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Gender and research publishing analyzed through the lenses of discipline, institution types, impact and international collaboration: a case study from India

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Abstract
Higher participation of women in higher education and research is a very important development goal in many countries across the world, with several countries creating special initiatives and schemes to increase participation of women in higher education and research. This article looks at a case study from India and aims to characterize the participation of women in research, by analysing the parameters of institution-type, discipline, citation impact and international collaboration. Research publication data from 50 most productive Indian institutions, along with data for 5 major institution systems, for a period of 10 years (2008–2017), as indexed in Web of Science, is obtained as sample data and analysed. Results obtained show that participation of women is found to vary in different disciplines, with biology (37%), agriculture science (32%), social science (31%) and medical science (32%) having relatively higher number of female 1st authored papers as compared to engineering (20%), information science (21%) and mathematics (22%). It is also observed that institutions specializing in medical sciences and social science have relatively better participation of women. In terms of location of institution in a big metropolitan city or an urban area, it was found that there do not exist any significant differentiation in levels of participation of women in research between institutions located in bigger cities or smaller towns. Further, analysis of citation and collaboration patterns show that though male authored papers have an edge in citation impact, women researchers get more internationally collaborated papers.

Keywords Gender studies · Gender audit · Research performance · Women in research · Women in science

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Introduction

Higher participation of women in higher education and research is an important development goal in many countries across the world. The 2030 agenda for Sustainable Development[1] by United Nations lists "Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" and "Goal 5. Achieve gender equality and empower all women and girls" as two of the seventeen development goals. Several initiatives and schemes are designed in different countries to increase the participation of women in higher education and research. However, according to UNESCO Institute for Statistics fact sheet 2018,[2] women account for less than 30% of the total researchers across the world.

India habituating 1/5th of the world population, having the third largest higher education and academic research system in the world after USA and China, has taken several initiatives to enhance enrolment of women in higher education and also to promote participation of women in research and development. According to data[3] from University Grants Commission of India, women accounted for about 48% of the total enrolment in higher education institutions in the year 2016–2017. Out of all Ph.D.s awarded in 2015–2016, women account for about 39% degrees awarded. According to a report[4] by Department of Science and Technology of India, as on 2015 there are about 14% women out of total full-time personnel engaged in R&D activities in the country. Similarly, women participation in extramural research projects supported by central and state government funding bodies has been about 29% as in 2014–2015.[5] Government of India has taken several initiatives and created many special programs to promote women's participation in research and development activities (Gupta 2019). However, the participation of women in research remains to be low.

It is often stated that women have more affinity towards certain disciplines (like biological sciences, medicine and social sciences). The paper, therefore, aims to find out if participation of women is higher in some disciplines as compared to others. The paper also aims to explore if institutions specializing in some discipline or those located in big metropolitan cities get higher women participation as compared to others. In addition, the paper goes ahead to characterize male and female authored papers, identifying differences in citation impact and international collaboration patterns. The key research questions addressed in the paper are described in the following section.

Research questions

The paper mainly aims to answer following research questions:

[1] Transforming our world: the 2030 Agenda for Sustainable Development, retrieved from https://sustainabledevelopment.un.org/post2015/transformingourworld accessed on 20th August 2019.

[2] UNESCO Institute for Statistics Fact Sheet No. 51, Women in Science, FS/2018/SCI/51, June 2018.

[3] UGC Annual report 2017-18. Retrieved from https://www.ugc.ac.in/pdfnews/5595965_UGC-ANNUAL-REPORT-English-2017-18.pdf on 14th August 2019.

[4] Research and Development Statistics 2017-18, December 2017 by DST. Retrieved from: http://www.nstmis-dst.org/PDF2017/Table7.pdf on 14th August 2019.

[5] NSTMIS Report 2017-18. Page. 7. Retrieved from: http://www.nstmis-dst.org/Statistics-Glance-2017-18.pdf on 14th August 2019.

RQ1: How much research output from India during the last 10 years has a female as main author and whether the contribution of female authors have increased during this period?
RQ2: How does female participation in research vary with discipline?
RQ3: Which institution types have better representation of female authors in the research output?
RQ4: Do there exists differences in citation impact of female and male authored papers?
RQ5: Do there exists differences in international collaboration patterns of female and male authored papers?

Related work

There are several previous studies that explored participation of women in research, and analysed different aspects related to female authored research output from different geographies. Different studies took data from different data sources and disciplines and focused on analysing several aspects ranging from a general assessment of participation of women in research to issues of disciplinary preferences, citation advantages and collaboration patterns. Here, we present some of these important previous studies that look at overall levels of female participation in research and analyse them in different ways. These previous studies helped us in design of the current analytical study.

Gender and research productivity

One of the initial works on gender and research publishing in this decade is Larivière et al. (2011). Authors analysed the entire population of professors at universities in the province of Quebec (Canada), and tried to understand the relationship between sex and research funding, publication rates, and scientific impact. The article showed that, after they have passed the age of about 38, women receive, on average, less funding for research than men; are generally less productive in terms of publications; and are at a slight disadvantage in terms of the scientific impact (measured by citations) of their publications. Various explanations for these differences were suggested, such as the more restricted collaboration networks of women, motherhood and the accompanying division of labour, women's rank within the hierarchy of the scientific community and access to resources as well as their choice of research topics and level of specialization. Larivière et al. (2013) further presented their results on a bibliometric analysis confirming that gender imbalances persist in research output worldwide.

