Evaluating the research performance of women scientists in Indian research laboratories based on Scopus citation database: A bibliometric analysis

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ABSTRACT

This study examines the contributions of women scientists currently working in various research organizations under the Ministry of Science and Technology, India. Women scientists were identified through the official websites of the research laboratories and their publication performance has been tracked using the Scopus database. There are 901 women scientists working in 78 research organizations under the Ministry and have published 21810 publications up to December 2019, almost 65 percent of which has been appeared during 2010 to 2019. The publication per scientist has risen from 6.85 article per year before 2000 to 10.45 paper in 2015-2019 which indicates increasing participation of women in science from India. Women scientists are primarily engaged in biological sciencesresearch, however fields such as materials sciences, nano-technology, and astrophysics are also becoming the preferred subject choices among women. Women scientists mostly published their articles as a member of a team of utmost 10 authors, however, their position in multi-authored articles is mostly as co-authors than that of principal authors. Women in the age group ofbetween31 to 40 produced maximum publications, and almost 98 percent of publications appeared in collaboration with other scientists.This study confirms that publication productivity does not decline with age. There are women scientists who stay active in research and keep their productivity at a high level until their retirement. The study suggests that the increasing participation of women in Indian science is encouraging, as such more funding opportunities to younger women researchers may be important to give them more lead time to build a strong career.

Keywords: Female researchers; Women in science; Scientometric assessment; Research evaluation; Publication productivity.

INTRODUCTION

During the last few decades, the participation of Indian women in most fields including the field of sciences is somewhat dismal. According to the All India Survey of Higher Education (AISHE) 2018-19, of the total women enrolled in the graduate studies, less than 0.5 percent pursued their doctoral degrees (Ministry of Human Resource Development (MHRD) 2019). The women manpower engaged in research and development (R&D) sectors of Indian science and technology (S&T) is only 15 percent (Garg and Kumar 2014). Considering the need of gender advancement in scientific fields at the institutional level, the government has launched various programme to promote gender equity in Science, Technology, Engineering, Mathematics and Medicine (STEMM).

The Ministry of Science and Technology, of the Government of India was established in 1971 with the aim to formulate science policy and to promote science and technological activities in India. The Ministry currently has three major departments including the Council of Scientific and Industrial Research (CSIR), the Department of Biotechnology (DBT) and the Department of Science and Technology (DST). At present, 44 research performing organizations are functioning under CSIR, 19 under DST, and 15 under DBT. The areas of specialization of these organizations range in different branches of S&T. While organizations working under the purview of CSIR mainly specialize in the domains of physical, chemical and engineering sciences including building, road, mining, drug, leather, chemical technology researches, the organizations working under DBT specialized in biological science including cell biology, immunology, biotechnology, regenerative medicine, and biomedical genomics. The organizations under DST mainly specialize in earth sciences, astrophysics, geomagnetism, cultivation sciences, nano-sciences, and medical sciences. Despite 2896 positions lying vacant in 2019[a], presently almost 4310 men and women scientists in India (designated as Scientist-B to Scientist-G) are working under various research performing organizations under the Ministry. Despite the increase in the proportions of women in science and engineering occupations over the past few years (Gupta and Sharma 2002), the extent of their contribution to system of science is yet to unfold. Godbole and Ramaswamy (2015) in *'Lilavati's Daughters: The Women Scientists of India'* wrote brief biographical and autobiographical sketches of about one hundred women scientists from India, however, it is believed that a larger segment of Indian women scientists has remained underrepresented.

To define scientific population, Xie (1989) applied three criteria: (a) contribution to scientific knowledge (contribution-based definition); (b) scientific education (supply-based definition); and (c) scientific occupation (demand-based definition). On the other hand, CSIR in 1973 defined scientific positions as those where the incumbents are expected to contribute by doing research and/or development of new methods or knowledge and/or new techniques (Council of Scientific & Industrial Research (CSIR) 2017). Quantity and quality publications, and citation impact have been and are still considered the main mission of the scientific community, after the 1990s, however, under the third criterion, the scientists are expected to participate in patenting activities along with other two criteria (Göktepe-Hulten and Mahagaonkar 2010). In the light of these, this paper has considered ‘scientists’ as those who meet the first criterion i.e. contribution to scientific knowledge as mentioned by Xi (1989) and as per the recommendation of CSIR.

LITERATURE REVIEW

Either nationally or globally, the contributions of women scientists have been measured in different dimensions including gender gap in scientific output (see for example Kretschmer and Kretschmer 2013; Lewison and Markusova 2011), the comparative contribution of women of different countries as well as different subject fields (see for example Muñoz-Muñoz 2005; Nourmohammadi and Hodaei 2014). Several studies on gender have shown

[a]https://www.newindianexpress.com/nation/2019/jul/13/2896-scientist-posts-lying-vacant-in-70-institutes-under-ministry-of-science-and-technology-govern-2003071.html

that women scientists tend to publish fewer articles than their male colleagues of the same age (Abramo and D'Angelo 2009; Duch et al. 2012; Kwiek and Roszka 2022; Bird 2011; Zuckerman 1991), publish papers in less reputed journals (Holman, Stuart-Fox and Hauser 2018; Lerback and Hanson 2017; Lerchenmüller, Lerchenmueller and Sorenson 2018) and received fewer citations (Caplar, Tacchella and Birrer 2016; King et al. 2017; Larivière et al. 2013). An explanation of low contribution by women has been pointed out by Ward and Grant (1996), where they mentioned that the female scientists devote more time to teaching and administrative work, while the male scientists focus more on the research and supervision of doctoral students. In a study by Husemann, et al. (2017), it was observed that the female scientists suffer more on "publicationism"- an index of stress arising from the pressure to publish(their publicationism score = 2.577), than their male counterparts (score=2.364) and further found that publicationism decreased with the increase of age (a drop of 0.19 index points).

