Indian Research on Artificial Neural Networks: A Bibliometric Assessment of Publications Output during 1999-2018

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ABSTRACT

The paper describes the quantitative and qualitative dimensions of artificial neural networks (ANN) in India in the global context. The study is based on research publications data (8260) as covered in the Scopus database during 1999-2018. ANN research in India registered 24.52% growth, averaged 11.95 citations per paper, and contributed 9.77% share to the global ANN research. ANN research is skewed as the top 10 countries account for 75.15% of global output. India ranks as the third most productive country in the world. The distribution of research by type of ANN networks reveals that Feed Forward Neural Network type accounted for the highest share (10.18% share), followed by Adaptive Weight Neural Network (5.38% share), Feed Backward Neural Network (2.54% share), etc. ANN research applications across subjects were the largest in medical science and environmental science (11.82% and 10.84% share respectively), followed by materials science, energy, chemical engineering and water resources (from 6.36% to 9.12%), etc. The Indian Institute of Technology, Kharagpur and the Indian Institute of Technology, Roorkee lead the country as the most productive organizations (with 289 and 264 papers). Besides, the Indian Institute of Technology, Kanpur (33.04 and 2.76) and Indian Institute of Technology, Madras (24.26 and 2.03) lead the country as the most impactful organizations in terms of citation per paper and relative citation index. P. Samui and T.N. Singh have been the most productive authors and G.P.S.Raghava (86.21 and 7.21) and K.P. Sudheer (84.88 and 7.1) have been the most impactful authors. Neurocomputing, International Journal of Applied Engineering Research and Applied Soft Computing topped the list of most productive journals.

1. Introduction

Artificial neural networks (ANN) have been around for a long time as a subset of deep learning concepts (McCulloch & Pitts, 1943). Neural networks are designed to learn and make intelligent

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decisions on their own on complex tasks such as classification of images, pictures, and concepts and also address prediction problems (Lek & Park, 2008). Over time, networks have expanded in data processing capabilities and the ability to process more complex tasks. ANN algorithms simulate the processing concepts of the human brain to model complex patterns and predictions problems. ANN algorithms work to extract information from raw data and represent it in some type of model. The model so developed provides intelligence on how to infer things from other data not yet modeled. Put simply, artificial neural networks have emerged as a family of computational models that exhibit artificial intelligence effective at solving tasks such as pattern recognition, learning, pattern approximation, generalization, classification, and clustering. Neural networks have been applied in diverse fields including aerospace, automotive, banking, defense, electronics, entertainment, financial, insurance, manufacturing, medical, oil and gas, speech, securities, telecommunications, transportation, and environment (Elprocus). ANN computing as a subject is fast expanding in all its dimensions, like ANN concepts, types, applications, and models. During the last two decades, a lot of papers have been published in the domain of ANN computing. Given these developments, it is deemed appropriate and necessary that a bibliometric study is undertaken to evaluate ANN research in India in the global context and describe India's performance in the subject in terms of its global ranking, and the institutions and researchers that are driving the research within the country.

The study is designed to examine qualitative and qualitative aspects of India's overall research output in the area of artificial neural networks as indexed in the Scopus database during 1999-2018. The specific objectives of this study are: (i) Analyze global research in the subject in terms of publications growth and global share of top 10 most productive countries, (ii) Analyze ANN research in India in terms of publications growth, its distribution by document types, source publication types, broad subject areas, network type, and ANN application sectors, (iii) Analyze ANN research in India in terms of citation impact and describe bibliographic features of highly-cited papers, and (iv) Identify top 25 most productive organizations and authors and top 20 journals for research communications.

2. Literature Review

Bibliometric/scientometric studies related to the analysis of the "Artificial Neural Networks" research covering publications and patents are not available in large numbers in the literature on the subject, both at the national and international levels. Amongst the existing studies, Kumar (2016a) examined Artificial Neural Networks (ANNs) research in India during 1991-14 on measures like research growth, global publication share, activity index, relative citation impact, and impact factor. Kumar (2016b) also examined the conformity of Lotka's law to authorship distribution in the field of Artificial Neural Networks research (ANNs) comprising 3411 articles and 5654 unique authors. Claude et al. (2004) studied the distribution of articles involving artificial neural networks in the fields of medicine and biology as indexed in ISI databases during 2000-2001 (1803 articles and 49 countries), with a focus on the parameters: the number of articles, the total impact factor, the

ISI journal category, the source country population, and the gross domestic product.

However, in addition to bibliometric studies on ANN research per se, quite a few bibliometric studies are available on the neural network. Amongst these studies, Noyons and van Raan (1996, 1998) evaluated neural network research to identify productive countries and research institutions globally. Using bibliometric mapping technique they developed a methodology of "self-organized" structuring of scientific fields. Tijssen (1993) examined perceptions of scientific experts regarding the intellectual shape and contents (cognitive structure) of their scientific domain. Amsaveni (2016) tested the possible application of Bradford law to the Indian literature (2001-15) on neural networks, consisting of 5209 articles and 58249 citations. Ponnudurai and Priya (2011) analyzed the relative growth rate and doubling time of neural network research output at the international level using time series data from 1969 to 2007.