Isfandyari-Moghaddam et al. (2012) studied the factors affecting research productivity of Iranian women as per records in Web of Science. They observed that the most motivational factors affecting positively publishing scholarly articles by Iranian women were 'getting promoted in scientific rank', 'intrinsic talents', 'perseverance and adventitious knowledge', 'feeling of being useful in society', 'getting promoted in job', 'being encouraged by friends and family', 'religious lessons regarding the importance of science', and 'attempt to show individual capabilities'.

In another set of studies, van Arensbergen et al. (2012) and Van Den Besselaar and Sandström (2016) analysed publication records of 852 social scientists at two different time periods, respectively. They showed that performance differences between genders indeed exist. However, it was also suggested that in the younger generation of

researchers these differences are not there and, in some cases, young female researchers outperform young male researchers. The trend in developed societies, that women increasingly outperform men in all levels of education, has also been seen in the science system. They also observed that productivity of male researchers grew faster than of female researchers.

Mauleón et al. (2013) analysed by gender the composition of the editorial boards of 131 high-quality Spanish journals in all fields of science, the presence of men and women as authors in a selection of 36 journals, and the evolution of these aspects from 1998 to 2009. It was found that female presence is lower than male presence in authorship, editorial board membership and editorship. It was observed that the gender gap tends to diminish over the years in most areas, especially in authorship and very slightly in editorial board membership.

In a later study (Aiston and Jung 2015), authors examined the research productivity gender gap from an international perspective by undertaking a gendered analysis of the 'Changing Academic Profession Survey'. They suggest that family is not, in all cases, operating as a form of negative equity in the prestige economy of higher education.

Tao et al. (2017) systematically compared gender differences in the publication productivity of academic scientists and engineers with doctoral degrees in the U.S. and China. Findings from negative binomial regressions showed that women publish less than their male counterparts in science but not in engineering in the U.S. Further, in China, women did not differ from men in publication productivity in science and publish more than their male counterparts in engineering.

Aguinis et al. (2018) examined the gender productivity gap in science, technology, engineering, mathematics, and other scientific fields (i.e., applied psychology, mathematical psychology), specifically among star performers. Results showed that there was a considerable gender productivity gap among stars in favour of men across fields. Specifically, the underrepresentation of women was more extreme in elite ranges of performance (i.e., top 10%, 5%, and 1% of performers). They advanced practical suggestions stating that women may have to accumulate more scientific knowledge, resources, and social capital to achieve the same level of increase in total outputs as their male counterparts.

Bendels et al. (2018) analysed the representation of female authorships in a large sample of papers from 2008 to 2016 and found that women publish fewer articles compared to men (39.0% female authors are responsible for 29.8% of all authorships) and are underrepresented at productivity levels of more than 2 articles per author. Holman et al. (2018) analysed the PubMed and arXiv databases for about 36 million authors from more than 100 countries publishing in more than 6000 journals, covering most STEM disciplines for last 15 years period and concluded that despite recent progress, the gender gap appears likely to persist for generations, particularly in surgery, computer science, physics, and maths.

Lundine et al. (2018) wrote about "gender system of social practice" and stated that "academic publishing is not immune to it". Mayer and Rathmann (2018) explored as to what extent the research productivity of psychology professors in Germany was related to gender, and observed that there exist significant gender differences for research productivity in academic journals, with females publishing lesser than male authors.

In a recent article in The Lancet, Boynton et al. (2018) observed that gender equity is being given much attention within policy areas. They stressed that "moving forward on this issue requires adherence to rigorous arguments and unbiased examinations of the evidence". They stated that "future calls for interventions focusing on gendered discrepancies be grounded upon sound scientific reasoning and evidence, rather than perception or ideological narrative".

Thus, most of the studies suggest for clear differences in productivity levels of female authors vis-à-vis male authors. It was a general observation across disciplines and geographies explored in different papers that female authors tend to be less productive in publishing in academic journals due to variety of reasons. Some studies, however, found connection of age with the productivity differences.

Gender and disciplinary preferences

Though most of the studies on gender and research publishing focused on productivity, some of them also looked if there exist some discipline preferences for women. Su et al. (2009) examined the magnitude and variability of sex differences in vocational interests according to Holland's (1959, 1997) categories (realistic, investigative, artistic, social, enterprising, and conventional), Prediger's (1982) things-people and data-ideas dimensions, and the STEM (science, technology, engineering, and mathematics) interest areas. Technical manuals for 47 interest inventories were used, yielding 503,188 respondents. Results showed that men prefer working with things and women prefer working with people, producing a large effect size on the things-people dimension. Men showed stronger Realistic and Investigative interests, and women showed stronger artistic, social, and conventional interests. Sex differences favouring men were also found for more specific measures of engineering, science, and mathematics interests. The study suggested that interests may play a critical role in gendered occupational choices and gender disparity in the STEM fields. The study finally concluded that relatively low numbers of women in some fields of science and engineering may result from women's preference for people-oriented careers over things-oriented careers.

Another very recent study (Thelwall et al. 2019) looked at gender and discipline connection in research. They compared practising US male and female researchers between and within 285 narrow Scopus fields inside 26 broad fields from their first-authored articles published in 2017. The comparison was based on publishing fields and the words used in article titles, abstracts, and keywords. They state that "the results cannot be fully explained by the people/thing dimensions". They found greater female interest in veterinary science and cell biology and greater male interest in abstraction, patients, and power/control fields, such as politics and law. They observed that it may be due to other factors, such as the ability of a career to provide status or social impact or the availability of alternative careers. They further observe that "as a possible side effect of the partial people/thing relationship, females are more likely to use exploratory and qualitative methods and males are more likely to use quantitative methods".

