Research performance of Indian Institutes of Technology

Sumit Kumar Banshal, Vivek Kumar Singh, Aparna Basu and Pranab Kumar Muhuri*

This article presents a computational analysis of the research performance of 16 relatively older Indian Institutes of Technology (IITs) in India. The research publication data indexed in Web of Science for all the 16 IITs is used for the analysis. The data is computationally analysed to identify productivity, productivity per capita, rate of growth of research output, authorship and collaboration pattern, citation impact and discipline-wise research strengths of the different IITs. The research performances of the IITs have been compared with those of two top ranking engineering and technology institutions of the world (MIT-USA and NTU-Singapore) and most cited papers from these IITs have also been identified. The analytical results are expected to provide a informative, up-to-date and useful account of research performance assessment of the IITs.

Keywords: Engineering research, IIT, research competitiveness, research performance, scientometrics.

THE Indian Institutes of Technology (IITs) are considered as the most prestigious engineering and technology institutions of India. At present there are 23 IITs in India, established during different periods of time. Pandit Nehru, the first Prime Minister of India, credited to take forward the initial ideas of Ardeshir Dalal from the Viceroy's Executive Council to envision the IIT system. The idea was to 'provide scientists and technologists of the highest calibre who would engage in research, design and development to help building the nation towards self-reliance in her technological needs'. The first Indian Institute of Technology was established in 1951 at Kharagpur, followed by IIT Bombay (1958), IIT Madras (1959), IIT Kanpur (1959) and IIT Delhi (1961). In 1961 the Institutes of Technology act was passed by Indian parliament which declared these institutions as institutes of national importance. All these five IITs were established through foreign collaboration process. Almost three decades later, IIT Guwahati was established in 1994. This was followed by converting Roorkee University to IIT Roorkee in 2001. During 2008–2012, nine more IITs were established (at Bhubaneswar, Gandhinagar, Hyderabad, Jodhpur, Patna, Ropar, Indore, Mandi and Varanasi). And most recently, 7 new IITs (at Palakkad, Tirupati, Dhanbad, Bhilai, Goa, Jammu and Dharwad) are proposed/established during 2015–16.

IITs in India, in addition to being most sought after by students, are also one of the highest funded educational institutions in the country. While the total government funding to most other Indian engineering colleges is around Rs 10–20 crores (USD 2–4 million) per year, the annual funding for IITs varies from Rs 90 crores to 130 crores (USD 18–26 million) for each IIT. The sanctioned faculty-to-student ratios in the IITs vary between 1 : 6 to 1 : 8 as against the target lower limit of 1 : 9 set by the Standing Committee of IIT Council (SCIC). Taking into account the importance of IITs, we have tried to measure their research performance. As IITs are of different age, we have grouped them into three different sets: old IITs (7 IITs which are at least 15 years old), new IITs (9 new IITs established during 2008–2012) and recent IITs (7 IITS established during 2015–16). Of these, we have excluded the recent IITs from analysis as they have come into existence within the last five years only.

IITs, despite being the most prestigious institutions in India, do not rank high in top universities list of the world. For example, none of the IITs figures in top 500 institutions list of Academic Ranking of World Universities (ARWU)[1] for 2015. Though the position of IITs in the recently announced University Ranking by Academic Performance (URAP) is better, with 10 IITs included in the top 200 world institutions, the world ranking of these institutions in other international rankings (such as QS, THE, Leiden, etc.) continues to be poor. While older IITs are placed in bracket of 300+ or still lower ranks, some newer IITs go unreported in many international rankings based on academic performance.

It is in this context that we have tried to do a detailed research performance assessment of the 16 IITs. The objective is to analyse the research performance of all the IITs (both older and newer ones) on various parameters and to compare them with the research performance of

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similar kind of high ranking world institutions. We have analysed the research performance in terms of both quantity and quality and identified disciplinary research strengths of each of the 16 IITs. Top cited papers are also identified along with their discipline. At the end, we have provided a quality–quantity composite research performance-based rank of the 16 IITs (based on our proposal of composite rank reported in Basu *et al.*[2]).

Related work

There have been some previous studies on research performance assessment of Indian institutions[3–6]. IITs being high performing institutions are included in several such studies even if they do not specifically focus on IITs only. The most notable ones include Prathap and Gupta[3], Nishy *et al.*[4], Prathap[5], and Prathap[6]. Prathap and Gupta[3] tried to identify top 30 Indian engineering and technological institutions according to their research performance in the time period 1999–2008. This rank included all 7 older IITs in the top 10 rank. In a later work, Prathap[5] benchmarked research performance of seven older IITs (corresponding to our old IIT set) based on research output data from Web of Science (WoS) and Scopus. Nishy *et al.*[4] performed an impact-Citation-Exergy (iCX) trajectory analysis of some leading research institutions in India using the publications for the time period 1999–2009 and citation window of 2004–2010. Prathap[6] mapped the research performance of higher educational institutions in India using SCImago Institutions Rankings (SIR) world reports[7] of 2013, which in turn was based on the indexed data from Scopus for the period 2007–2011. Some other studies also tried to measure research performance of a specific institution or a group of institutions[8–10].