While the overall women participation in higher education has been growing around the world in the past decades, studies have tried to explain the career-choices of women in terms of people-related and thing-related by explaining women underrepresentation in mathematically intensive areas (Holman, Stuart-Fox and Hauser 2018), and over-representation in life sciences (Su, Rounds and Armstrong 2009) but are unable to explain why their attendance is low in subjects such as medicine, surgery, and dentistry (Su and Rounds 2015). Subjects such as computer sciences, engineering, and physics may have been avoided by women because of male-dominance in these disciplines, which make them unattractive for women (Britton 2017). In the context of women as authors in scientific literature, Bendels et al. (2018) found the proportion of female authorship was 35.3 percent for *Life sciences*, 30.6 percent for *Multidisciplinary,* 24.0 percent for *Earth & Environmental Sciences,* and 23.2 percent for *Chemistry* out of a total of 293,557 articles published in 54 journals indexed in Nature Index.

To show how the age and the scientific position are related to research productivity, Over (1988) observes that younger researchers are more productive than older ones. Even, the Dutch social scientists found that young female researchers outperformed young male researchers in terms of the number of publications (van Arensbergen, van der Weijden and van den Besselaar 2012) whereas Kyvik (1990) points out that the researchers with more recognition keep publishing more frequently even after their less-recognised colleagues reach their peak. Barjak (2006) observes that the average production of publications increases with the age and reaches the peak at some point during the career and then declines (Costas and Bordons 2011; Rørstad and Aksnes 2015).

Scientific collaboration has become the rule and no longer an exception (Kartz and Martin 1997); the predominant factors that encourage authors to collaborate are that works carried out in collaboration have more potential towards getting more visibility and impact (Uzzi and Spiro 2005). However, collaboration also has some problem, the position of each author's name need to be determined earlier. Up to now, there has been no established norm available to determine the role of an author in any scientific article by looking at his or her authorship position in the article. The better-known norms by the International Committee of Medical Journal Editors Group (2007) ask authors to mention the role or contribution of the author in the article rather than the order of authorship. Nevertheless, the existing literature shows that the principal author appears either in the first or the last place, consequently, these positions are considered to have more value in the list of authors (Riesenberg and Lundberg 1990). After a slightly deeper analysis, some suggest that the last position is usually occupied by a researcher with a good background or by the director/head of the research group (Bhandari et al. 2014; Tscharntke et al. 2007). However, in some fields such as high energy physics, where there are often over a hundred authors on a research paper, the alphabetical order is the accepted norm.

OBJECTIVE AND METHOD

The persistent gender gap in the STEMM fields over the last 70 years has been widely discussed and has posited myriad reasons for that. The intention of this study however is not to test whether gender inequality in Indian science exists or not, but to assess the contributions of women scientists exclusively. The government of India during the last few years has taken several initiatives to provide strong support to women scientists working in various academic as well as R&D organizations, by introducing various women scientist schemes/programmes[b]. How much such initiatives have translated into actual overall growth in science, is important to understand. The scientific productivity and collaboration at the national or institutional level is an important issue for policymakers in science and higher education to decide sanction of research grants. It also holds an important key to achieve future success in the science system.

This paper has therefore, primarily taken up the research productivity issue focusing on the women scientists working in various research organizations and to understand whether the issue of the underrepresentation of women scientists reported again and again still persists across different types of organizations under the Ministry or whether signs of change towards their greater contribution can be detected. The specific research questions posed are as follows:

(a) Whether the contribution of Indian women working in research organizations has increased in terms of publication, patents and awards over the year and if so whether the subject of research has gained any new dimension?
(b) In what ways have women contributed more, and to what extent do they collaborate?
(c) Does publication of working women increase or decrease with the increase of age and position?

To identify the name of women scientists, the official websites of various research organizations under CSIR, DST and DBT were visited. Each author's gender was confirmed by inspecting available photographs on the author's institutional website, or through an Internet search if necessary. In case a photo was unavailable, the given name of the scientist was considered. In general the given name of an Indian woman mostly ends with the letter like 'a'[Amit vs Amita, Anil Vs Anila], 'ee'[Kiranmay vs Kiranmayee] or 'i'[Parmeshwar vs Parmeshwari]. After deciding the gender, necessary information such as designation, date of birth, position served over time, patents filled and granted, awards and achievements received, were noted from the official websites. In case the required information was incomplete, various official sources, such as Annual Report and Fact-file, as well as academic social networking sites (such as ResearchGate, Academia.edu and LinkedIn) were consulted. By using these means, if the required information remained incomplete, an online questionnaire was sent, followed by personal visits to their research organizations. A few scientists whose required information was unavailable in spite of using all these means were assigned as 'Unidentified'. As of March 2020, there is a total of 902 women scientists under the Ministry of Science and Technology, the Government of India, who are working in permanent position (junior scientists and upward). They

[b]see https://dst.gov.in/scientific-programmes/scientific-engineering-research/ women- scientists-programs or https://indiabioscience.org/media/articles/Spoorthi_Grants_v1.pdf

comprised 618 women scientists in 44 CSIR organizations, 178 scientists in 19 DST organizations and 106 scientists in 15 DBT organizations. These numbers exclude Ph.D. scholars, ad-hoc scientists, and guest faculty-cum-scientists, who have not been considered for the present study. The male-female ratio of these organizations is 84:16 for CSIR, 77:23 for DST, and 70:30 for DBT. It has been observed that overall CSIR has a large number of women scientists per organization (14 women scientists/organization) as compared to DST & DBT, both have 7 women scientists/organization respectively. However, the percentage of the women scientists as compared to the male scientists is higher in the DBT organizations, followed by DST.

To identify their publications, all identified scientists' name along with their organization presently they serve was searched through 'Author Search' tab in the Elsevier's Scopus database. The complete surname along with the full first name were used in the search. In case where the full first name was unavailable, the abbreviated first name or few letters (initials) of the first name along with wild characters were used. The search results were manually verified to confirm that each result is the correct representation of the scientists identified in this study. In case of any doubt about scientists having the same surname with the same abbreviated first name (eg. Khare, P. for Puja Khare and Priyanka Khare) the author-ID of Scopus was used to gain higher precision. The publication data was searched in the last two weeks of March 2020, however, only publications up to December 2019 were considered. The publication data of individual scientists were exported in .csv format for analysis.