3. Methodology

In order to undertake a study of India's contribution to the artificial neural network research, publications data was sourced from the Scopus database (http://www.scopus.com) covering a 20-year period 1999-2018. Single keyword "Artificial neural networks" was used in "Keyword tag" as well as in "Article Title tag" (joined by Boolean operator "OR") simultaneously and restricted the output to period "1999-2018" in the "period tag", to get global publication data (consisting of 84,509 records). The above-described search strategy was refined by country of publication (including India) to get publication output data on the top 10 countries. India's publication output comprised of 8260 records. The search strategy for obtaining India's output was further refined to get statistics on India's output by subject, collaborating country, organization, author, and journal. Citations to publications were counted from the date of their publication till 20 November 2019. Separate search strategies were formulated to get data on various types of networks, tasks, and applications. A complete counting method, wherein every contributing author or organization covered in multiple authorship papers was fully counted and used. All authors or organizations of multi-authored papers have received equal credit in data counting and analysis. All types of publications have been used in this study.

(KEY ("Artificial neural networks") OR TITLE ("Artificial neural networks")) AND PUBYEAR > 1998 AND PUBYEAR < 2019 AND (LIMIT-TO (AFFILCOUNTRY, "India"))

4. Results

4.1 Publication Growth

The global research output in the field of "Artificial Neural Networks" (ANN) in 20 years was 84,509 publications during 1999-2018, an average of 4225.4 publications per year. India accumulated 8,260 publications during the period, with an average of 413 publications per year. India registered

10.53% growth compared to 24.53% by the world. India's absolute growth between 1999-2008 and 2008-2018 was 388.74% compared to 130.64% by the world. India contributed 9.77% share to global output in 20 years; its 10-year global publications share surged from 5.49% (1999-2008) to 11.63% (2009-2018). In the field of ANN research, India's citation impact on a 20-year window averaged to 11.95 citations per paper (CPP), and its 10-year citation impact dropped from 25.99 CPP to 9.07 CPP during 1999-2008 to 2009-2018 (Table 1, Fig. 1).

Table 1. Annual and Cumulative Publications on "Artificial Neural Network Research" (ANN) in India during 1999-2018

Publication Year	Global Publications (TP)	Indian Publications					
		TP	%TP	TC	CPP	ICP	%ICP
1999	1477	31	2.10	1321	42.61	3	9.68
2000	1547	45	2.91	979	21.76	7	15.56
2001	1701	41	2.41	1404	34.24	7	17.07
2002	1905	91	4.78	2521	27.70	12	13.19
2003	2063	98	4.75	3099	31.62	17	17.35
2004	2474	123	4.97	5058	41.12	15	12.20
2005	2850	175	6.14	4489	25.65	25	14.29
2006	3332	220	6.60	5890	26.77	34	15.45
2007	3592	241	6.71	5188	21.53	30	12.45
2008	4609	338	7.33	6511	19.26	43	12.72
2009	5248	406	7.74	6907	17.01	51	12.56
2010	5362	474	8.84	8101	17.09	52	10.97
2011	5385	493	9.16	6462	13.11	52	10.55
2012	4736	525	11.09	6484	12.35	73	13.90
2013	4819	485	10.06	6220	12.82	55	11.34
2014	5378	667	12.40	6666	9.99	77	11.54
2015	5606	751	13.40	6792	9.04	73	9.72
2016	6389	1007	15.76	7159	7.11	113	11.22
2017	6865	813	11.84	4230	5.20	95	11.69
2018	9162	1236	13.49	3176	2.57	164	13.27
1999-2008	25559	1403	5.49	36469	25.99	193	13.76
2009-2018	58950	6857	11.63	62197	9.07	805	11.74
1999-2018	84509	8260	9.77	98666	11.95	998	12.08

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; ICP=International Collaborative Papers

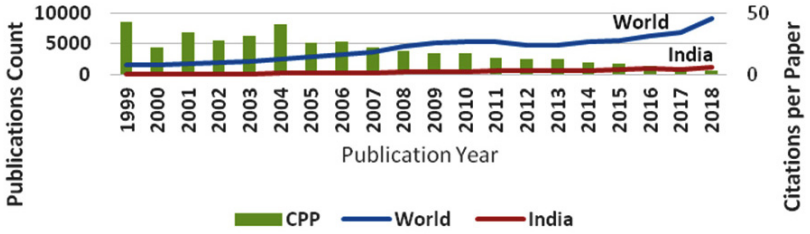

Fig. 1. Artificial Neural Networks Research Growth- Global Vs India 1999-2018

Of the total publications, 63.85% appeared as articles, 31.69% as conference papers, 2.08% as reviews, 1.33% as book chapters, and all others less than 1.0%.

4.2 Top 10 Countries in Artificial Neural Network

In all, 163 countries participated in global Artificial Neural Network (ANN) research. The distribution of ANN research across participating countries was uneven. For instance, 57 countries published 1-10 papers, 32 published 11-70 papers, 7 published 71-100 papers, 38 published 101-600 papers, 10 published 601-1000, 15 published 1001-5000 papers and 4 published 5001-16744 papers.

The bulk of the global research output (75.15%) in the field was contributed by the top 10 most productive countries alone. China and USA are in the leadership position in the world ranking, accounting for 19.81% and 14.79% global publications share respectively. India ranks third in the world ranking with 9.77% share. The global publication share of 7 other top 10 counties has been in single-digit ranging between 0.14% and 6.82% (Table 2, Fig. 2).