The present analytical study is not only different from most of the previous studies in many respects but it also adds value to the analytical results reported earlier. The salient differences include: (a) a large period of 25 years data being used for analysis, (b) comprehensive coverage of both older and newer IITs, (c) a text analytics approach to identify disciplinary research strengths of different IITs, and (d) a composite quantity–quality rank computation for the 16 IITs. We have analysed research publication data for all 16 IITs and performed various computations. The analysis produces most up-to-date results of research performance assessment of IITs and also compare them with two top perfoming world institutions. Identification of disciplinary research strengths, most cited papers and generating quantity–quality composite ranking are the most notable contribution of this study.

Data and methodology

For the research performance analysis, we have downloaded the research output data for the 16 IITs as indexed in *WoS* for the 25-year period (1990–2014). The data was downloaded through an institution-based search query using the search strings of the form: CU=INDIA AND OG= (INDIAN INST TECHNOL IIT DELHI OR INDIAN INST TECHNOL NEW DELHI OR INDIAN INSTITUTE OF TECHNOLOGY IIT DELHI OR INDIAN INST DELHI) Time span = 1990–2014 Indexes = SCI-EXPANDED, SSCI, A&HCI. A total of 79,643 publication records were obtained, of which 79,063 are unique records. A majority of these records (76,352 to be precise) correspond to old IITs and 3,291 records are contributed by new IITs. In addition to the research output data, we have also collected other relevant data including year of establishment and existing faculty strengths as on 1 January 2014 (from IIT council faculty size report 2014)[11] for all the IITs. Table 1 presents summary of data for all the IITs.

A systematic analysis of the collected data has been performed by computing different scientometric indicators and writing computer programs to process textual fields of collected data. Directly measured scientometric indicators include: Total papers (TP) and total citations (TC). The computationally derived indicators include: average citation per paper (ACPP), productivity per capita (PPC), citations per capita (CPC), highly cited papers (HiCP), international collaborative papers (ICP) and *h*-index. The ACPP value is computed by dividing TC by TP. The CPC value for each institution is computed by dividing the TC value of that institution with its faculty size. The HiCP value is computed with respect to the given set of institutions from the TC values sorted in descending order. The top 1% of most cited papers of the set constitute HiCP instances. The indicator values are computed for the full 25-year period (1990–2014) as well as most recent 5-year period (2010–2014). Further, the data is processed to categorize the research records into different subject categories (15 broad disciplinary areas). This helps in identifying disciplines in which different IITs have strong research presence. Finally, different indicator values computed are used to compute composite quantity–quality ranks for the IITs. Analysis is performed computationally by writing programs in R and using other standard data analytics and visualization software.

Research productivity

As IITs are of different age and varying faculty sizes, it would be reasonable to expect differences in their research productivity. Table 1 shows the research outputs for the full 25-year period and the most recent 5-year period for all the IITs (except the recent IITs which are just announced). We can observe the variation in TP values among different IITs. This variation is not only seen between the old and new sets but also among the IITs in the same set. Table 2 presents different indicator values and

Table 1. Summary of data for 23 Indian Institutes of Technology

Institute (Abbr.)	Year of establishment/ conversion	Existing faculty strength*	Total research paper output (1990–2014)	Total research paper output (2010–2014)
Old IITs				
IIT Kharagpur (IITKGP)	1951	582	16,510	5,871
IIT Bombay (IITB)	1958	565	12,937	4,680
IIT Madras (IITM)	1959	506	13,208	4,905
IIT Kanpur (IITK)	1959	374	12,111	3,789
IIT Delhi (IITD)	1961	423	13,136	4,574
IIT Guwahati (IITG)	1994	358	2,247	1,754
IIT Roorkee (IITR)	2001‡ (founded in 1847)	457	6,203#	3,452
New IITs				
IIT Bhubaneswar (IITBBS)	2008	59	142#	141
IIT Gandhinagar (IITGN)	2008	89	149#	147
IIT Hyderabad (IITH)	2008	136	502#	501
IIT Jodhpur (IITJ)	2008	36	87#	87
IIT Patna (IITP)	2008	73	121#	119
IIT Ropar (IITRPR)	2008	54	305#	304
IIT Indore (IITI)	2009	76	389#	389
IIT Mandi (IIT Mandi)	2009	62	152#	152
IIT Varanasi (IIT(BHU))	2012‡ (founded in 1919)	232	1,443#	1,443
Recent IITs				
IIT Palakkad (IITPKD)	2015	NA	NA	NA
IIT Tirupati (IITTP)	2015	NA	NA	NA
IIT(ISM) Dhanbad (IITISMD)	2016 (founded in 1926)	NA	NA	NA
IIT Bhilai (IITBH)	2016	NA	NA	NA
IIT Goa (IIT Goa)	2016	NA	NA	NA
IIT Jammu (IITJMU)	2016	NA	NA	NA
IIT Dharwad (IITDH)	2016	NA	NA	NA

*Faculty strength between 25 July 2013 and 3 December 2014.
#Research output from establishment year till 2014. ‡Conversion to IIT.
NA: The data for recent IITs are not available and hence they are excluded from analysis.