To explain the characteristics of data, simple descriptive statistics were used. One of the most critical consideration of this study was to group research output in a set of sub-fields. To address this, the revised Fields of Science & Technology (FOS), classification in the Frascati Manual of OECD (2007) was adopted. The authorship, on the other hand, was determined by analysing the position of the sampled scientists in this study. To know how many publications a scientist produced at different age, the data pertaining to publication year of an article was adjusted with the year of birth and the year the scientist joined the organization. Therefore, the publication output per scientist per year was used as a measure (instead of the total number of publication).

To gauge the extent of collaboration a scientist made during her tenure, the residue analysis method (method of eliminating alternative potentials causes on the basis of previous known fact) was followed. As the publications of the scientist were searched by author's name, it was ascertained that in each article obtained there were at least one scientist who belonged to the sample (source author). Therefore, in the 'Authors with Affiliation' field of a multi-authored article, the country of institution for other authors (target author) was checked against this study's source authors. If the affiliation of any target author of a multi-authored article was located in an institution outside India, it is considered as 'global collaboration'. Likewise, if the affiliation of any target author was from a university, college or academia, it is marked as 'academy-Industry collaboration'.

This study also moved forward to know the other types of collaboration. As every downloaded article in Scopus contains EID (Unique Academic Work Identifier) tag, the common EID between all articles of scientists of the same organization was searched. If duplicate EIDs were found for the same articles under two different women scientists' name (source author), it implies that the articles were written jointly by those two authors from the sampled organizations (between women of same organization). Articles having unique EID was further used to understand whether the collaboration is between the authors of same organizations or different organizations. The 'affiliation' tag of Scopus results mentioned the organization name only once when all authors of the article belonged to the same organization. If the affiliation tag contains names of more than one institution, it means that the article has been written by authors of other organizations instead of with authors of same organization.

RESULTS

Contribution of Women Scientists in Terms of Publications, Patents and Awards

In the Scopus database up to December 2019, it was found that a total of 21810 publications were contributed by all 902 women scientists in this study, on an average of 24 publications per scientist. Eighty-five scientists from CSIR, 18 from DST, and 7 from DBT do not have any publications that are indexed by Scopus. Of the total publications, 86 percent of publications appeared as journal articles, followed by 6 percent as conference proceedings, 2 percent as book articles or chapters in books, and the remaining 6 percent publications appeared as reviews, short surveys, retracted articles, notes, letters, editorials and data papers. For the purpose of the present study, only the publications that appeared as articles, conference proceedings, and book & book chapters were considered for further analysis. The total number of such publications was 20366. The term publications and/or articles are used throughout this paper when referring to these four types of documents.

The increasing participation of Indian women in scientific research as evident in Table 1 during the 2015-2019 is promising. Before 2000, per scientist publications were 6.26for CSIR, 6.96 for DBT and 7.35 for DST which increased to 10.11 articles for CSIR, 9.61 articles for DBT and 11.63 articles for DST by the end of 2019. There was a continuous growth of per scientist publication in respect of previous years however the reason for decline from 2000 to 2004 is unknown. Irrespective of organizations, almost 65 percent of papers published during 2010 to 2019 indicates increasing participation of women in science in concurrent years.

Table 1: Research Output of Indian Women Scientists

Year	CSIR (n=13015)				DBT (n=2341)				DST (n-5010)			
	TP (%TP)	NS (PS*)	NP (NS)	AW	TP (%TP)	NS (PS)	NP	AW	TP (%TP)	NS (PS)	NP	AW
Before 2000	833 (6.40)	133 (6.26)	16 (8)	19	174 (7.43)	25 (6.96)	5 (3)	9	338 (6.75)	46 (7.35)	9 (3)	8
2000-2004	994 (7.64)	216 (4.60)	45 (24)	32	235 (10.04)	48 (4.90)	9 (6)	12	492 (9.82)	74 (6.65)	17 (6)	11
2005-2009	2253 (17.31)	350 (6.44)	109 (39)	17	359 (15.34)	71 (5.06)	15 (10)	13	969 (19.34)	107 (9.06)	34 (11)	14
2010-2014	3880 (29.81)	458 (8.47)	122 (50)	34	727 (31.06)	85 (8.55)	31 (12)	16	1478 (29.50)	140 (10.56)	62 (20)	13
2015-2019	5055 (38.84)	500 (10.11)	262 (106)	51	846 (36.14)	88 (9.61)	28 (13)	16	1733 (34.59)	149 (11.63)	58 (14)	12

TP= Total Publications, %TP= Percentage of the total, NS=No. of Scientists involved, PS= Per Scientist Publications NP= Number of Patents, AW: No. of Scientists received Awards (No. of Awards), n= number.

* Per scientist publication is based on publications equivalent per person per year of currently working scientists. Non-publication scientists have been excluded here.

To explain the growth pattern, three growth models, i.e. linear, logarithmic, and exponential, were tested on the data. Although all three regression models were statistically significant and captured a high proportion of explained variance, the proportion of variance is explained greater in the exponential model (R^2= 0.9488) than in the linear (0.7277) or in the logarithmic (0.3998), thus showing that the exponential model provides the best-fit model to the observed data. However, the decline in the growth of overall women scientists in these laboratories is alarming. This may be because of a considerable number of scientists are superannuating every year, and new scientists are not being appointed on regular basis. As a result, a number of positions remain vacant.

Consistent with the observations of the other studies, it was observed in the present study that a small group of prolific women authors contributed to a significant share of publications for their organizations. For example, 61 CSIR women scientists (10%) contributed 39.40 percent of publications, while 11 DBT women scientists (10%) contributed 34.27 percent and 17 DST women scientists (10%) contributed 35.95 percent of publications. In contrast, it was observed that 117 (18 %) of the total 618 authors from CSIR, 14 (13%) of the total 105 authors from DBT and 17 (10%) of the total 169 authors from DST contributed less than five publications.