Table 2. Global Artificial Neural Network Research: Top 10 Most Productive Countries 1999-2018

S.No	Name of the Country	Number of Papers			Share of Papers		
		1999-2008	2009-2018	1999-2018	1999-2008	2009-2018	1999-2018
1	China	4392	12351	16743	17.18	20.95	19.81
2	USA	4852	7651	12503	18.98	12.98	14.79
3	India	1403	6857	8260	5.49	11.63	9.77
4	Iran	658	5103	5761	2.57	8.66	6.82
5	U.K.	1949	2846	4795	7.63	4.83	5.67
6	Turkey	896	2757	3653	3.51	4.68	4.32
7	Spain	938	2079	3017	3.67	3.53	3.57
8	Germany	1171	1842	3013	4.58	3.12	3.57
9	Canada	1072	1831	2903	4.19	3.11	3.44
10	Italy	989	1870	2859	3.87	3.17	3.38
	Total	18320	45187	63507	71.68	76.65	75.15
	World	25559	58950	84509			

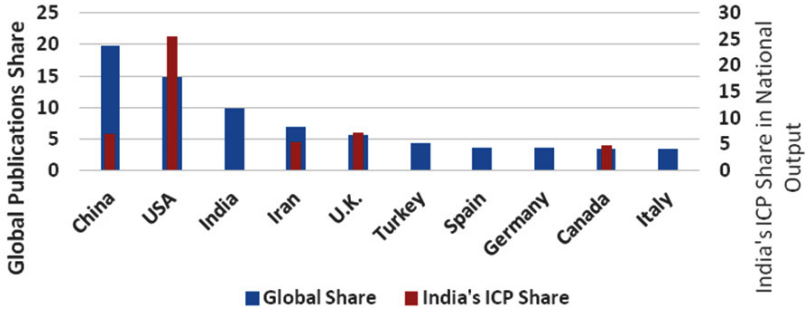

Fig. 2. Global ANN Research : Top 10 Most Productive Countries 1999-2018

4.2.1 India's International Collaboration

During 1999-2018, India's collaboration with 10 select countries was the largest, nearly 12% (998 papers) of its total output in ANN research (8260). Five of India's collaborative countries have also been the world's most productive countries - USA, UK, China, Iran, and Canada (Table 3, Fig. 2). India's collaboration with the USA was the largest (25.55% of India's ICP output), but with the other 9 of 10 collaborative countries, its international collaborative publications (ICP) share was in single-digit between 4.51% and 7.72%.

Table 3. India' International Collaboration in ANN Research during 1999-2018

S.No.	Collaborative Country	International Collaborative Papers (ICP)			Share of ICP		
		1999-2008	2009-2018	1999-2018	1999-2008	2009-2018	1999-2018
1	USA	72	183	255	37.31	22.73	25.55
2	South Korea	11	66	77	5.70	8.20	7.72
3	U.K.	23	48	71	11.92	5.96	7.11
4	China	0	69	69	0.00	8.57	6.91
5	Malaysia	5	54	59	2.59	6.71	5.91
6	Iran	0	55	55	0.00	6.83	5.51
7	Saudi Arabia	0	54	54	0.00	6.71	5.41
8	Australia	0	53	53	0.00	6.58	5.31
9	Canada	11	36	47	5.70	4.47	4.71
10	Singapore	10	36	46	5.18	4.47	4.61
	Total India's ICP output	193	805	998	100.00	100.00	100.00

4.3 Subject-Wise Distribution of India's Research Output

In all, Artificial Neural Network (ANN) research in India intersected with 14 disciplines (as identified in Scopus database classification). Of these, engineering and computer science have been the most favored subject areas in ANN research pursuits (with 45.67% and 41.79% national publications share respectively). In the other 12 disciplines, national publications share ranged between 3.04% and 10.87%.

Research activity index in all of 14 disciplines witnessed fluctuations between 1999-2008 and 2009-2018. Compared to the world average index of 100, seven disciplines registered a significant rise in their activity index, and in 5 other disciplines, it registered a significant decline. In two other areas, the decline in the activity index was marginal. Neuroscience recorded the highest citation impact per paper of 23.40 and mathematics the least (7.23) during 2008-19 (Table 4, Fig. 3).

Table 4. Subject-Wise Breakup of Indian Publications in Artificial Neural Network Research during 1999-2018

S.No	Subject*	Number of Papers (TP)			Activity Index		TC	CPP	%TP
		1999-2008	2009-2018	1999-2018	1999-2008	2009-2018	1999-2018		
1	Engineering	673	3099	3772	105.04	98.97	40661	10.78	45.67
2	Computer Science	465	2987	3452	79.31	104.23	37178	10.77	41.79
3	Environment Science	220	678	898	144.23	90.95	19776	22.02	10.87
4	Mathematics	130	757	887	86.29	102.81	6410	7.23	10.74
5	Materials Science	154	601	755	120.09	95.89	9966	13.20	9.14
6	Energy	95	602	697	80.24	104.04	9556	13.71	8.44
7	Earth & Planetary Sciences	133	527	660	118.64	96.19	8906	13.49	7.99
8	Physics & Astronomy	93	505	598	91.56	101.73	6458	10.80	7.24
9	Chemical Engineering	137	398	535	150.76	89.61	7437	13.90	6.48
10	Biochemistry, Genetics & Molecular Biology	94	433	527	105.01	98.97	7785	14.77	6.38
11	Medicine	60	449	509	69.40	106.26	7962	15.64	6.16
12	Agriculture & Biological Sciences	49	291	340	84.85	103.10	4650	13.68	4.12
13	Pharmacology, Toxicology & Pharmaceutics	21	249	270	45.79	111.09	2646	9.80	3.27
14	Neurosciences	52	199	251	121.97	95.50	5873	23.40	3.04
	World Output	1403	6857	8260			98666	11.95	