Differences in citation impact of male and female researchers

Some analytical studies tried to look at differences in citation impact of male and female authors at different stages of career. Aksnes et al. (2011) used data for 8500 Norwegian researchers and analysed more than 37,000 publications covering all areas of knowledge, and concluded that the publications of female researchers are less cited than are those of men, although the differences are not large. The attributed the gender differences in citation rates to differences in productivity.

Beaudry and Larivière (2016) analysed the discipline-normalised citation rates of individual academics in Quebec and found that academic women publish less and receive fewer citations in health and NSE fields and that in journals of similar impact factors, female

health scientists are less cited. Bendels et al. (2018) observed that articles with female key authors are less frequently cited than articles with male key authors.

Thelwall (2018) tried to assesses whether there are gender differences in the average citations and/or Mendeley readers of academic publications. He investigated field normalised logged Scopus citations and Mendeley readers from mid-2018 for articles published in 2014 for articles with first authors from India, Spain, Turkey, the UK and the USA in up to 251 fields. The study found that although female-authored research is less cited in Turkey (−4.0%) and India (−3.6%), it is marginally more cited in Spain (0.4%), the UK (0.4%), and the USA (0.2%). A little practical gender difference in citation impact was found in countries with mature science systems. In another recent study, Thelwall (2019) investigated the evolution of gender differences in citation impact for data during 1996–2018 for six million articles from seven large English-speaking nations: Australia, Canada, Ireland, Jamaica, New Zealand, UK, and the USA. The results showed that a small female citation advantage has been the norm over time for all these countries except the USA, where there was no practical difference observed. The female citation advantage was found largest, and statistically significant in most years, for Australia and the UK.

There are thus different observations obtained from different studies that looked at data for different countries and diverse disciplines. While, many of them concluded that female authored papers are marginally lesser cited than male authored papers, some studies found reverse patterns.

Differences in collaboration patterns of male and female researchers

Some studies on gender and research publishing focused their attention on differences in collaboration patterns of male versus female authors. Abramo et al. (2013) analysed the issue of gender aspects in research collaborations by applying a bibliometric approach based on the propensity for collaboration by individual academics. They analysed the scientific production data of Italian academics and observed that women researchers register a greater capacity to collaborate in all the forms analysed, with the exception of international collaboration, where there is still a gap in comparison to male colleagues.

Nielsen (2016) performed a cross-sectional bibliometric study investigating the link between gender and research performance in the Danish context. In addition to other parameters, they compared collaborative patterns of 3293 male and female researchers. They did not find any clear indication of any noteworthy gender gap in the citation rates of male and female researchers but they found that small, statistically significant differences exist with respect to research collaboration and the relative impact scores of the journals in which men and women publish their papers. It was seen that women had slightly lower propensity for international research collaboration than their male colleagues, and they tend to publish more single-authored articles than men.

Fell and König (2016) did a scientometric analysis and observed that female researchers engage in more scientific collaborations. Meng (2016) tried to understand the gender gap in academic patenting in the U.S. They found that female academic scientists are not disadvantaged in collaboration, whether in terms of general collaboration network size or having any of the specified boundary-spanning collaboration ties. Zeng et al. (2016) studied whether female and male researchers in science, technology, engineering, and mathematical (STEM) disciplines differ in their collaboration propensity. They performed an empirical analysis of the complete publication records of 3980 faculty members in six STEM disciplines at select U.S. research universities. They observed that female faculty

have significantly fewer distinct co-authors over their careers than males, but that this difference could be fully accounted for by females' lower publication rate and shorter career lengths. They also found that female scientists have a lower probability of repeating previous co-authors than males.

Araújo et al. (2017) analysed a unique dataset of more than 270,000 scientists and discovered substantial gender differences in scientific collaborations. They observed that men are more likely to collaborate with other men, and that women are more egalitarian. This was consistently observed over all fields and regardless of the number of collaborators a scientist had. The only exception was observed in the field of engineering, where this gender bias disappeared with increasing number of collaborators. In interdisciplinary research, they showed that men and women behave similarly across fields, except in the case of natural sciences, where women with many collaborators are more likely to have collaborators from other fields.

Another study (Jadidi et al. 2018) investigated gender-specific differences in collaboration patterns of more than one million computer scientists over the course of 47 years. They explored how these patterns change over years and career ages and how they impact scientific success. They found that successful male and female scientists reveal the same collaboration patterns. When compared to scientists in the same career age, women tend to collaborate with more colleagues than other scientists, seek innovations as brokers and establish longer-lasting and more repetitive collaborations.

While most of the previous studies observed that women tend to collaborate more than their male counterparts, some observed contrary patterns. Some studies also found that women collaborate less internationally. It would, therefore, be interesting to see what patterns are observed for Indian research output analysed.

Studies on gender and research publishing in India

Though there have been quite many studies involving analysis of research output from India (Banshal et al. 2017, 2018; Marisha et al. 2017; Basu et al. 2016; Solanki et al. 2016; Nishy et al. 2012; Prathap 2014; Prathap and Sriram 2017), but very little attention is paid on analysing the women's participation in research output coming from India. The most relevant and recent study that look gender and research publishing in India is Thelwall et al. (2019). This study analysed the research publication data from Scopus for India for the year 2017 and observed that there is a high gender inequality with female to male author ratio of about 0.35 in 2017. They also observed that the participation varies across different disciplines with medical sciences, arts and humanities, and social sciences having higher female to male ratio as compared to disciplines like engineering, information science etc. They concluded that the disciplinary variation patterns were a bit different from those observed in USA. The study, however, looks at a data for just 1 year (2017) and does not analyse the other questions on citation differences, collaboration patterns and institution types and their connectedness with women participation in research publishing.