Although on average per scientist publication was the highest in DST (9.05 publications) followed by CSIR (7.17publications) and DBT (7.06 publications), it was observed that the Pearson correlation, between the number of scientist and number of patents was almost equal in CSIR (0.97398), DST (0.964431) and DBT (0.920178).On the other hand, per scientist award was higher among DBT women scientists (0.55 awards) than DST (0.37 awards) and CSIR (0.24 awards). There are six women scientists from DBT who are the recipients of the prestigious National Bio-Science Award - two received NASI-Reliance Award, and three scientists bagged Infosys award in Life Sciences for their seminal contribution to biological sciences. One scientist from CSIR is the recipient of Santi Swarup Bhatnagar extent of collaboration and five scientists are the recipient of the National Geoscience Award of the Government of India. In India, these prestigious awards are conferred upon those who have made outstanding contribution, scientific breakthroughs and developed deeper understanding in science.

Major Research Areas of Indian Women Scientists

Table 2 shows the major research areas where Indian women scientists made maximum contribution. The prominent research area among CSIR women scientists is Engineering & Technology (2596 or 20% publications) where almost 158 women scientists in 17 laboratories are carrying out their research. This is followed by fields related to biological sciences (1952 or 15% publications) where 80 women scientists are working in 20 laboratories. The prominent research area of DBT is medical and allied health sciences (1178 or 50% publications) where 47 women scientists are working in 8 laboratories. This is followed by biological sciences (1015 or 43% publications) where 50 scientists are working in 11 laboratories. On the other hand, the prominent research areas of DST are materials science and nano-technology (1174 publications, by 27 women scientists from 6 institutions) followed by physical sciences (1140 publications by 25 women scientists from 4 institutions). Overall, 94 percent women scientists from DBT, and 35 percent scientists from CSIR and DST respectively are engaged in research in biological science. Several studies have shown that life sciences and its related disciplines are the preferred choices of subject among women (e.g. Adamo 2013). Other than biological sciences, engineering and technology is the most preferred area of research among CSIR women scientists and materials sciences, earth sciences, nano-technology, and astrophysics are other subject areas where most of women scientists from DST are engaged in.

Table 2: Research Areas of Indian Women Scientists

Broad Area of Research	CSIR			DBT			DST		
	NL	NS	NA	NL	NS	NA	NL	NS	NA
Biological Sciences & Allied	20	80	1952	11	50	1015	5	18	845
Biotechnology (including food, agricultural and industrial biotechnology)	19	83	1986	4	8	150	4	17	489
Medical & Allied Health Sciences	12	52	1633	8	47	1178	5	40	718
Chemical Sciences & Allied	18	68	1744	-	-	-	4	9	361
Physical Sciences & Allied (including astronomy & astrophysics)	7	39	941	-	-	-	4	25	1140
Earth Sciences & Allied	6	55	926	1	1	0	4	34	643
Materials Science & Nanotechnology	10	47	1059	-	-	-	6	27	1174
Engineering & Technology	17	158	2596	-	-	-	-	-	-
Computer Science & Allied	9	22	348	-	-	-	-	-	-
Others	4	14	16	-	-	-	2	8	17

NL= No. of Laboratories, NS= No. of Scientists, NA= No. of Articles

Authorship Pattern of Women Scientists

The authorship pattern as indicated in Table 3 clearly shows that women authors in these three research organizations prefer to work in collaboration and as a member in a team consisting of three to ten authors. The percentage of articles under solo authorship is only 1.26 percent for CSIR; 1.19 percent for DBT and 2.39 percent for DST. Irrespective of any authorship line up, women authors from CSIR, DBT and DST represent a low percentage, the series that obtained the highest value is that of the last position; a maximum 39 percent for DST, followed 20 percent for CSIR and 24 percent for DBT. On the contrary, the first orcorresponding author position, in which the highest values are presented, is a maximum 30 percent for DST, followed by 26 percent for CSIR and 21 percent for DBT.

Table 3:Authorship Pattern in Research Publications

Authorship	CSIR, n=13015 (%)	DBT, n=2341 (%)	DST, n=5010 (%)
Single Authored paper	165 (1.26)	28 (1.19)	120 (2.39)
Two-Authored paper	1521 (11.68)	214 (9.14)	844 (16.84)
As First or Corresponding Author	631 (4.84)	89 (3.80)	347(6.92)
As Last Author	67 (0.51)	108 (4.61)	517(10.31)
Multi Authored paper (>2 &<= 10)	10818 (83.11)	1772 (75.69)	3807 (75.98)
As First or Corresponding Author	2692 (20.68)	364(15.54)	1132(22.59)
As Last Author	2671 (20.52)	451 (19.26)	1401(27.96)
Mega Authored paper (>10)	511 (3.92)	328 (14.01)	239 (4.77)
As First or Corresponding Author	46 (0.35)	33 (1.40)	37 (0.73)
Last Authored paper	78 (0.59)	22 (0.93)	57(1.13)

n= Number of articles

In spite of the scarce values in terms of percentage of articles under various authors' position as shown Table 3, the value shows that the role of women in research team changes to that of a leader and they tend to sign more as the last author and less often as the first author. If we bear in mind that the first-position authors are generally held to have made the greatest contribution to the research (Clement 2014), the last position typically represents some one the most senior, predominantly in the supervisory role (Costas and Bordons 2011) or one who usually leads a team, thus showing that women scientists are occupying more significant position in scientific researches in India. The reason behind the increasing volume of work under last authorship among the DST scientists is that there are at least 12 organizations under DST where almost 78 scientists have their own research laboratory wherein they are working as the head or leader of a research group or similar group. They have developed their specialized laboratory where a number of junior scientists and scholars are working under them and a considerable number of research projects are coming out from such research groups. This kind of culture is not so much prevalent in DBT and in CSIR, reflecting that there is more predominance of men in these two research organizations.

Collaboration Patterns

From Table 3, it is clear that women mostly contribute to publications through collaboration with others. Attempts have also been made to understand the collaboration patterns. The increasing specialization in science makes it more difficult to become an expert in all related domains, insisting/requiring more collaboration among scientists who share common interest. Table 4 presents the percentage of publications the women scientists have made as joint authors at five different levels, reflecting their collaboration patterns.