* There is overlapping of literature covered under various subjects

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

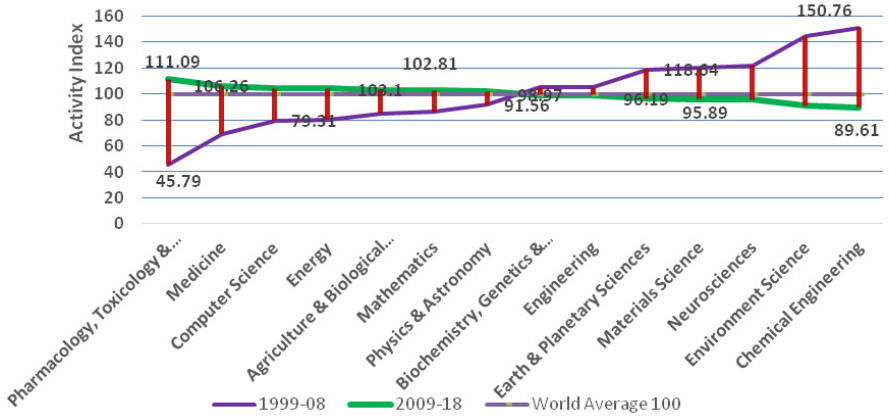

Fig. 3. Global ANN Research : Activity Index Change between 1999-2008 and 2009-19

4.4 Distribution of Publications by Type of ANN Research

In all, ANN research can be classified into 10 types and these 10 types account for 19.46% share of total output by India in the subject. Of these, Feed Forward Neural Network type and Adaptive Neural Network type account for the predominant share (15.56%) of the national output in ANN research in the country. The other eight types account for a marginal 3.9% national publications share (Table 5). Nearly 10% of the national output of the country was devoted to ANN research by network architecture. Of this, Radial Basis Network type research accounted for 4.97% share and Multi-Layer Neural Network type research, 3.93% national share. Research in other network architecture type accounts for 2.22% national share (Table 6).

Table 5. Classification of India's Publications on ANN by Type of Network during 1999-2018

S.No	Type of ANN	Number of Papers			Share of Papers			TC	CPP
		1999-2008	2009-2018	1999-2018	1999-2008	2009-2018	1999-2018	1999-2018	
1	Feed Forward Neural Network	235	606	841	16.75	8.84	10.18	10280	12.22
2	Feed Backward Neural Network	54	156	210	3.85	2.28	2.54	2104	10.02
3	Convolution Neural Network	0	55	55	0.00	0.80	0.67	434	7.89
4	Modular Neural Network	3	6	9	0.21	0.09	0.11	136	15.11
5	Fixed Weight Neural Network	1	22	23	0.07	0.32	0.28	434	18.87
6	Adaptive Weight Neural Network	53	391	444	3.78	5.70	5.38	4777	10.76
7	Bayesian regularized Neural Network	2	16	18	0.14	0.23	0.22	340	18.89
8	Competitive Neural Network	2	5	7	0.14	0.07	0.08	114	16.29
	Total	1403	6857	8260					

Table 6. Classification of India's Publications on ANN by Type of Network Architecture during 1999-2018

S.No.	Classification by Architecture Type	Total Papers (TP)			%TP			TC	CPP
		1999-2008	2009-2018	1999-2018	1999-2008	2009-2018	1999-2018	1999-2018	
1	Single Layer Neural Network	2	31	33	0.14	0.45	0.40	192	5.82
2	Radial Basis Network	47	341	388	3.35	4.97	4.70	4904	12.64
3	Multi-Layer Neural Network	31	294	325	2.21	4.29	3.93	3366	10.36
4	Recurrent Neural Network	13	100	113	0.93	1.46	1.37	2269	20.08
5	Hopfield Network	4	24	28	0.29	0.35	0.34	251	8.96
6	Boltzmann Machine	1	8	9	0.07	0.12	0.11	32	3.56
	Total	1403	6857	8260					

4.5 Distribution of ANN Publications by Applications and Task

In all, 74.41% of ANN research in India was devoted to ANN applications in 19 disciplines. Of these, ANN applications in medical science and environment science accounted for the largest 11.82% and 10.84% national share respectively during 1999-2018. ANN applications in the remaining disciplines ranged between 0.08% and 9.12% national share. Among application areas, marketing registered the highest citation impact per paper of 98.43, followed by hydrology (49.24), environment science (22.89), water resources (22.74), etc. (Table 7).

Table 7. Distribution of ANN Research by Applications during 1999-2018

S.No	Application Area	Number of Papers			Share of Papers			TC	CPP
		1999-2008	2009-2018	1999-2018	1999-2008	2009-2018	1999-2018	1999-2018	
1	Medical Science	124	852	976	8.84	12.43	11.82	16618	17.03
2	Environment Science	219	676	895	15.61	9.86	10.84	20484	22.89
3	Materials Science	154	599	753	10.98	8.74	9.12	10327	13.71
4	Energy	95	601	696	6.77	8.76	8.43	9892	14.21
5	Chemical Engineering	137	402	539	9.76	5.86	6.53	7715	14.31
6	Water Resources	123	402	525	8.77	5.86	6.36	11940	22.74
7	Mining	15	301	316	1.07	4.39	3.83	3307	10.47
8	Management	45	248	293	3.21	3.62	3.55	4316	14.73
9	Geosciences	56	234	290	3.99	3.41	3.51	4465	15.40
10	Security	14	138	152	1.00	2.01	1.84	1817	11.95
11	Agriculture	19	117	136	1.35	1.71	1.65	673	4.95
12	Banking, Finance & Insurance	11	120	131	0.78	1.75	1.59	1400	10.69
13	Manufacuring	21	107	128	1.50	1.56	1.55	1039	8.12