Table 2. Computed indicator values for IITs (2010–2014)

Institution	TP	TC	ACPP	HiCP	ICP	*h*-index	Papers per capita
Old IITs							
IITKGP	5,871	26,991	4.6	35	1394	43	10.1
IITM	4,905	20,413	4.2	42	1396	44	9.7
IITB	4,680	24,118	5.2	85	1470	50	8.3
IITD	4,574	20,480	4.5	31	1198	38	10.8
IITK	3,789	17,135	4.5	25	1008	35	10.1
IITR	3,452	16,330	4.7	39	805	39	7.6
IITG	1,754	9,032	5.1	19	472	34	4.9
New IITs							
IIT(BHU)#	1,443	2,110	1.462	11	410	19	6.2
IITH	501	1,545	3.084	7	165	15	3.7
IITI	389	1,950	5.013	19	161	22	5.1
IITRPR	304	1,446	4.757	5	99	17	5.6
IIT Mandi	152	271	1.783	1	73	9	2.5
IITGN	147	382	2.599	4	65	9	1.7
IITBBS	141	422	2.993	0	41	11	2.4
IITP	119	418	3.513	1	19	10	1.6
IITJ	87	165	1.897	0	31	6	2.4

TP, Total papers; TC, Total citations; ACPP, Average citations per paper; HiCP, Papers in top 1% cited papers; ICP, Internationally collaborative papers.
#Data from establishment year till 2014.

Table 3. Data for two world universities ranking high in ARWU World Ranking and IISc Bengaluru (2010–2014)

Institution	Year	TP	TC	ACPP	*h*-index
Nanyang Technological University (NTU)	2010	3,184	64,856	20.37	99
	2011	3,542	65,669	18.54	97
	2012	4,014	68,400	17.04	98
	2013	4,291	48,114	11.21	72
	2014	4,476	26,463	5.91	57
Massachusetts Institute of Technology (MIT)	2010	5,909	221,452	37.48	188
	2011	6,260	205,099	32.76	175
	2012	6,585	173,983	26.42	154
	2013	7,014	115,584	16.48	120
	2014	7,335	58,886	8.03	76
Indian Institute of Science (IISc), Bengaluru	2010	1,466	15,194	10.36	45
	2011	1,474	12,132	8.23	41
	2012	1,596	8,440	5.28	29
	2013	1,688	5,092	3.01	21
	2014	1,328	1,082	0.81	8

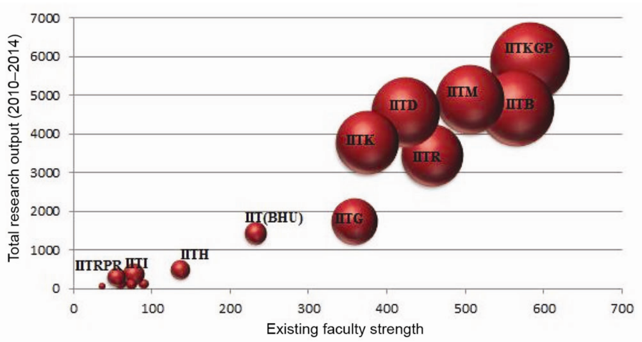

Figure 1. Research output–faculty strength plot (2010–2014) of IITs.

computed results for different IITs for the most recent five-year period to assess their research performance. We observe that IITKGP (the oldest IIT) has the highest value for indicators like TP and TC. On indicators of HiCP and ICP, IITB has the highest value. It may be seen that TP value of IITKGP is more than three times that of IITG. While IITKGP, IITB and IITD have indicator values in close range, larger differences are seen in indicator values for other older IITs. We can also observe that three IITs (IITKGP, IITD and IITK) have the per capita output value greater than 10 indicating that on an average at least 2 research papers per year per faculty are produced by them. Among the new IITs, IIT(BHU) has larger indicator values because it already existed as an institution before its conversion to IIT. Among the truly *de novo* IITs, IITH and IITI have better performance values compared to other new IITs. To clearly visualize the PPC, we have drawn a TP versus faculty strength plot in Figure 1. This plot marks the position of each IIT according their research productivity in relation to their faculty strength. To further differentiate the research quality, the bubble sizes for each of the IITs are proportional to their TC values (greater size denoting higher total citation). We can observe that IITs are placed in two broad clusters, one corresponding to most of old IITs and the other corresponding to most of new IITs.