Table 4: Collaboration Patterns among Indian Women Scientists

Laboratory	Between women of same organization	Others in same organization	Other authors of other organizations	Academy-industry	Global
CSIR (n=12850)	680 (5.29)	4237 (32.97)	2374 (18.47)	3516 (27.36)	2043 (15.89)
DBT (n=2313)	169 (7.30)	347 (15.00)	278 (12.01)	593 (25.63)	927 (40.07)
DST (n=4890)	85 (1.73)	1477 (30.20)	1025 (20.96)	943 (19.28)	1360 (27.81)

Note: Publications showing here are publications by joint authors only, therefore value of n (number) is less here than in Table 3.
* Industry-Industry means collaboration between scientists of the Ministry of Science and Technology with the scientists from other Ministries.

The distribution in Table 4shows that collaboration between women scientists of the same organization is a maximum of 7 percent (column 2), collaboration with the scientists of other organizations is a maximum of 21 percent (column 4), irrespective of the fact that the collaborator belonged to the different organizations of the Ministry. However, it has been observed that CSIR scientists collaborated more (33%) with the scientists from their own organizations followed by scientists working in the academic institutions (27%). Whereas, DBT scientists collaborated more with authors from other countries (40%), followed by scientists in the academic institutions (26%). On the other hand, DST scientists collaborated more with authors of the same organization (30%) which is closely followed by collaboration with international authors (28%). The plausible reason behind the increasing percentage of publications under global collaboration among the women scientists of DBT and DST is that at least 55 percent and 35 percent of scientists from DBT and DST respectively have completed their post doctorate or doctorate degrees from some foreign universities. Therefore, they have established global link during their research programme with their research groups, of which they are still maintaining ties. Overall, the global collaboration is still less and it may be due to cultural and political boundaries, however much more is expected for the betterment of the system of science.

Age Dynamics in Scientific Contribution

At what age do women scientists tend to publish productively? Attempts are made to link scientist age with scientific productivity. Some empirical studies like Simonton's (1984) model of creativity suggest that individuals have an initial 'creative potential' that decreases over time. Kuhn (1962) also suggested that young researchers have a fresh look at scientific problems and are more likely to cause scientific revolution. In Table 5, the publication patterns are presented according to the chronological age of the scientists as well as their service age i.e. number of years spent in the research organizations. The sum of scientists as mentioned in column 'N' of CSIR, DBT and DST might exceed the total number mentioned earlier in this study, because the total publications of each individual scientist have been adjusted with respect to their age group. Therefore, the occurrence of a scientist's name may appear more than once if the scientist has publications in different service and physical age group.

Table 5: Contributions by Women Scientists at Choronological Age and Different Service Age

	CSIR (%)			DBT (%)			DST (%)		
Service age	**N (%W)**	**TP (%T)**	**PS**	**N (%W)**	**TP (%T)**	**PS**	**N (%W)**	**TP (%T)**	**PS**
Publications before joining current organization	323 (52.27)	2317 (17.80)	7.17	83 (78.30)	957 (36.61)	10.33	124 (69.66)	1158 (23.11)	9.34
Publications after joining	520 (84.14)	10698 (82.20)	20.57	94 (88.68)	1384 (63.39)	15.79	164 (92.13)	3852 (76.89)	23.49
Publications within 5 years of joining	444 (71.84)	3042 (28.44)	6.85	88 (83.02)	581 (39.15)	6.60	140 (78.65)	1245 (32.32)	8.89
Publications during 6-10 years of joining	379 (61.33)	3118 (29.15)	8.23	60 (56.60)	448 (30.19)	7.47	114 (64.04)	1027 (26.66)	9.01
Publications during 11-15 years of joining	270 (43.69)	1994 (18.64)	7.39	33 (31.13)	236 (19.27)	8.67	66 (37.08)	459 (11.92)	6.95
Publications after 15 years of joining	169 (27.35)	2544 (23.78)	15.05	19 (17.92)	119 (11.39)	8.89	45 (25.28)	1121 (29.10)	24.91
Physical age									
Publications up to 30 years of age	335 (54.21)	1939 (14.90)	5.79	64 (60.38)	216 (9.23)	3.38	97 (54.49)	568 (11.34)	5.86
Publications between 31-40 years of age	475 (76.86)	5102 (39.20)	10.74	90 (84.91)	939 (40.11)	10.43	135 (75.84)	1834 (36.61)	13.59
Publications between 41-50 years of age	331 (53.56)	4352 (33.44)	13.15	64 (60.38)	778 (33.23)	12.16	95 (53.37)	1491 (29.76)	15.69
Publications more than 50 years of age	132 (21.36)	1622 (12.46)	12.29	21 (19.81)	408 (17.43)	19.43	59 (33.15)	1117 (22.30)	18.93

Note: Date of Birth Unidentified: 9 women scientists from CSIR, 1 women scientists from DBT, 4 women scientists from DST. Date of joining for 8 women scientists from CSIR is unknown.
N= Number of women scientists, %W=Percentage of women scientist, TP=Total Publication, %T=Percentage of the total publications, PS=Publication/Scientist

As indicated in Table 5, the women scientists contribute most articles during their first ten years of service and in terms of chronological age, between the ages of 31 to 40. Their contribution becomes less subsequently with the increase of their age. Obviously, publication output per scientist was higher when they reached the age of 50 or were more than 50 years of age. At the institutional level, it was observed that CSIR scientists produced more during their six to ten years of joining the Council (29%), while for DBT andDST scientists they produced more during the first five years (39% and 32%, respectively). On the other hand, it was observed that irrespective of the three organizations, the scientists produced the most during between the age of 31 to 40 years. Almost 37 to 40 percent of their total scientific productivity came at this age duration. The Pearson Correlation between age and publications is 0.39972 for CSIR, 0.37372 for DST, and 0.4659 for DBT, indicating that both age and publication move in the same direction. The findings are in association with earlier findings (Simonton 2003) where it was proposed that, that being creatively productive is a complex mixture of a person (including personality characteristics, intelligence, skill and age) and process (including field expertise and scientific constraints) variable that can put a scientist in 'right place at right time' to make an important contribution. No single factor is sufficient to explain research productivity.

