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Citation analysis of Mathematics: a scientometric study based on PhD theses, Tripura University

MITHU ANJALI GAYAN
mithuanjaligayan@tripurauniv.in

Sanjay Kumar Singh
sksgu1@gmail.com

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Dr. Mithu Anjali Gayan,
Assistant Professor,
Department of Library and Information Science,
Tripura University,
Tripura, India
mithu.anjali@gmail.com,

Dr. Sanjay Kumar Singh
Professor and Head,
Department of Library and Information Science,
Gauhati University,
Assam, India
sksgu1@gmail.com

Abstract:

Citation analysis of theses helps in evaluating research performance of departments and universities. The aim of the present study is to evaluate the theses available in Central library, Tripura University from the department of Mathematics. Theses available in the central library for the period of ten years from 2007 to 2016 constitute the sample as the university was converted to central university in 2007. The authorship pattern of the articles was measured with collaborative measures. Bradford law and Leimkuhler model were tested against the dataset. It was revealed that the journals are the most preferred type of documents having the share of 82.07%. Until 1950, single authored papers were dominating and in the recent decades the trend is seen to be shifting towards large group collaborations. The dataset did not fit well against Bradford's law of scattering. However, we acknowledge the acceptability of modified Bradford's distribution given by the Leimkuhler model. The results revealed should assist the researchers in the area of Mathematics in improved understanding the characteristics of the field.

Key-words: Citation Analysis, Scientometrics, Bradford's law, Tripura University, PhD theses.

Key Messages: The core journals and core books found from the study should be purchased by the library authority as they are most relevant for the researchers.

Introduction:

The rapid development of scientific literature, interdisciplinary characteristics of research and movement towards specialization has created many inconveniences both to the scientists and librarians. The widespread explorations and the profusion of literature being published and contributed to enormous acceleration of cost for the libraries, as the acquisition of published literature became a gradually more complex mission. Citation analysis of theses helps in evaluating research performance of departments and universities. Today, most of the libraries are facing problems in Journal subscription cost, shrinking library budget, lack of space for library holdings, etc., which have resulted in number of user studies, being studied. The limited financial resources have caused a lot of problems to the librarian; so they are forced to look for an alternative system for collection development and provide quality document to the user community. That's where Citation Analysis proves to be one of the most essential and needful Study. This study recalls the nature of information used by the researchers and enables the librarian to plan and to provide better information services and better collection development.

Tripura is one of the eight Northeast Indian states and Tripura University is the only central university in the state. Presence of research in both Scopus and Web of science from Tripura shows that research is being produced form this part of the country but it is never being evaluated before. As a thesis is one of the most authentic research products and contain maximum number of citations, Mathematics theses from this university were selected as a sample to conduct the study. The study tried to understand different characteristics in the field of Mathematics such as authorship pattern, types of document cited and half life of journals in the field.

The key objectives of the study are

1. To find out the type of documents cited in Mathematics
2. To identify the authorship pattern in the field of mathematics
3. To test the applicability of Bradford's law of scattering

Bradford put forwarded the concept of scattering of journal literature in a given field. This concept was published as a law in the ''Engineering'' Journal by Bradford in 1934 and later in his book ''Documentation'' in 1948. According to him "If scientific journals are arranged in order of decreasing productivity of articles on a given subject, they may be divided into a nucleus of periodicals more particularly devoted to the subject and several groups or zones containing the same articles as the nucleus, when the number of periodicals in the nucleus and succeeding zones will be as 1: n: n2, where 'n' is a multiplier".[1-2] Vickery[3] tested the Bradford's law of scatting of periodicals as he observed algebraic misunderstanding caused by Bradford and his collaborators. Vickery suggested that the zones should not just be restricted to 3. Interpretation of verbal formulation of the Bradford's