S.No	Application Area	Number of Papers			Share of Papers			TC	CPP
		1999-2008	2009-2018	1999-2018	1999-2008	2009-2018	1999-2018	1999-2018	
14	Hydrology	43	70	113	3.06	1.02	1.37	5564	49.24
15	Transport	18	68	86	1.28	0.99	1.04	1402	16.30
16	Education	5	38	43	0.36	0.55	0.52	393	9.14
17	Construction	9	33	42	0.64	0.48	0.51	377	8.98
18	Policy	2	20	22	0.14	0.29	0.27	290	13.18
19	Marketing	4	3	7	0.29	0.04	0.08	689	98.43
		1403	6857	8260				79282	9.60

Nearly 41% of ANN research in India accounts for task-specific applications: prediction (21.25%), classification (16.14$), and pattern recognition (4.27%). Prediction task accounted for the largest number of papers (255) in environmental science, followed by materials science (206), medical sciences (168 papers), energy (139 papers), chemical engineering (138 papers), etc. Pattern recognition task accounted for the largest number of papers (65) in medical sciences, followed by materials science (15), energy (14 papers), mining (13), security and chemical engineering (9 each), agriculture (8 papers), management (7 papers), etc. Classification type task accounted for the largest number of papers (238) in medical sciences, followed by energy (75 papers), mining (70 papers), materials science (62 papers), environment science (53 papers), chemical engineering (36 papers), etc. during 1999-2018 (Table 8).

Table 8. Classification of ANN by Task in Indian Artificial Neural Network LiIterature

S.No.	Classification by Task							TC	CPP
		1999-2008	2009-2018	1999-2018	1999-2008	2009-2018	1999-2018	1999-2018	
1	Prediction	290	1465	1755	20.67	21.37	21.25	26474	15.08
2	Pattern Rcognition	89	264	353	6.34	3.85	4.27	5780	16.37
3	Classification	210	1123	1333	14.97	16.38	16.14	15473	11.61
	Total	1403	6857	8260					

4.6 India's Top 25 Most Productive Organizations

In all, 2194 organizations participated in Indian research on "Artificial Neural Network" during 1999-2018, of which 1243 organizations published 1 paper each, 543 organizations published 2-5 papers each, 251 organizations 6-10 papers each, 133 organizations 11-20 papers each and 74 organizations 21-50 papers, 50 organizations 51-289 papers each. The productivity of the top 25 most productive organizations varied from 69 to 289 publications per organization; together they contributed 41.50% (3428) Indian publications share and 54.77% (54041) Indian citations share during 1999-2018.

Their HI has been above average citations per paper (Table 9, Fig. 4).

- Nine organizations registered their publications output above their group average (137.12): Indian Institute of Technology, Kharagpur (289 papers), Indian Institute of Technology, Roorkee (264 papers), Anna University, Madras (237 papers), etc.;
- Twelve organizations registered their citations per paper and relative citation index above the group average (15.76 and 1.32) of all organizations: Indian Institute of Technology, Kanpur (33.04 and 2.76), Indian Institute of Technology, Madras (24.26 and 2.03), Indian Institute of Technology, Bombay (22.94 and 1.92), Indian Statistical Institute, Kolkata (22.7 and 1.9), Indian Institute of Technology, Roorkee (22.41 and 1.88), Indian Institute of Science, Bangalore (21.91 and 1.83), etc.

Table 9. Scientometric Profile of Top 25 Most Productive Indian Organizations in Artificial Neural Networks during 1999-2018

S.No	Name of the Organization	TP	TC	CPP	HI	ICP	%ICP	RCI
1	Indian Institute of Technology, Kharagpur	289	6253	21.64	41	53	18.34	1.81
2	Indian Institute of Technology, Roorkee	264	5917	22.41	40	37	14.02	1.88
3	Anna University, Madras	237	2059	8.69	23	18	7.59	0.73
4	Vellore Institute of Technology	222	1301	5.86	20	30	13.51	0.49
5	Indian Institute of Technology, New Delhi	219	3440	15.71	30	20	9.13	1.31
6	Jadavpur University, Calcutta	204	3263	16.00	31	27	13.24	1.34
7	National Institute of Technology, Rourkela	189	3066	16.22	28	21	11.11	1.36
8	Indian Institute of Technology, Bombay	180	4129	22.94	36	26	14.44	1.92
9	Indian Institute of Technology, Madras	178	4319	24.26	34	26	14.61	2.03
10	Indian Institute of Science, Bangalore	129	2827	21.91	28	32	24.81	1.83
11	Indian Institute of Technology, Guwahati	117	2223	19.00	27	19	16.24	1.59
12	National Institute of Technology, Tiruchirappalli	111	1089	9.81	18	1	0.90	0.82
13	Indian Institute of Technology, Kanpur	107	3535	33.04	31	21	19.63	2.76
14	SHASTRA Deemed University	100	831	8.31	18	17	17.00	0.70
15	Sathyabama Institute of Science & Technology	95	203	2.14	7	2	2.11	0.18
16	University of Calcutta	91	943	10.36	17	10	10.99	0.87
17	Birla Institute of Technology & Science, Mesra	89	865	9.72	15	6	6.74	0.81
18	Indian School of Mines, Dhanbad	84	527	6.27	14	3	3.57	0.53
19	Birla Institute of Technology & Science, Pilani	82	1392	16.98	22	11	13.41	1.42
20	Shiksha o Anusandhan Deemed University	80	528	6.60	10	4	5.00	0.55
21	Amity University, Noida	78	479	6.14	11	8	10.26	0.51
22	Indian Statistical Institute, Kolkata	73	1657	22.70	23	17	23.29	1.90
23	Institute of Technology, BHU, Varanasi	71	1471	20.72	20	8	11.27	1.73
24	National Institute of Technology, Surathkal	70	1009	14.41	16	13	18.57	1.21
25	MN National Institute of Technology, Allahabad	69	715	10.36	15	4	5.80	0.87
	Total of 25 organizations	3428	54041	15.76	23.00	434	12.66	1.32
	Total of World	8260	98666	11.95				
	Share of top 25 organizations in India's total output	41.50	54.77					