DISCUSSION

With regard to the publication productivity of the women scientists, although the overall results showed that female researchers tend to publish fewer publications, however results also showed a significant increase and interest in their respective fields over the last few decades, particularly from 2005 onwards, when a steady increase is discerned. The publication productivity shows an exponential growth. When compared by organizations, women scientists from DST have produced slightly more articles (9.05 publications per scientist) compared to those from CSIR and DBT (7 publications per scientist).Only 18 percent of the women scientists from CSIR have produced 50 percent of total publications; whereas the same amount of publication has been produced by almost 15 percent of scientists from both DST and DBT. Furthermore, a considerable number of patents, although it is as low as 0.9 patents per scientist, are granted under the credit of CSIR women scientists. It was also observed that a number of women scientists from DBT are the recipients of the various prestigious awards of the Government of India. These awards are conferred upon those who have made outstanding contribution to science. All these may be promising indicators related to the increased participation of women in science. A much earlier study has shown a positive relationship between a scientific publication and patenting activities (Agrawal and Henderson 2002), and one should keep in mind that publication and patenting are complementary and not competing activities of researchers (Jensen and Murray 2005). Siegel, Waldman and Link (2003) in this regard, showed that organizational factors, particularly scientist's reward systems and compensation, influence scientists' productivity of technology transfer activities and thus motivate the scientists to disclose their inventions.

The study shows that the proportion of women scientific authors is relatively high in disciplines such as biological sciences, medical sciences, and biotechnology. However, their involvement in subjects such as materials science, nano-technology and physical sciences indicate diversification and specialization of women in different disciplines and women have shown their interest in these fields too. As their participation in these subjects is still unbalanced, funding from the government to the early career women researchers, is quite important for increasing the contribution to these newly emerging fields.

With regard to the number of authors, a larger number (almost 98%) of articles were collaborative, however, the women scientists' position in multi-authored articles is mostly as a member of the team than that of a leader. This recalls the observation "the women are more collaborative and less competitive than men in decision making, making them potentially better collaborators" (Bart and McQueen 2013, p. 97). In general, the sampled women scientists in this study have shown a higher tendency to occupy the last authorship position than first position. Women served as a leader in the group of multi-authored papers only in the maximum of 40 percent publications, and as first author only in 30 percent of publications. These findings reflecting that women still lag behind in directing works maybe due to their familial and social obligations which place indirect constraints on women, or permit them less time and involvement.

The increase in the number of collaborative publications have not been accompanied by greater international collaboration, except for the women scientists from DBT (about 40%); those from the other two organizations have collaborated not more than 28 percent with international organizations. Theircollaboration patterns are mostly intra-institutional or with 'academic-industry' and their collaboration with the peers within their own organizations are negligible.

As far as publication in terms of age dynamics, it was observed that women scientists mostly published their articles either during the first five years of their joining or in the following five years. Almost 60 percent of their publications came out in the first ten years of service and the remaining 40 percent during their remaining service tenure. When it comes to the publications pattern at different ages, it was observed that the age-period of 31 to 40 is the most productive period for Indian women scientists working in research laboratories. Almost 75 to 80 percent of the total scientists contributed during this age-period. This may be because they strive to be promoted to a senior position, and one needs a longer publication list to justify the promotion. This findingscorroborate the view that 'the young female researchers are more productive than the older' (Stroebe 2010, p. 671). However, it is a reasonable expection that a scientist in a senior position is more likely to have better ability to conduct research and publish, and often they have leadership roles in the research process and involved in a number of research projects. To confirm whether publication rate increases or declines with time, it was observed that there are almost 20 percent scientists from CSIR and DST, and 33 percent from DBT whose publication rate does not decline on attaining age 50 years or more. They have contributed almost 18 to 19 publications each. This means that as a general finding of this study, publication productivity does not decline with age. There are women scientists who stay active in research and keep their productivity at a high level until their retirement. This study therefore supports the notion that 'a scientist in a senior position is more likely to have a better ability to do research and write articles and the juniors are less experienced as researchers because knowledge is cumulative' (Tien and Blackburn 1996, p. 18).

The study is limited to only women scientists presently working in various research organizations under the Ministry of Science & Technology, therefore women who did not hold any scientific post throughout entire observation period (i.e. 2018 to 2019) were not included in the dataset, eliminating all those who had superannuated before 2018 but the study included those who retired during 2019. The women scientists who changed research sector for whatever reasons during the period of observation were also excluded. The present analysis is based on the publication output obtained from the Scopus database. The sum of publications realized by the women scientists by the end of 2019 were taken into consideration.

CONCLUSIONS

The reliance on bibliometric indicators for research assessment and performance-based funding of research is rising worldwide. The results of this study suggest an upward trend in both the number of papers and the number of women scientists in organizations.

However, this increase was not accompanied by the increase at a similar rate in earlier years. The data showed a high dispersion of the literature with a small set of core authors engaged in research. The research area with the highest frequency of paper was in biological sciences, however, there is a significant increase in the number of research areas over the years. Furthermore, the fact that women have subject-specific interest in research, suggest strengthening of other fields for the overall improvement in the science system. Science is a collaborative endeavour, therefore, there is a need for more global collaboration and the government may extend funds for developing specialized laboratories to increase women contribution in science. The age and the productivity issue suggest that older researchers' effective role in the production of high quality papers cannot be neglected. Moreover, if the turning points age of 31 to 40 are relatively stable in a truly longitudinal sense, then providing better funding opportunity to young researchers would give them more lead time to build strong career. The results of the present study may help us to understand the priorities for future interventions and suggest the need for effective investments to increase the participation of women in the science system of India.

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REFERENCES

Abramo, G., D'Angelo, C. and Caprasecca, A. 2009. Gender differences in research productivity: A bibliometric analysis of the Italian academic system. *Scientometrics*, Vol.79, no.3: 517-539

Adamo, S.A. 2013. Attrition of women in the biological sciences: workload, motherhood, and other explanations revisited. *BioScience*, Vol. 63, no. 1: 43-48. Available at: doi: 10.1525/bio.2013.63.1.9.