In order to further analyse the research performance of IITs, we have compared the indicator values obtained for them with those for two high ranking world engineering institutions (NTU and MIT) and with Indian Institute of Science (IISc), Bengaluru. Table 3 presents indicator values for these three institutions for a period of five years (2010–2014). Comparing the values in Tables 2 and 3, it is clear that the top performing IITs are still far in the research performance of NTU and MIT. For 2010–2014 period, MIT produced 33,103 research papers and NTU produced 19,507 research papers compared to 5871 research papers by IITKGP. The productivity values of these institutions are many times higher than those of IITs. Values of TC, ACPP and *h*-index follow similar differentiation between the two sets. Further, IITs are yet to match the research performance of IISc, which is an indigenously created institution unlike many older IITs established under foreign mentorship. The comparison indicates that IITs have a long way to go if they have to become comparable to the best institutions in the world in terms of research performance.

Citation impact

Assessment of quality of research is equally important for research performance assessment. Citation-based measurements are considered as measures of quality and impact of research. In addition to directly available value of TC for each institution, we have computed ACPP and HiCP counts. The computed values of these indicators for each of the IITs are compared across different IITs as well as with three benchmark institutions. Table 2 shows the TC, ACPP and HiCP values for the 2010–2014 period for different IITs. We can see that IITKGP has received the highest number of citations (TC value 26,991) followed by IITB (24,118) among all the IITs. We have seen earlier that they are placed on top, in this order, on productivity measure (TP) as well. Among new IITs, IIT(BHU) leads with TC value of 2,110 followed by IITI (1,950). When we look at the ACPP values, we find that IITB has the highest value of 5.153. Given the fact that IITB has significantly high TP value, its place shows high quality of research output being produced by it. We also observe that IITI and IITRPR have comparable ACPP values with old IITs, even though their TP values are not bad taking into account their age. The *h*-index values for all the IITs are also computed, as shown in Table 2. The highest *h*-index value among IITs is obtained by IITB (50) followed by IITM (44). For a more detailed visualization, we have plotted a TP versus ACPP plot for each of the IITs, in Figure 2. The bubble sizes are proportional to TC values of the respective IITs (greater size denoting higher total citation). The plot shows that old IITs (IITKGP, IITB, IITM) occupy better positions.

For each of the IITs, HiCP counts have been computed. For this, first top 1% most cited papers in the entire set were identified and then HiCP instances for each of the IITs were counted. It was observed that only 6 IITs contribute more than 75% HiCP in the set, with IITB leading the set with 85 such papers. Table 4 shows the percentage of HiCP papers contributed by each IIT. It is seen that IITB has more than 20% HiCP instances, which include 1.33% of its published output. This is followed by IITKGP (~15%) and IITD (~13%). Among the new IITs, IIT(BHU) contributes about 5% of the papers to HiCP set. IITI shows impressive performance among the new IITs. In order to see what kind of papers are among the HiCP set, details of 20 most cited papers along with their subject categories are shown in Table 5. Seven papers are seen having more than 1000 citations each, among which 2 are from computer science and 1 from nuclear physics and the rest from multidisciplinary science, interdisciplinary engineering, chemistry and energy and fuels. It is also found that most of HiCP instances from all IITs are from the field of computer science having cumulative citation of 6500.

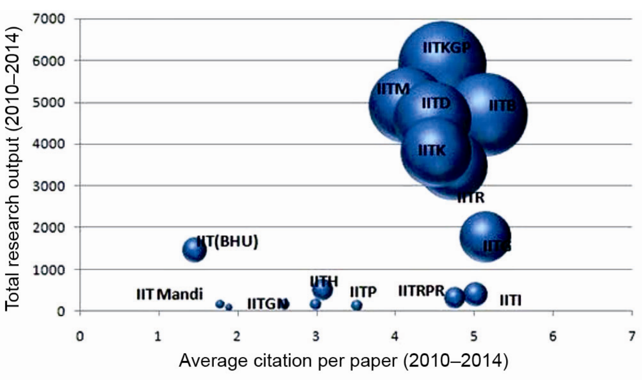

Figure 2. TP versus ACPP plot for all IITs (2010–2014).

After computing all citation-based values for each of the IITs and their comparison within the set, they are compared with the corresponding values for the three benchmark institutions, as shown in Table 3. It is observed that both MIT and NTU have ACPP values at least four times higher than the top performing IIT in the set. TC values are substantially higher as well. The comparison of *h*-index values shows similar differentiation. The *h*-index value of the best performing IIT during 2010–2014 is 50 compared to the lowest annual *h*-index value of 76 and highest annual *h*-index value of 188 of MIT during the 2010–2014 period.