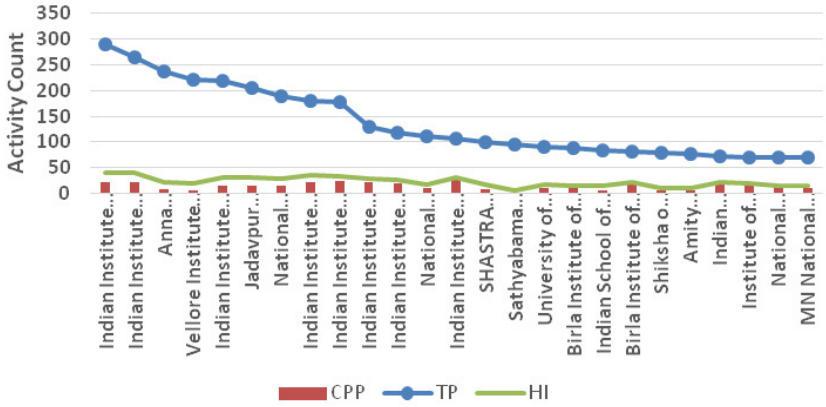

Fig. 4. ANN Research in India : Top 25 Productive Organizations 1999-2018

4.7 India's Top 25 Most Productive Authors

6546 authors participated in Indian research on "Artificial Neural Network" during 1999-2018, of which 4451 authors published 1 paper each, 1440 authors 2-5 papers each, 109 authors 6-10 papers each, 133 authors 11-20 papers each, 74 authors 21-50 papers each and 1 author 58 papers. The research productivity of the top 25 most productive authors varied from 19 to 58 publications per author. Together they contributed 8.17% (675) global publications share and 19.13% (18872) global citations share during 2009-2018. Their detailed scientometric profile is presented in Table 10.

- Eight of the top 25 authors registered their publications output above the group average of 27.0: P. Samui (58 papers), T.N. Singh (42 papers), M.C. Deo (35 papers), G. Panda (35 papers), K.P. Sudheer(34 papers), R. Rakkiyappan and K.K. Sarma (32 papers each) and P. Chandra (30 papers);
- Ten of the top 25 authors registered their citation per paper and relative citation index above the group average (27.96 and 2.34) of all authors: G.P.S.Raghava (86.21 and 7.21), K.P. Sudheer (84.88 and 7.1), A. Jain (77.0 and 6.44), R. Rakkiyappan (45.34 and 3.79), T.N. Singh (39.62 and 3.32), G. Panda (34.57 and 2.89), M. Khandelwal (34.08 and 2.85), M.C. Deo (32.47 and 2.72), S.S. Tampa (29.62 and 2.48) and N.R.Pal (29.0 and 2.43).

Table 10. Scientometric Profile of Top 25 Most Productive Indian Authors in Artificial Neural Network Research during 1999-2018

S.No	Name of the Author	Affiliation of the Author	TP	TC	CPP	HI	ICP	%ICP	RCI
1	P. Samui	Indian Institute of Science, Bangalore	58	721	12.43	16	19	32.76	1.04
2	T.N. Singh	Institute of Technology, BHU, Varanasi	42	1664	39.62	21	5	11.90	3.32