Agrawal, A. and Henderson, R. 2002. Putting patents in context: exploring knowledge transfer from MIT. *Management Science*, Vol. 48, no. 1: 44-60. Available at: doi: 10.1287/mnsc.48.1.44.14279.

Barjak, F. 2006. Research productivity in the internet era. *Scientometrics*, Vol. 68, no. 3: 343-360. Available at: doi: 10.1007/s11192-006-0116-y.

Bart, C. and McQueen, G. 2013. Why women make better directors. *International Journal of Business Governance and Ethics*, Vol. 8, no. 1: 93–99. Available at: doi: 10.1504/IJBGE.2013.052743.

Bendels, M.H.K.; Bauer, J.; Schöffel, N. and Groneberg, D.A. 2018.The gender gap in schizophrenia research.*Schizophrenia Research*, Vol. 193: 445-446. Available at: doi: 10.1016/j.schres.2017.06.019.

Bhandari, M., Guyatt, G.H., Kulkarni, A.V., Devereaux, P.J., Leece, P., Bajammal, S., Heels-Ansdell, D. and Busse, J.W. 2014. Perceptions of authors' contributions are influenced by both byline order and designation of corresponding author. *Journal of Clinical Epidemiology*, Vol. 67, no. 9: 1049-1054. Available at: doi: 10.1016/j.jclinepi.2014.04.006.

Bird, K.S. 2011. Do women publish fewer journal articles than men? Sex differences in publication productivity in the social sciences. *British Journal of Sociology of Education*, Vol.32, no.6: 921-937.10.1080/01425692.2011.596387

Britton, D.M. 2017. Beyond the chilly climate: the salience of gender in women's academic careers. *Gender & Society*, Vol. 31, no. 1: 5-27. Available at: doi: 10.1177/0891243216681494.

Caplar, N., Tacchella, S. and Birrer, S. 2016. Quantitative evaluation of gender bias in astronomical publications from citation counts. *Nature Astronomy*, Vol.1, no.6: 1-5.

Clement, T.P. 2014. Authorship matrix: a rational approach to quantify individual contributions and responsibilities in multi-author scientific articles. *Science and Engineering Ethics*, Vol. 20, no. 2: 345-361. Available at: doi: 10.1007/s11948-013-9454-3.

Costas, R. and Bordons, M. 2011. Do age and professional rank influence the order of authorship in scientific publications? Some evidence from a micro-level perspective. *Scientometrics*, Vol. 88, no. 1: 145-161. Available at: doi: 10.1007/s11192-011-0368-z.

Council of Scientific & Industrial Research (CSIR). 2017. *Classification of posts.*Council of Scientific & Industrial Research, Ministry of Science & Technology, Govt. of India. Available at: https://www.csir.res.in/document/classification-posts.

Duch, J., Zeng, X.H.T., Sales-Pardo, M., Radicchi, F., Otis, S., Woodruff, T.K. and Nunes Amaral, L.A. 2012. The possible role of resource requirements and academic career-choice risk on gender differences in publication rate and impact. *PLOS ONE*, Vol.7, no.12.

Garg, K.C. and Kumar, S. 2014. Scientometric profile of Indian scientific output in life sciences with a focus on the contributions of women scientists. *Scientometrics*, Vol. 98, no. 3: 1771–1783. Available at: doi: 10.1007/s11192-013-1107-4.

Godbole, R.M. and Ramaswamy, R. 2015. Women scientists in India.In: Report on Women in Science and Technology in Asia, 1*1th AASSA (Association of Academies and Societies of Sciences in Asia) Regional Workshop on 'Gender issues in science research and education', Gender Summit 6 – Asia Pacific 2015*. Annex India 03:67-84. AASSA: Panmun Education. Available at: https://nassl.org/wp-content/uploads/2016/01/AASSA_Report_Women_in_S_T_in_Asia.pdf.

Göktepe-Hulten, D. and Mahagaonkar, P. 2010. Inventing and patenting activities of scientists: in the expectation of money or reputation? *Journal of Technology Transfer*, Vol. 35: 401–423. Available at: doi: 10.1007/s10961-009-9126-2.

Gupta, N. and Sharma, A.K. 2002.Women academic scientists in India. *Social Studies of Science*, Vol. 32, no. 5-6: 901-915. Available at: doi: 10.1177/030631270203200505.

Holman, L., Stuart-Fox, D. and Hauser, C.E. 2018. The gender gap in science: how long until women are equally represented? *PLOS Biology*, Vol. 16, no. 4: e2004956. Available at: doi: 10.1371/journal.pbio.2004956.

Husemann, M., Rogers, R., Meyer, S. and Habel, J.C. 2017. "Publicationism" and scientists' satisfaction depend on gender, career stage and the wider academic system. *Palgrave Communications*, Vol. 3, no. 1: 17032. Available at: doi: 10.1057/palcomms.2017.32.

International Committee of Medical Journal Editors. 2007. *Uniform requirements for manuscripts submitted to biomedical journals: writing and editing for biomedical publication*. Updated October 2007. Available at: http://www.icmje.org/.

Jensen, K. and Murray, F. 2005. Intellectual property landscape of the human genome. *Science*, Vol. 310, no. 5746: 239-240. Available at: doi: 10.1126/science.1120014.

Kartz, J.S. and Martin, B. 1997. What is research collaboration? Research Policy, Vol. 26, no. 1: 1-18. Available at: doi: 10.1016/S0048-7333(96)00917-1.

King, M.M., Bergstrom, C.T., Correll, S.J., Jacquet, J. and West, J.D. 2017. Men set their own cites high: gender and self-citation across fields and over time. *Socius: Sociological*

Research for a Dynamic World, Vol. 3. Available at: doi:10.1177/2378023117738903.

Kretschmer, H. and Kretschmer, T. 2013. Gender bias and explanation models for the phenomenon of women's discriminations in research careers. *Scientometrics*, Vol. 97, no. 1: 25-36. Available at: doi: 10.1007/s11192-013-1023-7.