International collaborative papers

It has been reported that International Collaborative Papers (ICP) obtain relatively higher impact than non-ICP instances[12,13]. Therefore, ICP values for all the IITs for the 2010–2014 period were measured (Table 2). It can be observed that IITB has the highest ICP value (1470) followed by IITM (1396) and IITKGP (1394). Among the new IITs, IIT(BHU) has 410 ICP instances followed by IITH (165) and IITI (161). To further analyse the international collaboration behaviour of the IITs, the major collaborating countries were identified. Table 6 lists the top 10 countries with which IITs have collaborated. It can be seen that USA has the highest collaboration output (5594), with IITB alone accounting for 1359 papers. The other top collaborating countries are Germany (2789), United Kingdom (1678), France (1403), Japan (1164), South Korea (1110), Canada (1060), China (941), Russia (764) and Australia (725). It is interesting to observe that new IITs are not far behind in international collaboration.

Table 4. Highly cited paper share within IITs (1990–2014)

Institution	Total	TP	% of TP	% of HICP
IITB	172	12937	1.33	20.74789
IITKGP	126	16510	0.763	15.19903
IITD	114	13136	0.868	13.75151
IITK	110	12111	0.908	13.269
IITR	106	6203	1.709	12.78649
IITM	93	13208	0.704	11.21834
IIT(BHU)	44	1443	3.049	5.3076
IITG	26	2247	1.157	3.136309
IITI	19	389	4.884	2.291918
IITH	8	502	1.594	0.965018
IITRPR	5	305	1.639	0.603136
IITGN	4	149	2.685	0.482509
IIT Mandi	1	152	0.658	0.120627
IITP	1	121	0.826	0.120627
IITBBS	0	142	0	0
IITJ	0	87	0	0

Table 5. Twenty most cited papers from the IITs research output data (1990–2014)

Publication year	Publication title	Authors	Affiliations	Citations	WoS category
2002	A fast and elitist multiobjective genetic algorithm: NSGA-II	Deb, K., Pratap, A., Agarwal, S. and Meyarivan, T.	IITK	6500	Computer science, artificial intelligence; computer science, theory and methods
2005	Experimental and theoretical challenges in the search for the quark-gluon plasma: the STAR collaboration's critical assessment of the evidence from RHIC collisions	371 authors	IITB & 48 other countries	1495	Physics, nuclear
2000	Comparison of multiobjective evolutionary algorithms: empirical results	Zitzler, E., Deb, K. and Thiele, L.	IITK and Swiss Fed Inst Technol, Switzerland	1376	Computer science, artificial intelligence; computer science, theory and methods
2002	Recent applications of the Suzuki–Miyaura cross-coupling reaction in organic synthesis	Kotha, S., Lahiri, K. and Kashinath, D.	IITB	1162	Chemistry, organic
2000	An efficient constraint handling method for genetic algorithms	Deb, K.	IITK	1066	Engineering, multidisciplinary; mathematics, interdisciplinary applications; mechanics
2009	The B73 maize genome: complexity, diversity, and dynamics	157 authors	IITB and 35 other countries	1053	Multidisciplinary sciences
2006	Technical aspects of biodiesel production by transesterification – a review	Meher, L. C., Sagar, D. V. and Naik, S. N.	IITD	1038	Energy and fuels
2001	Hydrogen production by biological processes: a survey of literature	Das, D. and Veziroglu, T. N.	IITKGP; University of Miami, USA	932	Chemistry, physical; electrochemistry; energy and fuels
2003	Recent developments in ring opening polymerization of lactones for biomedical applications	Albertsson, A. C. and Varma, I. K.	IITD and Royal Inst Technol, Sweden	774	Biochemistry and molecular biology; chemistry, organic; polymer science
2000	Size-dependent elastic properties of nanosized structural elements	Miller, R. E. and Shenoy, V. B.	IITK and Univ Saskatchewan, Canada	744	Nanoscience and nanotechnology; materials science, multidisciplinary; physics, applied
2007	Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines	Agarwal, A. K.	IITK	702	Thermodynamics; energy and fuels; engineering, chemical; engineering, mechanical
1999	A review of active filters for power quality improvement	Singh, B., Al-Haddad, K. and Chandra, A.	IITD and Ecole Technol Super, Canada	651	Automation and control systems; engineering, electrical and electronic; instruments and instrumentation
2002	Energy-aware wireless microsensor networks	Raghunathan, V., Schurgers, C., Park, S. and Srivastava, M. B.	IITM and Univ Calif Los Angeles, USA	627	Thermodynamics; engineering, mechanical
1994	Bulk superconductivity at an elevated temperature (T(C) approximate to 12 K) in a nickel containing alloy system Y–NI–B–C	Nagarajan, R. and 8 authors	IITB and CNRS, France	623	Physics, multidisciplinary
2003	Temperature dependence of thermal conductivity enhancement for nanofluids	Das, S. K., Putra, N., Thiesen, P. and Roetzel, W.	IITM; Univ Bundeswehr and Inst Thermodynam, Germany	622	Thermodynamics; engineering, mechanical; mechanics

(*Contd*)

Table 5. (*Contd*)

