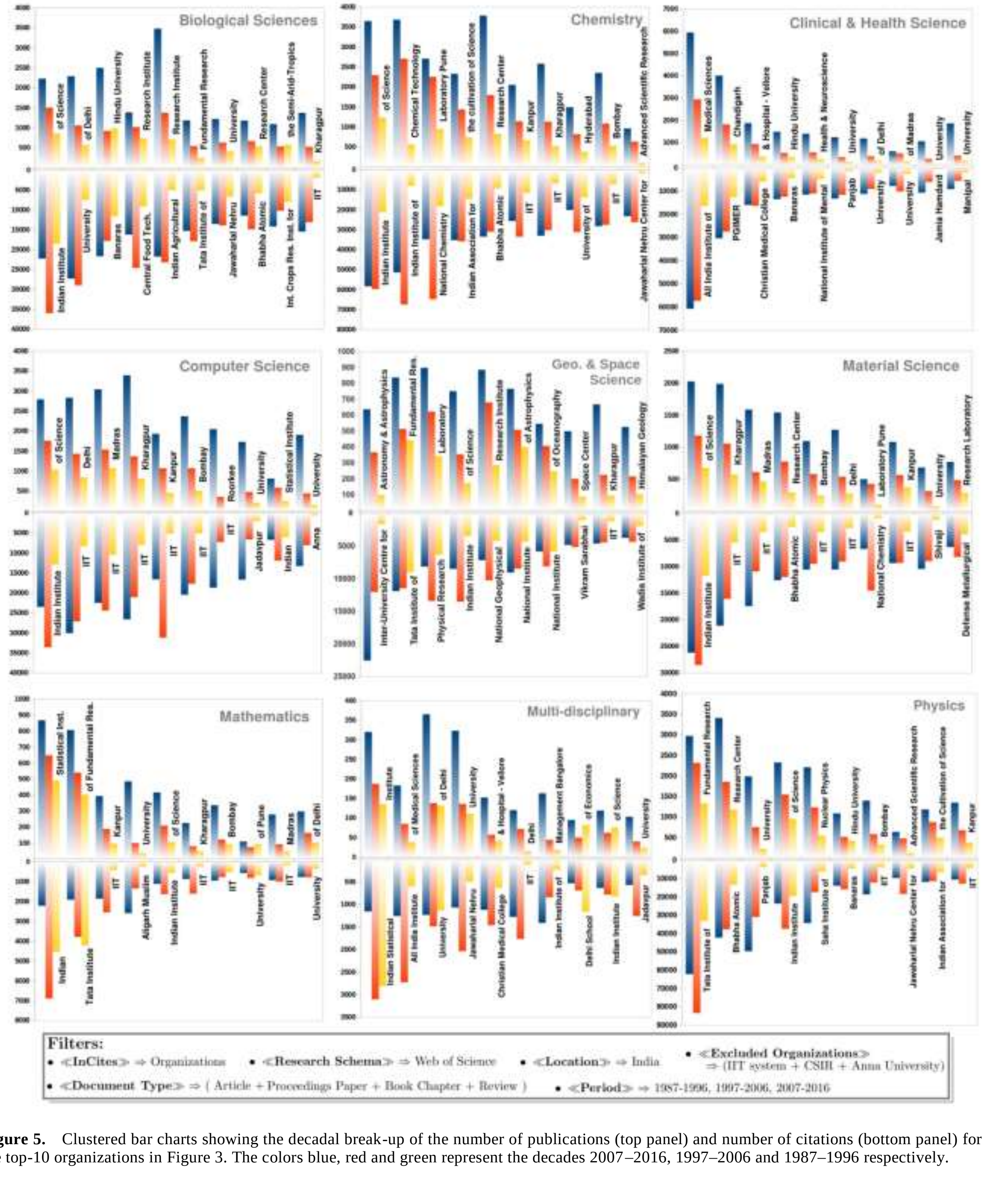

Figure 5. Clustered bar charts showing the decadal break-up of the number of publications (top panel) and number of citations (bottom panel) for the top-10 organizations in Figure 3. The colors blue, red and green represent the decades 2007–2016, 1997–2006 and 1987–1996 respectively.

engineering. These data show a wide disparity among the top publishing countries. We then compare citation data for the top-20 science-and-engineering research organizations in India. We carry out a subject-wise comparison in the third part of the study. We also compare our findings with a few, representative, earlier studies of research in science and engineering in India[14,25]; our study covers a much longer time span than other studies[14,25].