Data and methodology

The research output data obtained from Web of Science for the period of 2008 to 2017 is used for the analytical study. Data for 50 most productive institutions is downloaded using institution-wise queries of the form CU=INDIA AND OG=BANARAS HINDU UNIVERSITY (Institutions name), Time Span=2008-2017, Indexes=SCI-EXPANDED, SSCI, A&HCI for

the institution "Banaras Hindu University". Data was downloaded in the month of February 2019. A total of 389,477 publication records were obtained for the 50 most productive institutions and 5 major institution systems. This constitutes about 65% of the total research output for India during this period. Thus, the sample data is a good representation of the overall research output from India, for a significant period of 10 years. The data for most productive institutions was used with the understanding that they have better infrastructure and more gender-neutral environment and hence may have better prospects of participation of women in research. The data is processed computationally by writing programs in R programming language.

Since the main point of analysis was participation of women in research, it was necessary to determine gender of authors. For this purpose, first author name for all publication records was extracted. The Gender API[6] has been used to find out whether the first author is a female or a male. It can detect the gender of the author and return "male" or "female" as a result and is known to be quite accurate. In case, gender of the author cannot be determined, it returns "null". Thus, with the help of Gender API, gender of first author of the papers in the data was identified. Those papers for which gender could not be determined were treated as 'indeterminate' and excluded from the computations. We have evaluated the accuracy of gender determination by taking three random samples of 100 records for which gender of the first author was determined and found accuracy of 98% or higher in all the three cases. In some cases where full name was not available, the API could not determine the gender.

After determination of gender for all the extracted names, the corresponding publication records were tagged as 'male first authored' or 'female first authored', as the case may be. The tagging information was used to compute several analytical results. These include female first authored to male first authored ratio for the whole data as well as for different disciplines and institutions. Disciplinary tagging of each article was done by using 'WC' field of WoS according to categorization scheme defined in Rupika et al. (2016). The fourteen broad disciplines are as follows: agriculture (AGR), art and humanities (AH), biology (BIO), chemistry (CHE), engineering (ENG), environment science (ENV), geology (GEO), information sciences (INF), material science (MAR), mathematics (MAT), medical science (MED), multidisciplinary (MUL), physics (PHY) and social science (SS). Each paper was thus tagged into one of the 14 broad disciplinary categories and results for different disciplines were computed accordingly.

Participation of women in institutions of different types and locations was analysed by manually tagging each institution into a specific category. Primary focus was to see the difference in participation levels in institutions located in big metropolitan cities and small towns. In addition, the research output data was further analysed to identify differences in citation impact and collaboration patterns of male and female authored papers. This was done by dividing the male and female authored papers in two sets and then computing average values for both sets.

Gender differences in research output

First aspect we looked at was the level of participation of women in research publishing. We analysed the research output data sample for India for 10-year period, identifying female and male 1st authored research papers. Table 1 shows the year-wise data for total papers, papers for which gender of first author could be determined, number of papers

[6] https://www.genderapi.io/, accessed during 20th May to 10th June 2019.

Table 1 Year-wise count of female and male authored papers and the ratio

Year	Total papers in WoS	Total papers for which gender is determined	Female 1st authored	Male 1st authored	Female/male ratio
2008	27,691	14,219	3694	10,525	0.35
2009	29,375	16,092	4283	11,809	0.36
2010	30,927	17,872	4708	13,164	0.36
2011	33,079	19,949	5244	14,705	0.36
2012	34,590	21,586	5837	15,749	0.37
2013	37,801	24,156	6646	17,510	0.38
2014	41,747	27,462	7784	19,678	0.40
2015	48,502	32,581	9380	23,201	0.40
2016	52,219	35,788	10,840	24,948	0.43
2017	53,546	37,932	11,482	26,450	0.43
Total	389,477	247,637	69,898	177,739	0.39

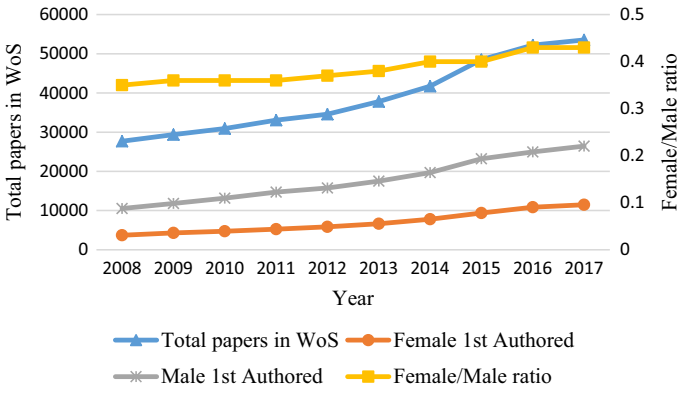

Fig. 1 Year-wise plot of number of female and male authored papers and the ratio

having female 1st author, number of papers having male 1st author and the female 1st to male 1st author ratio. As could be observed, the gender could be successfully determined for 247,637 out of 389,477 total papers in the data, i.e. for about 64% of the papers in the data. Out of these 247,637 papers, a total of 69,898 papers are found to have female 1st author and 177,739 papers are found to have male 1st author. Thus, out of total papers in the data, 28% papers have female first author and 72% papers have male first author. It is interesting to see that the ratio of female to male authored papers has increased during the 10-year period, starting from 0.35 in 2008 to reach to 0.43 in 2017.