Publication year	Publication title	Authors	Affiliations	Citations	WoS category
1996	An FFT-based technique for translation, rotation, and scale-invariant image registration	Reddy, B. S. and Chatterji, B. N.	IITKGP	620	Computer science, artificial Intelligence; engineering, electrical and electronic
2004	Polymers in sensor applications	Adhikari, B. and Majumdar, S.	IITKGP	546	Polymer science
2010	Electrospinning: a fascinating fiber fabrication technique	Bhardwaj, N. and Kundu, S. C.	IITKGP	544	Biotechnology and applied microbiology
2000	Finite-time stability of continuous autonomous systems	Bhat, S. P. and Bernstein, D. S.	IITB; Univ Michigan, USA	532	Automation and control systems; mathematics, applied
2006	Electrophilicity index	Chattaraj, P. K., Sarkar, U. and Roy, D. R,	IITKGP	476	Chemistry, multidisciplinary

Table 6. ICP for each IIT with top 10 collaborating countries (1990–2014)

Institutes	United States	Germany	United Kingdom	France	Japan	South Korea	Canada	China	Russia	Australia
IITB	1359	660	429	429	258	256	163	298	282	169
IITM	898	442	172	151	190	223	94	150	122	76
IITKGP	764	453	286	110	155	158	204	79	24	79
IITK	948	380	177	215	122	82	144	36	14	79
IITD	786	270	230	180	106	57	205	104	13	107
IITG	233	198	138	112	93	91	111	83	171	141
IITR	249	147	107	55	58	50	90	36	5	37
IIT(BHU)	107	91	14	67	71	97	16	64	56	3
IITI	72	87	63	59	78	63	1	71	75	4
IITH	40	29	27	9	19	3	9	6	0	11
IITRPR	27	7	19	4	2	22	9	4	0	1
IITGN	42	9	7	4	1	3	1	1	0	0
IIT Mandi	37	3	8	4	3	1	3	4	0	1
IITBBS	15	7	1	3	2	4	5	3	2	0
IITJ	8	5	0	1	6	0	4	1	0	4
IITP	9	1	0	0	0	0	1	1	0	13
Total	5594	2789	1678	1403	1164	1110	1060	941	764	725

Discipline-wise research strengths

The analysis done so far helped in assessment of overall research performance of different IITs, but it did not tell which IIT is doing good research in which subject area. It was thought to be very interesting and useful to know which IIT has what strong research area/department. For this purpose we categorized the research outputs of all the IITs into 15 broad subject categories[14] (originally used by Rupika *et al.*[15]). These 15 subject categories correspond to broad research disciplines pursued in IITs. Each paper is assigned to one of the 15 subject categories and then the total number of research papers in each of the 15 categories for all the IITs is computed. We have first plotted the discipline-wise distribution of the total research output for all the IITs taken together (Figure 3). The plot shows the discipline-wise distribution for the 1990–2014 and 2010–2014 periods. We observe that a majority of the research output from the IIT set belongs to physics, chemistry (including chemical engineering) and material sciences, during both the periods – 25 year as well as 5 years. This is a little surprising taking into account the fact that IITs are primarily engineering and technology institutions and have higher faculty strengths in engineering departments. It is also interesting to observe that approximately 33% of the research work in all the disciplines is done during the last five years.

The discipline-wise research performance of individual IITs has also been analysed. Table 7 shows the research strengths (measured in terms of TP) of different IITs in different disciplines. It is observed that IITKGP and IITB are placed on top in several disciplines, while other institutions such as IITM, IITR and IITD are placed high in some other disciplines. For example, IITKGP and IITB produce a good amount of research in CHEM discipline. IITM produces a good amount of research in CIV and MECH disciplines. New IITs are comparatively less visible for obvious reasons. This analysis of research outputs