law was given by Leimkuhler. It was concluded that literature from different time periods may show different results in the same subject area. He suggested the relation $F(X) = \log (1+\beta x) \div \log (1+\beta)$, where β is related to the particular subject and entirety of communication.[4] A Scientometrics analysis of "Pramana - Journal of Physics" found that numbers of collaborated papers were increasing; 21.85 references per article were observed[5]. A study on 30 chemical science doctoral theses, Tezpur University revealed ann average of 366.10 citations per thesis; more than 3 authored citations were predominant; journals were the preferred sources[6]. 17 theses of Agronomy and Plant Breeding department, Chaudhary Charan Singh Haryana Agricultural University (CCHAU) was studied and found that Co authored journal articles dominated the citations; Bradford's law did not fit well for the dataset[7]. Application of Bradford's law on "Science" journal was tested. 10.85 average authors were detected for each paper. The dataset did not fit to the Bradford's law however fitted the Leimkuhler's model[8].A Scientometric study of "Nature" revealed that Nature publishes maximum research articles followed by Editorial and News Item; [9]. "Advanced Applied Mathematics" literature was studied and was found that maximum papers were from Mathematics followed by computer science; journal articles were the most preferred type of documents[10]. Geology literature published by Indian Geologists was securitized. The quantitative analysis of the authorship data showed that the articles were mostly produced as a result of collaboration in groups[11].

Subjects and Methods:

For conducting the study theses submitted to central library, Tripura University in the field of Mathematics were considered. The university was converted to central university in July 2007. So, for this study theses submitted for ten years from July 2007 to June 2016 were considered. For this time period a total of 25 Mathematics theses were found in the library with 1829 citations. The scientometric techniques used are mentioned below,

a. **Degree of collaboration (DC):** Subramanyam[12] propounded the DC, a measure to calculate the proportion of single and multi-author papers and to interpret it as a degree. According to Subramanyam,

   DC=Nm/(Ns+Nm)

   Nm = the number of multi-authored papers

   Ns = the number of single author papers

b. **Collaborative Coefficient (CC)**

Ajiferuke [13] put forwarded the formula for collaboration coefficient (CC) as

$$CC = 1 - \frac{\sum_{j=1}^{A}\left(\frac{1}{j}\right)f_j}{N}$$

Here**,** Fj denotes the number of j authored research papers; N denotes total number of research papers published; k is the greatest number of authors per paper.

c. **Modified Collaborative Coefficient (MCC)** CC differentiates single and multiple authors. But it fails to yield 1 for maximal collaboration except when number of authors is infinite. It was rectified by Savanur and Srikanth[14] by the factor (1 – 1/A) with CC and enunciated as **MCC = (A/A-1)*** $\{1-\frac{\sum_{j=1}^{A}\left(\frac{1}{j}\right)f_j}{N}\}$

d. **Collaboration Index (CI):** Collaboration Index has been calculated by using the formula as given by Lawani in 1980[15]. The Collaboration Index (CI) is the simplest index presently used to explore the literature, which is to be interpreted the mean number of authors per paper. $CI = \frac{\sum_{j=1}^{A} jf_j}{N}$

Where,

f_j is the number of J authored papers published in a discipline during a certain period of time; N is the total number of research papers published in a discipline during a certain period of time

e. Co-authorship Index Garg and Padhi [16] suggested formula to compute CAI

$$\mathbf{CAI} = \frac{\mathbf{Nij/Nio}}{\mathbf{Noj/Noo}} \mathbf{*100}$$

Where, Nij = Number of publications having j author for a particular block; Nio = Total output for the particular block; Noj = Number of papers having j authors for all blocks; Noo = Total number of papers for all authors and all blocks. CAI = 100 the number of publications corresponds to the average within a co-authorship pattern. CAI >100 the number of publications are higher than the average. CAI <100 the number of publications are lower than the average

Results:

Type of documents cited per thesis citation wise distribution

Type of documents preferred and average citation per thesis count is measured in this section. It is found that 73.16 average documents are cited per thesis. It is revealed that Journals are the most preferred type of documents with a total of 1508 citations in 25 theses having the share of 82.07%. Books are the second highest cited documents having received a total of 153 citations in 25 theses with the share of 8.64%. This pattern of preference of document corroborates the literature surveyed.

Authorship pattern and collaborative measures

Table 1 represents the different collaborative measures applied in this study. To find out the value of DC, CC, MCC, CI and CAI formulas mentioned in “a” to “e” of methodology part are used. DC remains at 0 when single author is dominant and increases with increasing number of authors till. It is found in this study that DC was at lowest of 0 from the first time period till 1941 – 1950 as only single authors were cited for that period. DC was highest in 2011 – 2014 at 0.83. Gradual increase DC from

0.00 to 0.83 proves growing trend toward multi author papers. Mean DC 0.25 shows dominance of single author papers.