Kuhn, T.S. 1962. *The structure of scientific revolutions*, Chicago: The University of Chicago Press.

Kyvik, S. 1990. Age and scientific productivity.Differences between fields of learning. *Higher Education*, Vol. 19, no. 1: 37-55. Available at: doi: 10.1007/BF00142022.

Kwiek, M. and Roszka, W. 2022. Are female scientists less inclined to publish alone? The gender solo research gap. *Scientometrics*, Vol.127, no.4: 1697-1735. https://doi.org/10.1007/s11192-022-04308-7

Larivière, V., Ni, C., Gingras, Y., Cronin, B. and Sugimoto, C. R. 2013. Bibliometrics: global gender disparities in science. *Nature*, Vol.504: 211–213.

Lerback, J., and Hanson, B. 2017. Journals invite too few women to referee. *Nature*, Vol.541, no.7638: 455-457.

Lerchenmüller, C., Lerchenmueller, M.J. and Sorenson, O. 2018. Long-term analysis of sex differences in prestigious authorships in cardiovascular research supported by the National Institutes of Health, *Circulation*, Vol. 137, no. 8: 880-882. Available at: doi: 10.1161/CIRCULATIONAHA.117.032325.

Lewison, G. and Markusova, V. 2011. Female researchers in Russia: have they become more visible? *Scientometrics*, Vol. 89, no. 1: 139–152. Available at: doi: 10.1007/s11192-011-0435-5.

Ministry of Human Resource Development (MHRD). 2019. *All India Survey on Higher Education (AISHE) (2018-2019)*, New Delhi: MHRD, Government of India. Available at: http://aishe.nic.in/aishe/viewDocument.action?documentId=263.

Muñoz-Muñoz, A.M. 2005.The scholarly transition of female academics at the University of Granada (1975-1990).*Scientometrics*, Vol. 64: 325–350. Available at: doi: 10.1007/s11192-005-0254-7.

Nourmohammadi, H. and Hodaei, F. 2014. Perspective of Iranian women's scientific production in high priority fields of science and technology. *Scientometrics*, Vol. 98, no. 2: 1455–1471. Available at: doi: 10.1007/s11192-013-1098-1.

OECD. 2007. *Revised field of science and technology (FOS) classification in the Frascati manual*. Paris: OECD. Available at: https://www.oecd.org/science/inno/38235147.pdf.

Over, R. 1988. Does scholarly impact decline with age? *Scientometrics*, Vol. 13, no. 5-6: 215-223. Available at: doi: 10.1007/BF02019959.

Riesenberg, D. and Lundberg, G.D. 1990. The order of authorship: who's on first? *JAMA*, Vol. 264, no 14: 1857. Available at: doi: 10.1001/jama.1990.03450140079039.

Rørstad, K. and Aksnes, D.W. 2015. Publication rate expressed by age, gender and academic position–A large-scale analysis of Norwegian academic staff. *Journal of Informetrics*, Vol.9, no.2: 317-333. https://doi.org/10.1016/j.joi.2015.02.003.

Siegel, D.S., Waldman, D. and Link, A. 2003.Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study. *Research Policy*, Vol. 32, no. 1: 27-48. Available at: doi: 10.1016/S0048-7333(01)00196-2.

Simonton, D.K. 1984. Creative productivity and age: a mathematical model based on a two-step cognitive process. *Developmental Review*, Vol. 4, no. 1: 77-111. Available at: doi: 10.1016/0273-2297(84)90020-0.

Simonton, D.K. 2003. Scientific creativity as constrained stochastic behavior: the integration of product, person, and process perspectives. *Psychological Bulletin*, Vol. 129, no. 4: 475-494. Available at: doi: 10.1037/0033-2909.129.4.475.

Stroebe, W. 2010. The graying of academia: will it reduce scientific productivity? *American Psychologist*, Vol. 65, no. 7: 660-673. Available at: doi: 10.1037/a0021086.

Su, R. and Rounds, J. 2015. All STEM fields are not created equal: people and things interests explain gender disparities across STEM fields. *Frontiers in Psychology*, Vol. 6: paper 189. Available at: doi: 10.3389/fpsyg.2015.00189.

Su, R., Rounds, J. and Armstrong, P.I. 2009. Men and things, women and people: a meta-analysis of sex differences in interests. *Psychological Bulletin*, Vol. 135, no. 6: 859–884. Available at: doi:10.1037/a0017364.

Tien, F.F. and Blackburn, R.T. 1996. Faculty rank system, research motivation, and faculty research productivity: measure refinement and theory testing. *The Journal of Higher Education*, Vol. 67, no. 1: 2-22. Available at: doi: 10.1080/00221546.1996.11780246.

Tscharntke, T., Hochberg, M.E., Rand, T.A., Resh, V.H. and Krauss, J. 2007.Author sequence and credit for contributions in multiauthored publications. *PLOS Biology*, Vol. 5, no. 1: e18. Available at: doi: 10.1371/journal.pbio.0050018.

Uzzi, B. and Spiro, J. 2005. Collaboration and creativity: the small world problem. *American Journal of Sociology*, Vol. 111, no. 2: 447-504. Available at: doi: 10.1086/432782.

vanArensbergen, P., van der Weijden, I. and van den Besselaar, P. 2012. Gender differences in scientific productivity: a persisting phenomenon? *Scientometrics*, Vol. 93, no. 3: 857-868. Available at: doi: 10.1007/s11192-012-0712-y.

Ward, K.B. and Grant, L. (1996).Gender and academic publishing. In J. C. Smart (Ed.), *Higher education, handbook of theory and research* (Vol. XI), Bronx: Agathon Press.

Xie, Y. 1989. *The process of becoming a scientist*. PhD diss., The University of Wisconsin-Madison.

Zuckerman, H. 1991. The careers of men and women scientists: A review of current research. In: Zuckerman, H., Cole, J. R., & Bruer, J. T., (Eds.). *The outer circle: Women in the scientific community*. 27-56, New York: W W Norton & Co.