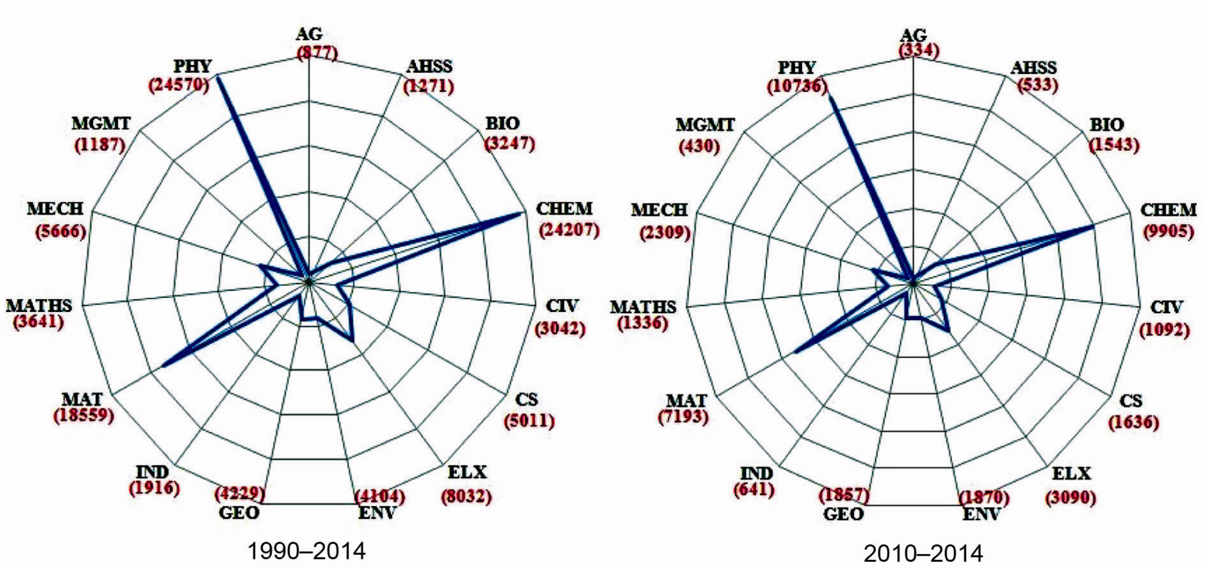

Figure 3. Discipline-wise research output size mapping.

according to subject areas may be used for identifying the institutes which may have potential for excellence in a particular discipline. The discipline-wise analysis can also be used by policy makers/funding agencies in instituting programmes for differential funding to institutions in particular disciplines. Prospective students can also use these outputs to select a suitable IIT for their research interests in a given discipline.

Composite rank of research performance

We have also tried to summarize the position of different IITs in various international rankings and compared them with a proposal for a quantity–quality composite rank of all IITs. As new IITs do not figure in international rankings, the composite rank serves as an initial ranking for their research performance. The proposed index is a composition of both quality and quantity indicators of research performance, as originally proposed in a previous work[2]. It is called a quality–quantity composite index (QQCI) and is based on bibliometric indicators: TP, TC, HiCP, ICP, ACPP and CPC. To implement QQCI, the values of each variable are reduced to a score lying between 0 and 1 by taking the ratio of the value to the maximum value of each corresponding field in the dataset. Two composite indices QQCI (1) and QQCI (2) are proposed

$$Q_{score} = \text{Mean}\,(TP_{score}, TC_{score}, HiCP_{score}, ICP_{score}), \quad (1)$$

$$QQCI(1) = Q_{score} * ACPP_{score}, \quad (2)$$

$$QQCI(2) = Q_{score} * CPC_{score}. \quad (3)$$

Table 8 shows the QQCI(1) and QQCI(2) ranks for the 2010–2014 period for all the IITs. We can see that IITB is placed high on both indices (QQCI(1) and QQCI(2)). IITKGP and IITD follow in order on QQCI(2) whereas IITM is placed higher than IITD on QQCI(1). Among the new IITs, IITI, IIT(BHU) and IITRPR have better scores on both QQCI(1) and QQCI(2) than other new IITs. We found a significant degree of rank correlation between QQCI(1) and QQCI(2), though one of them depends on average citations whereas the other on faculty size. Table 8 also shows the rank position of the concerned IITs in different international rankings. The international ranking data included in the table is for QS ranking[16] (2015–16), THE[17] ranking (2015–16), URAP[18] (2015–16) and Webometrics[19] ranking. It may be noted that none of the IITs is included in ARWU[20] ranking (2015). The table includes NIRF[21] rankings recently introduced by the Government of India, for a complete overview, though it is not a research performance ranking system.

It is observed that mainly the old IITs are included in international rankings (except URAP which includes three new IITs). One interesting fact to observe is that QQCI(1) and QQCI(2) ranks correlate well with most of the international rankings especially the ones which are based on research performance rather than perceptual factors. For the old IITs, QQCI(1) is entirely consistent with the THE ranking and differs only one position with URAP. This can be taken as a sense of credibility of the methodology and that QQCI(1) and QQCI(2) rank orders for new IITs are correct rankings for their research performance. We also see variation in rank positions in NIRF, which ranks IITM at the top position (3rd and 4th for QQCI(1) and QQCI(2) respectively). This may be an acceptable departure as NIRF is not an entirely research

Table 7. Discipline-wise research strengths of IITs (1990–2014)

	AG	AHSS	BIO	CHEM	CIV	CS	ELX	ENV	GEO	IND	MAT	MATHS	MECH	MGMT	PHY
IITB	60	269	427	4445	397	718	1379	560	842	242	2783	666	705	178	4117
IITD	168	211	782	3644	434	840	1681	716	597	334	2513	409	868	273	4292
IITG	31	39	148	922	58	80	149	142	48	27	369	96	154	12	796
IITK	36	257	292	3838	331	708	799	422	508	263	3137	847	773	152	4147
IITKGP	391	181	599	5161	618	1320	1822	955	972	438	4363	602	1161	283	4352
IITM	59	177	624	3935	698	956	1378	412	463	404	3556	688	1421	189	4164
IITR	92	87	193	1619	469	298	619	776	679	168	1365	247	439	83	1522
IIT Mandi	0	5	2	42	1	8	13	3	0	1	48	15	6	2	71
IITP	0	1	3	35	2	11	15	2	0	3	22	10	13	1	40
IITH	1	9	9	204	15	17	65	24	13	8	127	17	40	0	177
IITI	0	4	7	154	4	18	41	2	3	15	56	10	22	4	166
IITJ	0	2	9	10	1	10	8	2	0	3	14	6	9	1	42
IITBBS	0	8	3	24	7	10	40	5	11	1	26	4	19	4	53
IITGN	1	18	14	41	5	10	7	6	17	0	26	16	1	2	37
IITRPR	0	3	11	133	2	7	16	6	1	9	91	8	35	3	91
IIT(BHU)	38	0	124	0	0	0	0	71	75	0	63	0	0	0	503