Table 1: Authorship pattern and collaborative measures

Sl.No.	Period	Single	Multiple	Total	DC	CC	CI	MCC	MCC-CC
1	before 1800	1		1	0.00	0	1	0	
2	1800 -1900	1		1	0.00	0	1	0	
3	1901- 1910	1		1	0.00	0	1	0	
4	1911 - 1920	3		3	0.00	0	1	0	
5	1921 - 1930	3		3	0.00	0	1	0	
6	1931 - 1940	9		9	0.00	0	1	0	
7	1941 - 1950	17		17	0.00	0	1	0	
9	1951 - 1960	38	11	49	0.22	0.112	1.22	0.114	0.002
10	1961 -1970	138	29	167	0.17	0.087	1.17	0.088	0.001
11	1971 - 1980	84	59	143	0.41	0.222	1.53	0.224	0.002
12	1981 - 1990	158	144	302	0.48	0.251	1.56	0.252	0.001
13	1991 - 2000	188	282	470	0.60	0.327	1.78	0.328	0.001
14	2001 - 2010	105	381	486	0.78	0.453	2.2	0.454	0.001
15	2011 - 2014	21	104	125	0.83	0.480	2.28	0.484	0.004

CI=Collaborative index, DC=Degree of collaboration, CC=Collaborative co-efficient, MCC=Modified collaborative co-efficient

The value of CC will be zero when single-authored papers dominate. This implication shows that higher the value of CC means higher the possibility of multi- authored papers in a discipline. In this study CC was lowest at 0 from the first time period till 1941 – 1950 and it was highest at 0.480 during 2011 to 2014. The value of CC has increased from top to bottom which shows that the trend is towards multi authorship.

CI is used to find out mean number of authors per paper. It cannot be interpreted as a degree because it has no upper-value limit. CI was lowest at 1 for the period from the first time period till 1941 – 1950 and it was highest at 2.28 for the period 2011 – 2014.

MCC is a customized version of CC but unlike CC, which remains strictly less than 1 for infinitely many authors, MCC smoothly tends to 1 as the degree of collaboration becomes maximal. The study found MCC was lowest during “before 1800” to “1941 – 1950”, when it was 0. It is highest during 2011 to 2014 when it is 0.484.

It is also observed from the table that the mean difference between CC and MCC is 0.001. The highest difference CC and MCC, which is 0.004, is observed during the period before 2011-2014.

It can be summarized from the above arguments that collaborative research activities are noticed in Mathematics literature. It can be concluded that no significant difference can be observed between CC values and MCC values, and also this variation narrows down when the number of authorships increases. It is quite evident that single authors remained dominant until 1950 but gradually increased

number authorships since then and now trend is towards multi authorship. For the collaborative measure studies et al, corporate, anonymous author, author not mentioned and year not mentioned categories are not included as they do not provide specific number of authors.

Productivity of Research Groups

Table 2 represents the productivity of research groups of different strengths. Out of total 1777 documents, small groups consisting of 2 to 5 authors produced maximum 1005 number of documents followed by single authors produced 767 documents. Medium group having 6 to 10 authors produced only 5 documents. Productivity of small groups of 2 to 5 authors only started after 1950 and productivity of medium group started after 1970. So, it is clear that these medium and large grouped collaborated studies are a recent phenomenon. It clearly demonstrates that small group of researchers are the most productive research group compared to other research groups. It also discloses that when the number of authors in the group increases the productivity decreases. Single author research shows a decline from 1991- 2000 to 2001-2010. Except that the research groups show increasing trend of productivity in the field of Mathematics.

Table 2: Productivity of Research Groups

Sl.No.	Period	Single author	No docs with 2–5 Authors(Small group)	No docs with 6–10 Authors (Medium group)	No docs with >10 Authors(large group)	Total
1	before 1800	1				1
2	1800 to 1900	1				1
3	1901- 1910	1				1
4	1911 - 1920	3				3
5	1921 - 1930	3				3
6	1931 - 1940	9				9
7	1941 - 1950	17				17
9	1951 - 1960	38	11			49
10	1961 -1970	138	29			167
11	1971 - 1980	84	58	1		143
12	1981 - 1990	158	144			302
13	1991 - 2000	188	281	1		470
14	2001 - 2010	105	378	3		486
15	2011 - 2014	21	104			125
Total		**767**	**1005**	**5**		**1777**

Co authorship Index

Table 3 illustrates the calculated values of Co-authorship Index (CAI) for publications having single author, two-authors, three authors, four authors and more than four authors termed as mega authors. CAI measures the tendency of co-authorship and it is measured with formula given in methodology numbered "h" from chapter 3. CAI = 100 indicates that the co-authorship effort for a particular type of authorship corresponds to the overall average, CAI > 100 reveals higher than average co-authorship effort and CAI < 100 proves lower than average co-authorship effort for a given type of authorship pattern.