Figure 1 plots the growth in number of female and male authored papers on the first y-axis and the ratio of female to male authored papers on the second y-axis. There is a growth of 23% in the ratio of female to male authored papers during the 10-year period, which is a welcome sign with respect to participation of women in research. Thus, it could be clearly observed that women's participation in research publishing in India has increased during last 10 years and they are contributing more in total research output coming from India. Though, this paper does not aim to study productivity differentiation of female vs

male authors, but the publication numbers and ratio indicate that women lag in number of researchers in the system. We found that 69,898 female authored papers are authored by 36,480 distinct female authors, resulting into per capita output for female authors as 1.91. On the other hand, 177,739 male authored papers are authored by 82,060, with per capita output for male authors being 2.17.

The gender and discipline connection

The second aspect analysed in the Indian research output data was to see if there exist disciplinary differences in the levels of participation of women in research publishing. As explained earlier, this was done by grouping the data into 14 broad disciplines through disciplinary tagging process. Table 2 shows the values obtained for different disciplines. It can be observed that disciplines like AGR, BIO, MED, MUL and SS have more than 30% of the total research output with female lead author. On the contrary, disciplines like ENG and INF have about 80% of the papers with male author, i.e. only 20% papers with female author. The ratio of female to male authored papers is best in BIO with a value of 0.58 followed by AGR with value of 0.47, MED with value of 0.47 and SS with value of 0.44. Disciplines like ENG (with ratio of 0.26), INF (with ratio of 0.26) and MAT (with ratio of 0.28) have lower female to male authored paper ratio. The case of lower participation of women in INF is particularly surprising, as it is often believed that Computer Science and IT careers are more suitable to women. To summarize BIO, AGR, MED and SS disciplines are more female in India as compared to other disciplines. This observation is congruent to some extent with findings of Thelwall et al. (2019) in their study, where they have concluded that MED, SS and AGR have higher female to male ratio and disciplines like ENG and INF have lower female to male ratio in research output. The People-and-Things differentiation seems to exist in Indian researchers as well.

Table 2 Total number of female and male authored papers in 14 broad disciplines

Subjects	Total papers	Total papers for which gender is determined	Female 1st authored	Male 1st authored	Female/male ratio
AGR	31,414	17,825	5667	12,158	0.47
AH	11,669	7263	1769	5494	0.32
BIO	1,12,697	83,168	30,640	52,528	0.58
CHE	1,00,382	69,294	18,833	50,461	0.37
ENG	52,120	31,098	6352	24,746	0.26
ENV	30,926	18,478	5635	12,843	0.44
GEO	33,000	18,975	5183	13,792	0.38
INF	20,071	14,106	2919	11,187	0.26
MAR	85,180	47,638	12,466	35,172	0.35
MAT	20,607	12,463	2714	9749	0.28
MED	97,177	69,512	22,256	47,256	0.47
MUL	14,616	10,092	3124	6968	0.45
PHY	1,21,003	66,659	16,564	50,095	0.33
SS	19,595	14,332	4408	9924	0.44

AGR agriculture, *AH* art and humanities, *BIO* biology, *CHE* chemistry, *ENG* engineering, *ENV* environmental science, *GEO* geology, *INF* information science, *MAR* material science, *MAT* mathematics, *MED* medicine, *MUL* multidisciplinary, *PHY* physics, *SS* social sciences

Table 3 The year-wise ratio of female to male authored papers for different disciplines

Subjects	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
AGR	0.38	0.42	0.42	0.42	0.41	0.44	0.48	0.51	0.52	0.54
AH	0.21	0.38	0.28	0.31	0.26	0.33	0.31	0.32	0.34	0.38
BIO	0.58	0.57	0.50	0.50	0.52	0.58	0.56	0.65	0.64	0.66
CHE	0.31	0.35	0.33	0.33	0.33	0.34	0.37	0.40	0.43	0.44
ENG	0.24	0.23	0.22	0.20	0.23	0.27	0.24	0.27	0.29	0.28
ENV	0.33	0.44	0.38	0.37	0.40	0.46	0.46	0.48	0.45	0.49
GEO	0.33	0.33	0.31	0.34	0.37	0.41	0.42	0.41	0.36	0.39
INF	0.19	0.29	0.20	0.22	0.24	0.27	0.26	0.26	0.33	0.26
MAR	0.36	0.32	0.32	0.29	0.36	0.36	0.39	0.36	0.36	0.38
MAT	0.24	0.23	0.23	0.21	0.28	0.22	0.30	0.32	0.33	0.32
MED	0.41	0.45	0.45	0.45	0.43	0.44	0.46	0.47	0.53	0.55
MUL	0.34	0.30	0.41	0.47	0.51	0.47	0.40	0.40	0.53	0.46
PHY	0.29	0.30	0.31	0.30	0.32	0.34	0.35	0.34	0.35	0.36
SS	0.42	0.45	0.40	0.46	0.46	0.38	0.38	0.42	0.52	0.47

AGR agriculture, *AH* art and humanities, *BIO* biology, *CHE* chemistry, *ENG* engineering, *ENV* environmental science, *GEO* geology, *INF* information science, *MAR* material science, *MAT* mathematics, *MED* medicine, *MUL* multidisciplinary, *PHY* physics, *SS* social sciences

It would be useful to also look at the year-wise values of female to male authored papers for all the disciplines. Table 3 shows the year-wise values of female to male authored papers ratio for the 10-year period, for all disciplines. It is observed that AGR and MED disciplines show significant growth in the female to male authored papers ratio during last 10 years. AGR starts with value of 0.38 in 2008 which rises to 0.54 in 2017. MED starts with value of 0.41 in 2008 which rises to 0.55 in 2017. BIO discipline also show growth towards the recent period, with a value of 0.66 in the most recent year (perhaps the time when higher output has been recorded). Disciplines like GEO (0.33–0.39), INF (0.19–0.26), MAT (0.24–0.32) show very low rise in the ratio. Some other disciplines like MAR (0.36–0.38), SS (0.42–0.47) and ENG (0.24–0.28) show almost no or negligible growth in the female to male authored paper ratio. Thus, while some disciplines seem to be becoming more attractive for women researchers, few other continue to remain unappealing for women researchers.