S.No	Name of the Author	Affiliation of the Author	TP	TC	CPP	HI	ICP	%ICP	RCI
3	M.C. Deo	Indian Institute of Technology, Bombay	38	1234	32.47	17	2	5.26	2.72
4	G. Panda	National Institute of Technology, Rourkela	35	1210	34.57	14	3	8.57	2.89
5	K.P. Sudheer	Indian Institute of Technology, Madras	34	2886	84.88	24	10	29.41	7.10
6	R. Rakkiyappan	Bharathiar University	32	1451	45.34	24	22	68.75	3.79
7	K.K. Sarma	Gauhati University	32	124	3.88	8	2	6.25	0.32
8	P. Chandra	G.G.S. Indraprashta University, Delhi	30	230	7.67	8	0	0.00	0.64
9	A. Shukla	ABV-IIIT & Management, Gwalior	26	227	8.73	10	1	3.85	0.73
10	A.Majumdar	Indian Institute of Technology, New Delhi	25	330	13.20	10	2	8.00	1.10
11	C. Balaji	Indian Institute of Technology, Madras	24	333	13.88	11	0	0.00	1.16
12	A.Jain	Indian Institute of Technology, Kanpur	24	1848	77.00	13	5	20.83	6.44
13	M.Khandelwal	M.P.University of Agriculture & Technology	24	818	34.08	14	13	54.17	2.85
14	R. Tiwari	ABV-IIIT & Management, Gwalior	24	227	9.46	10	0	0.00	0.79
15	B.Majhi	G.G..Vishwavidyale, Indore 23	23	145	6.30	8	1	4.35	0.53
16	S.Chattopadhyay	Palian College of Management & Technology	22	385	17.50	11	1	4.55	1.46
17	S.K. Das	National Institute of Technology, Rourkela	22	465	21.14	10	5	22.73	1.77
18	S.Dutta	Indian Institute of Engineering Science & Technology, Shibpur	22	297	13.50	10	3	13.64	1.13
19	D.Devaraj	Kalasalingam Academy of Research & Education	21	430	20.48	9	0	0.00	1.71
20	S.S.Tampa	National Chemical Laboratory, Pune	21	622	29.62	11	2	9.52	2.48
21	V.Jothiprakash	Indian Institute of Technology, Bombay	20	198	9.90	9	2	10.00	0.83
22	S.S.Mahapatra	National Institute of Technology, Rourkela	19	471	24.79	12	0	0.00	2.07
23	N.R.Pal	Indian Statistical Institute, Kolkata	19	551	29.00	12	6	31.58	2.43
24	H.Malik	Netaji Subhash Institute of Technology, Delhi	19	367	19.32	10	0	0.00	1.62
25	G.P.S.Raghava	Institute of Microbial Technology, Chandigarh	19	1638	86.21	18	1	5.26	7.21
	Total		675	18872	27.96	12.8	105	15.56	2.34
	Total of World		8260	98666	11.95				
	Share of 25 Authors in World Total Output		8.17	19.13					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index

4.8 Medium of Research Communication

Nearly 67.0% (5534) of ANN research in India appeared in 1053 journals, 25.91% (2140) in conference proceedings, 5.63% (465) in book series, 0.98% (81) as books, 0.47% (39) in trade publications and 0.01% (1) as undefined. Of the 1059 journals (reporting 5534 articles), 802 published 1-5 papers each, 165 published 6-10 papers each, 59 published 11-20 papers each, 29 published 21-50 papers each and 4 published 51-136 papers each during 1999-2018.

The top 20 most productive journals accounted for 16.77% of total Indian output in journals (covering artificial neural networks research) during 1999-2018, The 10-year output in journals increased from 14.43% to 17.33% between 1999-2008 and 2009-2018. Neurocomputing was the topmost productive journal (with 136 papers) in reporting Indian research in the field of ANN research, followed by the International Journal of Applied Engineering Research (106 papers), Applied Soft Computing (71 papers), Neural Computing & Applications (51 papers), etc. during 1999-2018 (Table 11).

Table 11. Top 20 Most Productive Journals in Artificial Neural Networks during 1999-2018

S.No	Name of the Journal	Number of Papers		
		1999-2008	2009-2018	1999-2018
1	Neurocomputing	31	105	136
2	International Journal of Applied Engineering Research	0	106	106
3	Applied Soft Computing	7	64	71
4	Neural Computing & Applications	1	50	51
5	Journal of Medical Systems	8	39	47
6	International Journal of Advanced Manufacturing Technology	18	28	46
7	Water Resources Management	15	29	44
8	Journal of Hydrological Engineering	22	19	41
9	Journal of Medical Imaging & Health	0	41	41
10	Expert Systems with Applications	2	34	36
11	Neural Networks	6	30	36
12	International Journal of Pharmacy and Technology	0	34	34
13	ARPN Journal of Engineering & Applied Science	0	33	33
14	Research Journal of Pharmacological Biological & Chemical Sciences	0	33	33
15	Indian Journal of Science & Technology	0	31	31
16	Biomedical Research India	0	29	29
17	International Journal of Biomedical Engineering & Technology	1	28	29
18	Journal of Hydrology	8	21	29
19	Journal of the Institute of Engineers INdia. Electrical Engineering Division	21	7	28
20	International Journal of Remote Sensing	15	12	27
	Total of 20 journals	155	773	928
	Total global journal output	1074	4460	5534
	Share of top 20 journals in global journal output	14.43	17.33	16.77

4.9 Highly - Cited Papers

Of the total research output on "Artificial Neural Networks" in India (8260 publications), only 126 (1.53% share) accumulated 100 to 942 citations per paper (cumulative total 22170 citations) since their publication during 2009-2018, averaging to 175.95 citations per paper. The distribution of these 126 highly cited papers is skewed. One hundred nine papers accumulated citations in the range 100-199 per paper, 17 papers were in citation range 211-294, 8 papers in citation range 309-457, and 2 papers were in citation range 610-942.