Table 3: Co authorship Index (CAI) in Mathematics

Period	Single author	CAI of 1	Two author	CAI of 2	Three author	CAI of 3	Four author	CAI of 4	Mega author	CAI of Mega	Total
before 1800	1	232	0	0	0	0	0	0	0	0	1
1800 to 1900	1	232	0	0	0	0	0	0	0	0	1
1901- 1910	1	232	0	0	0	0	0	0	0	0	1
1911 - 1920	3	232	0	0	0	0	0	0	0	0	3
1921 - 1930	3	232	0	0	0	0	0	0	0	0	3
1931 - 1940	9	232	0	0	0	0	0	0	0	0	9
1941 - 1950	17	232	0	0	0	0	0	0	0	0	17
1951 - 1960	38	180	11	57	0	0	0	0	0	0	49
1961 -1970	138	191	29	44	0	0	0	0	0	0	167
1971 - 1980	84	136	47	83	11	54	0	0	1	78	143
1981 - 1990	158	121	123	103	16	37	5	84	0	0	302
1991 - 2000	188	93	211	113	65	97	5	54	1	24	470
2001 - 2010	105	50	223	115	129	186	17	178	12	274	486
2011 - 2014	21	39	62	125	32	180	8	325	2	178	125
Total	**767**		**706**		**253**		**35**		**16**		**1777**

Table 3 reports that value of CAI for single authors have decreased from 232 to 39, which mean there is a considerable decrease in the single authorship with respect to overall output. The CAI for two authors remained 0 until 1950 and then it gradually increased from 57 during 1951-1960 to 125 during 2011 - 2014. It is below average since 1951 to 1980. For three authors group, CAI remained 0 until 1970 and then increased from 54 to 180 from the period of 1971-1980 to the period of 2011-2014. It was below average from 1971 to 2000. For four author group, the CAI remained 0 until 1980 and increases from 84 to 325 since 1981 to 2014. It remained below average since 1981 to 2000.For mega authors, remained 0 until 1970 and the CAI gradually increases from 1971 -1980 to 2001 – 2010 from 78 to 274 which and again it declined during 2011 – 2014.

Ranking of most cited books in Mathematics

Books play a very significant role in scholarly communication. Books are used and cited by scholars across disciplines across the globe. Out of total citations in mathematics theses, second highest citations belong to books. Table 6 represents the ranking of most cited books in Mathematics arranged on the basis of the number of times it was referred. The bibliography of popular books is shown to avoid the bulkiness of the thesis and books title cited once are not shown in the table.

The book “Fuzzy set theory and its Application” scores the top position with 11 (6.96%) citations; second rank goes to “Digital Image Processing” with 6 (3.80%) citations followed by two books titled “Intuitionistic Fuzzy Sets: Theory and Applications” and “Stresses in shells” stands on third rank with 4 (2.53%) citations each.

BRADFORD'S LAW OF SCATTERING

For testing the validity of the law, the journal citations are arranged in the decreasing order of productivity. The verbal and graphical theory of the Bradford’s Law of Scattering is applied to the citations appended in Mathematics theses. Citations are arranged in the decreasing order of its frequency in table no 31. Table 4 reports that a total of 1501 citations come from 358 journals. The top ranked journal consists of 254 citations followed by the second journal having received 96 citations and the third ranked journal received 60 citations.