The citation data used in this article, namely, the number of publications and number of citations, give a total measure of the quantity of research output. To compare the research performance of different research

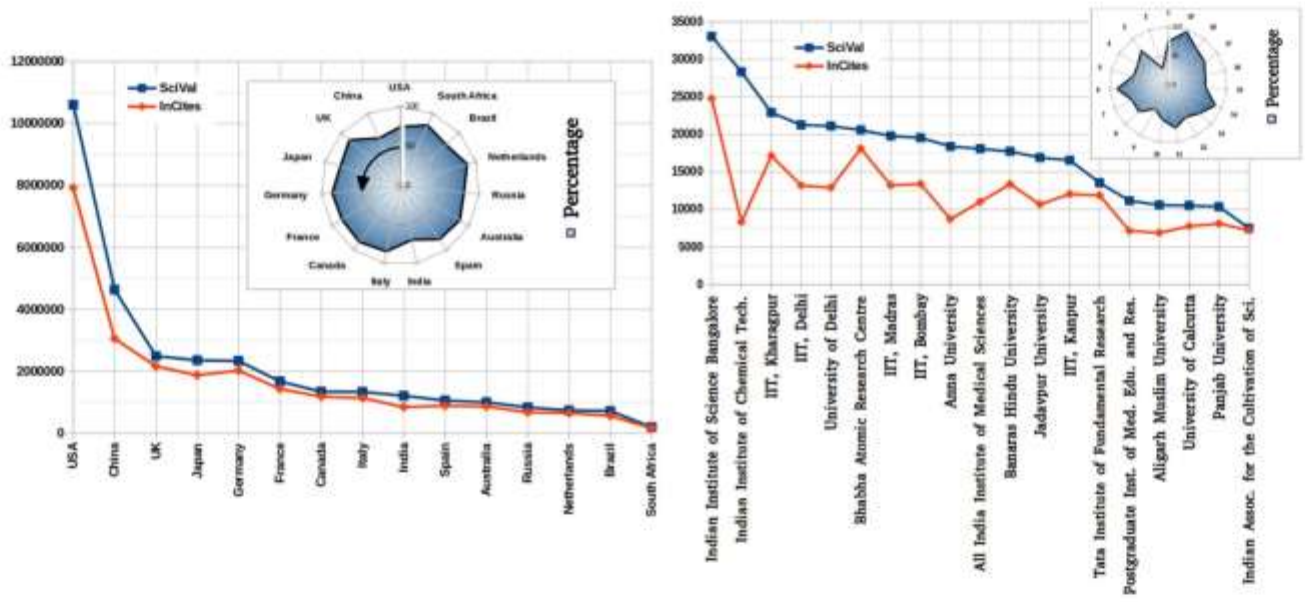

Figure 6. (Left) A line plot of the number of publications for the top 15 countries from the SciVal© and InCites™ tool, for the period 2011–2016. The inset shows the InCites™ data as percentage of SciVal© data in an angular plot. (Right) The corresponding plot for top-20 Indian academic organizations.

organizations, it is possible, in principle, to use intensive quantities (in the sense of statistical mechanics), such as the number of publications per faculty member or the number of citations per faculty member. However, for the large number of research organizations included in our study, it is not easy to find the number of faculty members for each one of the years we consider. Furthermore, in a particular department, faculty members may publish in journal categories outside their departmental designations which makes the normalization procedure uncertain. Other normalized indicators, such as, papers per faculty member, citations per faculty member, funding per faculty member and, therefore, the financial cost per paper published can add to our insight into the publications from India in the areas of science and engineering. At this moment, reliable data regarding the number of faculty members and funding are not readily available to us to obtain such results for science-and-engineering research organizations in India. The only intensive quantity we have been able to obtain with certainty is the number of citations per paper (or Citation Impact), which we have shown in Figures 3 and 4. Here as well, organizations with a small number of publications can lead to skewed statistics. As we know well from statistical mechanics that intensive variables are meaningful only in the thermodynamic limit (in our study that means a very large number of publications for each one of the organizations considered).

In this article our aim is not to provide a detailed comparison of research organizations or to rank them. Our intent is to present, for some Indian institutions, the curated data that are now becoming available and being used for building scientometric measures by university-ranking systems. Furthermore, we provide instances of some anomalies in databases because of multiple names for a given institution; and we examine briefly the problem with the uniformity in the measures used across fields.

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ACKNOWLEDGEMENT. We thank J. Modak and G. N. Chandan for discussions and the Department of Science and Technology, New Delhi for support under the DSTO1359 grant.

Received 11 July 2017; revised accepted 19 February 2018

doi: 10.18520/cs/v115/i3/399-409