Gender distribution in the research output in different institution types

For a more detailed analysis of gender distribution in the 50 most productive institutions, the institution-wise numbers for female and male authored papers and the ratio were computed. Table 4 shows the computed data for the 50 institutions included in the analysis. It can be observed that participation of women as main author in research is different for different institutions. University of Delhi has the highest female to male authored paper ratio of 0.70 as well as percentage (41%) of female authored papers. Other institutions with reasonably good amount of female authored papers are Jawaharlal Nehru University (39.2%), University of Pune (36.6%), Manipal University (35.5%), University of Calcutta (35.6%) and Panjab University (33.5%). It may be noted that majority of the institutions with higher

Table 4 Total papers and female and male authored papers for the 50 most productive Indian institutions

Name of the institution	Institution type and location	Total papers in WoS	Papers for which gender was determined	Female 1st authored	Male 1st authored	Female/male ratio
Indian Institute of Science Bangalore (IISC), Karnataka	MUL and metro city	16,707	10,643	2674 (25.12%)	7969 (74.88%)	0.34
All India Institute of Medical Sciences (AIIMS), Delhi	MED and metro city	13,636	10,141	3294 (32.48%)	6847 (67.52%)	0.48
Indian Institute of Technology, Kharagpur (IITKGP), West Bengal	TEC and urban	13,510	9268	2015 (21.74%)	7253 (78.26%)	0.28
Bhabha Atomic Research Center (BARC), Maharashtra	MUL and metro city	12,407	6595	1946 (29.51%)	4649 (70.49%)	0.42
Banaras Hindu University (BHU), Uttar Pradesh	MUL and urban	11,254	7918	2281 (28.81%)	5637 (71.19%)	0.40
University of Delhi (DU), Delhi	MUL and metro city	11,011	8773	3598 (41.01%)	5175 (58.99%)	0.70
Indian Institute of Technology Bombay (IITB), Maharashtra	TEC and metro city	10,899	7445	1651 (22.18%)	5794 (77.82%)	0.28
Indian Institute of Technology, Madras (IITM), Tamil Nadu	TEC and metro city	10,863	5169	1079 (20.87%)	4090 (79.13%)	0.26
Indian Institute of Technology Delhi (IITD), Delhi	TEC and metro city	10,761	7918	2342 (29.58%)	5576 (70.42%)	0.42
PGIMER Chandigarh (PGIMER), Punjab	MED and urban	9253	7003	1819 (25.97%)	5184 (74.03%)	0.35
Indian Institute of Technology Kanpur (IITK), Uttar Pradesh	TEC and metro city	8761	6565	1236 (18.83%)	5329 (81.17%)	0.23
Indian Institute of Technology Roorkee (IITR), Uttarakhand	TEC and Rural	8614	6321	1531 (24.22%)	4790 (75.78%)	0.32
Jadavpur University (JU), West Bengal	MUL and metro city	7941	5826	1427 (24.49%)	4399 (75.51%)	0.32
Anna University (ANU), Tamil Nadu	MUL and metro city	7457	2098	508 (24.21%)	1590 (75.79%)	0.32
Tata Institute of Fundamental Research (TIFR), Maharashtra	MUL and metro city	7120	4514	1261 (27.94%)	3253 (72.06%)	0.39
Manipal University (MU), Karnataka	MUL and urban	6615	4289	1525 (35.56%)	2764 (64.44%)	0.55
University of Calcutta (CU), West Bengal	MUL and metro city	6597	5101	1819 (35.66%)	3282 (64.34%)	0.55
Panjab University (PU), Punjab	MUL and urban	6437	4492	1504 (33.48%)	2988 (66.52%)	0.50
Aligarh Muslim University (AMU), Uttar Pradesh	MUL and urban	6178	4495	1082 (24.07%)	3413 (75.93%)	0.32
Vellore Institute of Technology (VIT), Tamil Nadu	TEC and urban	5983	2659	804 (30.24%)	1855 (69.76%)	0.43

Table 4 (continued)