AG, Agricultural Sciences; AHSS, Art, Humanities and Social Science; BIO, Biological Sciences; CHEM, Chemistry and Chemical Engineering; CIV, Civil Engineering; CS, Computer Science; ELX, Electronics; ENV, Environmental Sciences; GEO, Geological Sciences; IND, Industrial Engineering; MAT, Material Science; MATHS, Mathematics; MECH, Mechanical Engineering; MGMT, Management Sciences; PHY, Physical Science.

Table 8. IITs in international rankings and the composite ranks

Institution	QS 15–16	THE 15–16	NIRF 2016	URAP 15–16	Webometrics 2016	QQCI 1 Rank	QQCI 2 Rank
IITB	202	351–400	2	607	511	1	1
IITKGP	286	401–500	3	558	872	2	2
IITD	179	401–500	4	648	786	3	4
IITM	254	401–500	1	667	631	4	3
IITK	271	501–600	5	716	699	5	6
IITR	391	501–600	6	721	1189	6	5
IITG	451–460	501–600	11	999	1407	7	7
IITI	–	–	16	1625	3366	8	8
IIT(BHU)	–	–	14	–	5558	9	10
IITRPR	–	–	9	1826	2884	10	9
IITH	–	–	7	1783	2208	11	11
IITGN	–	–	8	–	2979	12	12
IITBBS	–	–	26	–	2556	13	15
IIT Mandi	–	–	20	–	5519	14	13
IITP	–	–	10	–	2873	15	14
IITJ	–	–	25	–	5618	16	16

performance ranking framework and includes several factors of teaching, learning and representation in the institutions. Overall the composite ranks prove to be a good measure of relative research performance of all IITs, perhaps the first of its kind to rank all 16 IITs in India.

Conclusion

A computational analysis for research performance assessment and ranking of 16 IITs in India has been performed. Research publication data from the IITs is analysed and different performance indicators are computed. The values for different IITs are compared for a relative assessment and ranking. Performance indicator values for IITs are also compared with those of three benchmark institutions. The discipline-specific research strength of each IIT is also computed. A composite rank for all the 16 IITs is derived and compared with the position of IITs in various international rankings. All these analytical results present a comprehensive analysis of research performance of IITs in India.

In the analysis, IITB ranks first on both QQCI(1) and QQCI(2) composite indicators. IITKGP (oldest among IITs) is placed second and obtains high values on many performance indicators computed. Other older IITs are also placed significantly higher than new IITs on most of the indicators. This is largely in agreement with the findings reported earlier[3,5,6]. The exact rank positions of these old IITs, however, differ slightly in these studies. IITB performs well on several indicators including HiCP and ICP. Among newer IITs, IIT(BHU) and IITI have shown overall promising performance in research. IITH and IITRPR have achieved good values on some of the indicators. In terms of composite ranking, IITB appears at the top followed by IITKGP. Among old IITs, IITD, IITM, IITK, IITR, IITG are placed thereafter. Among the new IITs, IITI and IIT(BHU) are relatively better placed than other new IITs. The exergy values for the IITs are also computed to compare the analytical results reported earlier[6]. It is found that IITB is leading the IITs in two years (2010 and 2014) and IITKGP is at first place during 2011, 2012 and 2013.

We would particularly like to highlight three important outcomes of the analysis. First, the analysis shows that there is a substantial difference in research performance levels of old IITs vis-à-vis the new IITs. This can be explained by the fact that new IITs are quite young for a research performance comparison with old IITs. Some new IITs, particularly the IITI, show promising research performance. Second, and the more important outcome of the analsysis is the fact that even the best performing IITs are far behind in research performance of the two top ranking world universities (MIT and NTU). Of these two, NTU established in 1991 (ref. 22) is younger than the five older IITs, which shows that the age of an institution alone does not necessarily matter for higher performance. If a new institution like NTU can achieve research performance levels to be included among top ranking world institutions then why not some of the Indian IITs? For IITs to be placed high among the world institutions, a lot of effort and support is required. Third, the discipline-wise research performance analysis indicates that majority of the research output from IITs is in PHY, CHEM and MAT disciplines and research in engineering disciplines lags behind substantially. IITs being primarily engineering and technology institutions, should produce more research work in core engineering disciplines.

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