- Of the 126 highly cited papers, 54 resulted from the contribution by single organizations per paper (non-collaborative papers) and 72 from two or more organizations per paper (40 national collaborative and 32 international collaborative papers).
- Among highly cited papers, USA collaborated in the largest number of papers (11 papers), followed by Singapore (4 papers), China and Iran (3 papers each), Australia, Japan, Malaysia, Portugal, Saudi Arabia and Turkey (2 papers each), Brazil, Canada, France, Greece, Iraq, Netherland, Nigeria, Norway, Serbia, South Africa, Taiwan, Turkey and Vietnam (1 paper each).
- The 126 highly cited papers belonged to 388 authors and 235 organizations.
- The leading organizations participating in highly-cited papers were: IIT-Roorkee (13 papers), IIT-Kanpur, IIT—Kharagpur and IIT-Chennai (9 papers each), IIT-Bombay (7 papers), IIT-Delhi (5 papers), NIT-Rourkela and IISc-Bangalore (4 papers each), Jadavpur University-Kolkata, IIT-Guwahati and NIT-Surathkal (3 papers each), BITS-Pilani, ISI-Kolkata and IIT-BHU-Varanasi (2 papers each), etc.
- The leading authors participating in highly cited papers were: K.P.Sudheer (IIT-Madras)(8 papers), A.Jain (IIT-Kanpur)(7 papers), T.N.Singh (IIT-BHU)(4 papers), M.C.Deo(IIT-Bombay), G.Panda (NIT-Rourkela), M.Khandelwal (M.P. Univ of Agr & Tech), and G.P.S.Raghava (IMTECH-Chandigarh (3 papers each), etc.
- Of the 126 highly cited papers, 109 were published as articles, 12 as review papers, 4 as conference papers and 1 as a short survey.
- These 126 highly cited papers appeared across 90 journals, of which 6 papers were published in the Journal of Hydrology, 5 papers in Applied Soft Computing Journal, 4 papers each in Journal of Hydrological Engineering, IEEE Transactions on Neural Networks, Hydrological Processes and the Journal of Materials Processing Technology, 3 papers each in Biochemical Engineering Journal, Expert Systems & Applications, Neurocomputing and Renewable & Sustainable Energy Review, 2 papers each in Biomedical Signal Processing & Control, BMC Bioinformatics, Computer Methods & Program in Biomedicine, IEEE Transactions on Power Delivery, IEEE Transactions on Systems, Man & Cybernetics, Part B, International Journal of Rock Mechanics & Mining Sciences, Neural Networks, Ocean Engineering, Water Resources Management, Water Resources Research, Journal of Irrigation & Drainage Engineering, IEEE Transactions on Power Systems. Journal of Medical Systems and Renewable Energy and other journals 1 paper each.

5. Conclusion

This paper analyzes India's research in the domain of "Artificial neural networks" (ANN) on select bibliometric indicators covering 20-year research as published during 1999-2019. During the period, ANN research by India registered a fast 24.52% average annual growth, contributed 9.77% share to global output, averaged citation impact of 11.95 citations per paper, and registered 126 papers (1.53% share of national output) as highly cited papers. In all, 163 countries contributed to global ANN research (84505 publications). The top 10 most productive countries in the world alone accounted for 75.15% bulk share to global publications output in the subject. China and the USA are in the leadership position in the world ranking, with 19.81% and 14.79% global publications share respectively. India ranks the third most productive country in the world with a 9.77% share. The global publication share of the other 7 amongst the top 10 counties has been in single digit ranging between 0.14% and 6.82%.

Engineering and computer science have been the preferred subjects in Artificial Neural Network (ANN) Research (with 45.67% and 41.79% publications share). Amongst the type of network in ANN research, Feed Forward Neural Network contributed the largest publication share (10.18%), followed by Adaptive Weight Neural Network (5.38% share), Feed Backward Neural Network (2.54% share), etc. during 1999-2018. In terms of research applications across subjects, medical science and environment science registered the highest publication share (11.82% and 10.84% share), followed by materials science, energy, chemical engineering, and water resources (from 6.36$ to 9.12%), etc. during the period.

The distribution of India research by participating organizations is skewed. The top 25 organizations (out of total 1243) contributed 41.50% publications share and 54.77% citations share respectively during the period. Indian Institute of Technology, Kharagpur (289 papers), Indian Institute of Technology, Roorkee (264 papers), Anna University, Madras (237 papers), have been the most productive research organizations in the country. The organizations leading in terms of citation per paper and relative citation index were: Indian Institute of Technology, Kanpur (33.04 and 2.76), Indian Institute of Technology, Madras (24.26 and 2.03), Indian Institute of Technology, Bombay (22.94 and 1.92), Indian Statistical Institute, Kolkata (22.7 and 1.9), etc. The distribution of India research by participating authors is highly scattered. The top 25 authors (out of total 6546) across India contributed merely 8.17% publications share and 19.13% citations share respectively during the period. Neurocomputing and International Journal of Applied Engineering Research are the top two most popular journals in the subject that published 136 and 106 papers respectively. India published the highest numbers of highly cited papers in collaboration with the USA (11 out of 126), followed by Singapore (4 papers), China and Iran (3 papers each), and others. In all, 126 highly-cited papers received a total of 22170 citations, averaging to 175.95 citations per paper.

Conclusion - The USA and China lead the global ranking in ANN research. India is the third most productive country in the world. Besides, India registered a fast 25% growth in its national output in the subject. India's AAN research pursuits were multidisciplinary and exploratory in nature, aimed at developing innovative technologies, new ANN applications, and ANN types. The top 25 research organizations in the country contributed high-quality ANN research as their h-index

have been consistently above the national average citations per paper. Indian Institutes of Technology at Kharagpur, Roorkee, and Anna University, Madras provided leadership in ANN research in the country. Computer science and engineering science were the most preferred areas in AAN research pursuits. But to reach the top position in the world ranking India will have to immensely improve its research productivity and also improve its research quality and impact.

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