Name of the institution	Institution type and location	Total papers in WoS	Papers for which gender was determined	Female 1st authored	Male 1st authored	Female/male ratio
University of Hyderabad (UoH), Telangana	MUL and metro city	5026	2686	716 (26.66%)	1970 (73.34%)	0.36
Annamalai University (ANMLIU), Tamil Nadu	MUL and Rural	4651	1268	138 (10.88%)	1130 (89.12%)	0.12
Jawaharlal Nehru University (JNU), Delhi	MUL and metro city	4434	3652	1432 (39.21%)	2220 (60.79%)	0.65
Christian Medical College Hospital, Vellore (CMCV), Tamil Nadu	MED and urban	4239	2895	1010 (34.89%)	1885 (65.11%)	0.54
University of Pune (UoP), Maharashtra	MUL and metro city	4023	3038	1112 (36.6%)	1926 (63.4%)	0.58
Tata Memorial Hospital (TMH), Maharashtra	MED and metro city	3784	2484	789 (31.76%)	1695 (68.24%)	0.47
University of Madras (UoM), Tamil Nadu	MUL and metro city	3465	1380	245 (17.75%)	1135 (82.25%)	0.22
Indian Institute of Technology BHU, Varanasi (IITBHU), Uttar Pradesh	TEC and urban	3462	2412	526 (21.81%)	1886 (78.19%)	0.28
Indira Gandhi Centre for Atomic Research (IGCAR), Tamil Nadu	MUL and urban	3415	1010	269 (26.63%)	741 (73.37%)	0.36
Sanjay Gandhi Postgraduate Institute of Medical Sciences (SGPI), Uttar Pradesh	MED and urban	3251	2446	731 (29.89%)	1715 (70.11%)	0.43
National Institute of Technology, Rourkela (NITR), Odisha	TEC and urban	3228	1963	522 (26.59%)	1441 (73.41%)	0.36
Institute of Chemical Technology, Mumbai (ICT), Maharashtra	CHE and metro city	3220	2593	524 (20.21%)	2069 (79.79%)	0.25
Jamia Millia Islamia (JMI), Delhi	MUL and metro city	3146	2539	791 (31.15%)	1748 (68.85%)	0.45
Bharathiar University (BHTU), Tamil Nadu	MUL and urban	3136	1131	226 (19.98%)	905 (80.02%)	0.23
Saha Institute of Nuclear Physics (SINP), West Bengal	PHY and metro city	3070	1828	537 (29.38%)	1291 (70.62%)	0.42
Guru Nanak Dev University (GNDU), Punjab	MUL and urban	3066	2568	615 (23.95%)	1953 (76.05%)	0.31
Thapar University (TU), Punjab	MUL and urban	3028	2624	685 (26.11%)	1939 (73.89%)	0.35
National Institute of Mental Health and Neurosciences India (NIMHANS), Karnataka	MED and metro city	3001	1968	590 (29.98%)	1378 (70.02%)	0.43

Table 4 (continued)

Name of the institution	Institution type and location	Total papers in WoS	Papers for which gender was determined	Female 1st authored	Male 1st authored	Female/male ratio
Birla Institute of Technology and Science, Pilani (BITS), Rajasthan	TEC and urban	2949	2130	495 (23.24%)	1635 (76.76%)	0.30
Sri Venkateswara University (SVU), Andhra Pradesh	MUL and urban	2921	699	177 (25.32%)	522 (74.68%)	0.34
Indian Space Research Organisation (ISRO)	TEC and metro city	2910	1455	348 (23.92%)	1107 (76.08%)	0.31
National Institute Technology, Tiruchirappalli (NITT), Tamil Nadu	TEC and urban	2906	764	156 (20.42%)	608 (79.58%)	0.26
Indian Statistical Institute, Kolkata (ISI), West Bengal	MUL and metro city	2752	2246	516 (22.97%)	1730 (77.03%)	0.30
Osmania University (OSU), Telangana	MUL and metro city	2685	1101	386 (35.06%)	715 (64.94%)	0.54
Bharathidasan University (BTDU), Tamil Nadu	MUL and urban	2671	1107	115 (10.39%)	992 (89.61%)	0.12
University of Allahabad (UoA), Uttar Pradesh	MUL and urban	2655	2042	710 (34.77%)	1332 (65.23%)	0.53
Jamia Hamdard University (JHU), Delhi	MUL and metro city	2606	2089	624 (29.87%)	1465 (70.13%)	0.43
University of Mysore (UoMY), Tamil Nadu	MUL and urban	2574	1000	234 (23.4%)	766 (76.6%)	0.31
Pondicherry University (PDU), Puducherry	MUL and urban	2450	1034	258 (24.95%)	776 (75.05%)	0.33
Indian Institute of Engineering Science Technology, Shibpur (IIEST), West Bengal	MUL and urban	2417	1731	389 (22.47%)	1342 (77.53%)	0.29

female authored papers are multidisciplinary Universities. The premier technological institutions of the country have much lesser percentage of female authored papers, with IIT Bombay having 22.1%, IIT Madras having 20.8% and IIT Kanpur having 18.83% of female authored papers. These technological institutions also have one of the lowest female to male authored papers ratio, ranging around 0.2.

There are two important points to notice in these results. First, female to male research output ratio is not seen to be better for institutions located in big metropolitan cities, as seen in the case of IITs located in Bombay and Madras. At the same time some institutions located in smaller cities like Allahabad, Varanasi, Vellore etc. have higher female participation in research, as measured from output. Therefore, it cannot be said that institutions located in big metropolitan cities are likely to have higher female participation in research.

The second aspect is to analyse the disciplinary focus of the institution and its female authored research output levels. From the data, it has been observed that institutions that have multiple disciplines being pursued in them are relatively better in levels of female participation in research. Institutions focusing mainly in Biological Science, Medical Science, Social Science and Arts and Humanities also have better female participation as compared to other institutions. Further, institutions that specialize in engineering and technology are found to have poor female to male ratio in research output. These findings thus uphold the disciplinary variations point observed in previous section. Disciplinary focus of an institution is found to be more differentiating factor, unlike its location, in respect to participation of women in research.

Citation impact of male versus female authored papers

The next aspect the paper analysed was the differentiation in citation impact of female and male authored papers. The objective was to identify if there exist any noticeable difference in citation impact between female and male authored papers. For this, purpose, the research output data for female and male authored papers were put in two sets. Thereafter, the year-wise values of citations per paper (CPP) are computed by dividing the total citations by total papers for that year. The objective was to find out if female authored papers attract more, less or similar citations per paper as that of male authored papers. Table 5 shows the values of citations per paper (CPP) for female and male authored papers. It is observed that female authored papers have lower CPP values than male authored papers during the whole 10-year period. The average CPP value for the whole period for female authored papers is 11.68 as compared to 13.26 for male authored papers. Though the difference in CPP values are not very high but female authored papers for each of the years have consistently lower CPP as compared to male authored papers. These patterns, thus, confirm findings of several previous studies (Aksnes et al. 2011; Beaudry and Larivière 2016; Bendels et al. 2018) about differences in citation impact of female and male authored papers. Further as observed by Thelwall (2018, 2019), that the citation impact differences vary in different countries, we notice that gender citation impact differences exist in Indian research output as well.

Table 5 Differences in CPP and ICP of female versus male authored papers

Year	Citations per paper (CPP)		Internationally collaborated papers (ICP)	
	Female 1st authored papers	Male 1st authored papers	Female 1st authored papers	Male 1st authored papers
2008	23.49	23.84	10.4	9.24
2009	20.73	22.28	10.81	8.81
2010	19.12	21.55	11.47	8.74
2011	18.04	19.3	11.16	10.15
2012	15.53	19.01	9.92	9.72
2013	13.5	14.58	10.14	9.82
2014	12.47	12.76	9.55	9.99
2015	8.54	9.41	10.77	9.46
2016	5.75	6.41	11.14	8.27
2017	3.18	3.47	9.73	9.99
Total	11.68	13.26	10.45	9.44

International collaboration patterns of male vs female authored papers

The last point of analysis was to find out if female researchers collaborate internationally more or less as compared to the male researchers. For this purpose, the proportion of papers that are internationally collaborated for both sets of female-authored as well as male-authored papers were identified. Table 5 shows the ratio of internationally collaborated papers (ICP) to total papers for female and male authored paper sets. It is observed that female authored papers have higher ICP proportion for the whole period, except in 2 years (2014 and 2017). The 10-year average value for ICP proportion for female-authored papers is 10.45 as compared to 9.44 for male-authored papers. Though the difference in values of ICP proportion of female and male authored papers is not much, but female authors are found to have an edge in the ability to form more international collaborations as compared to male authors. These findings agree in general with observations of several previous studies (Abramo et al. 2013; Fell and König 2016) which observed that female authors have higher propensity of collaborations, including at international level as compared to male authors. Some other studies (Nielsen 2016) showed that women collaborate less as compared to their male authors. However, as far it goes for India, it is quite clearly observed that women have a slight edge over men in international collaboration.

Summary and conclusion

The paper analysed research output from most productive Indian institutions in the country and computed female to male authored papers ratio for different institutions as well as different disciplines. Differences in citation impact and collaboration patterns are also computed for female and male authored papers. The results obtained, present interesting and useful insight about participation of women in research publishing in India and provide meaningful answers to research questions, as detailed below:

Firstly, it is observed that only about 28% papers are female 1st authored papers in the total data. The participation of females in research publishing in India as significantly lesser than male participation. These patterns are similar to those observed in many different countries. The female to male authored papers ratio has, however, increased from 0.35 in 2008 to 0.43 in 2017. In terms of output per capita for female and male authored papers, we observe that female authors produce on an average 1.91 papers per person whereas, male authors produce average 2.17 papers per person. Thus, male authors have an edge in productivity measured as per capita output.

Secondly, significant disciplinary variations in female to male authored papers are found, with disciplines like AGR, BIO, MED, MUL and SS have more than 30% of female authored papers, whereas disciplines like ENG and INF have only about 20% female authored papers. Interestingly, disciplines like AGR, MED and BIO observe growth in female to male author ratio as compared to disciplines like MAR and ENG which show very negligible growth. Therefore, the people-thing paradigm appears to be valid in context of Indian research as well.

Thirdly, no noticeable advantage is seen in terms of female participation in institutions located in big metropolitan cities as compared to institutions located in smaller towns and rural areas. Engineering and technology institutions located in big metropolitan cities are found to have lower female participation. However, differences are observed in female participation levels in institutions focusing on certain disciplines (multidisciplinary universities, biological and medical science focused institutions) as compared to other institutions with engineering and technology focus. Thus, disciplinary differentiation is more prevalent whereas no advantage is seen for female participation for institution's location in a big metropolitan city.

Fourth, female authored papers are observed to have a little lower number of citations per paper as compared to male authored papers. These differences, though marginal, are seen across data for the whole 10-year period. Thus, male authored paper's citation edge is seen in Indian research output as well, as observed in many other studies for different countries.

Fifth, female authored papers have higher proportion of international collaboration as compared to male authored papers. Though, the difference is again marginal, but females are found to have an edge in international collaboration as compared to male authors. These observations are again similar to patterns observed in many previous studies for different countries.

The paper thus presents interesting results and bring to light unexplored facts about participation of women in research in India, which can be used for a variety of purposes ranging from status enquiry to evidence-based policy formulation. It is quite clear that female participation in research in India is much lesser than males. More efforts and systematic strategies are perhaps required to achieve higher participation of women in research. Any barriers that may exist in India for females, including in the underrepresented disciplines need to be identified and appropriate efforts need to be put in for ensuring higher participation of women in research activities and publishing. Women researchers should not only be facilitated through relaxations (such as in age for consideration of research awards and grants) but should also be rewarded preferentially so that they can be role models for young female students.

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