Table 4: Decreasing Frequency of Journal Citations in Mathematics

Sl. No.	Rank	No. of periodicals	Cumulative No. of journals	No. of citations	Total	Cumulative citations
1	1	1	1	254	254	254
2	2	1	2	96	96	350
3	3	1	3	60	60	410
4	4	1	4	57	57	467
5	5	1	5	40	40	507
6	6	1	6	39	39	546
7	7	1	7	33	33	579
8	8	1	8	21	21	600
9	9	1	9	18	18	618
10	10	1	10	17	17	635
11	11	1	11	16	16	651
12	12	1	12	15	15	666
13	13	2	14	14	28	694
14	14	2	16	13	26	720
15	15	1	17	12	12	732
16	16	1	18	11	11	743
17	17	4	22	10	40	783
18	18	2	24	9	18	801
19	19	11	35	8	88	889

20	20	7	42	7	49	938
21	21	5	47	6	30	968
22	22	14	61	5	70	1038
23	23	17	78	4	68	1106
24	24	23	101	3	69	1175
25	25	69	170	2	138	1313
26	26	188	358	1	188	1501

Bradford's zone for Mathematics

Based on table 4, three Bradford zones of journals having equal number of citations are presented in table 5. In this case, each zone accounts for nearly 500 citations. Table5 depicts the data in three Bradford zones. Difference in data is high and hence, it is concluded that the dataset does not fit into Bradford's law.

Table 5: Bradford zones

Zone	No. of Periodicals	number of citations	Cumulative number of citations	Bradford multiplier
1	5	507	507	1
2	50	501	1008	10
3	303	493	1501	60.6

The three zones in the scattering of Bradford law of Mathematics display that in the first zone there are 5 journals with 507 citations; in the second zone there are 50 journals with 501 citations and in the third zone there are 303 journals with 493 citations. The relationship of the each zone in the present table is explained with the following equations,

'F' denotes Finding, 'R' denotes Result and 'E' denotes excepted result

$F = 1.n:n^2$; R= 1:10: 60.6 ; E=1.10: 100

i.e. 1:10: 60.6 $\neq$ 1: n: n^2

Thus, it does not fit well into the law. Hence, to examine the verification of Bradford's Law of Scattering, Leimkuhler Model (Leimkuhler, 1967)[4] of distribution is employed. Leimkuhler model has been used many times in previous studies such as (Kalita, 2016)[8] (Tripathi & Sen, 2016)[17] (Wardikar & Gudadhe, 2013)[18] to study its applicability for calculating non cumulative rank frequency calculation.

Leimkuhler model of Bradford's distribution is a size frequency measure and in this model at first the core journals with specific citations in the first zone is determined and then Bradford Multiplier is found out. Accordingly with its multiples the journals in the following zones are counted. Bradford's multiplier (K) for Leimkuhler distribution is counted with Egghe's formula (Egghe, 1986)[19].

Leimkuhler's model based on Bradford's verbal formulation is,

$R0 = T\,(K\text{-}1)/(Kp\text{-}1)$,

To apply this formula, first we have to find out value of "*K"* with the Egghe's mathematical formula for calculating the Bradford multiplier

$K = (e^{y}Y_m)^{1/p}$ where, $\{e^{y} = 1.781$ (Euler's No)$\}$

Y_m = no of citations in the most productive journal i.e. $Y_m = 254$ (From table no. 31)

P =Bradford's group of no of zones of distribution i.e. $P = 3$

By applying our data,

$K = (1.781 * 254)^{1/3} = (452.374)^{1/3} = 7.676$

Now, let's find out number of journals in the Nucleus of each zone by using Leimkuhler developed model,

$R_0 = T\,(K\text{-}1) / (K^{p} - 1)$, [$T$ = Total no of journals = 358 (table 7)]

$=358 * [(7.676\text{-}1) / \{(7.676)^{3} - 1\}] = 358 * (6.676/451.277411)$

$=358 * 0.014793561 = 5.296$

So, for this dataset $R_0 = 5.296$

That means in the Leimkuhler model of Bradford's distribution the core group contains 5.296 (≈5) journals.

Hence, the modified Bradford's distribution from Leimkuhler model can be written down as

= R0: R0 *K: R0 *K2

$= 5.296: 5.296 \times 7.676: 5.296 \times (7.676)^{2} = 5.296: 40.652:312.045 = 357.993$

% Error = {(358-357.993) ÷358} ×100

= 0.00195% = 0.002%

So, from the above equation % of error is found out to be 0.002% which is a very slight deviation. So we can acknowledge the acceptability of new modified Bradford's distribution given by the Leimkuhler model.

After application of Leimkuhler model we got three zones which are illustrated in table 6. The core zone which is Zone 1containing 5 journals with 33.78 % share of citations, Zone 2 containing 41 journals with 30.31 % and Zone 3 containing 312 journals with 35.91 % share of citations.

Table 6: Leimkuhler model Bradford's Distribution in 3 zones

Zone	No of Journals	cumulative no of journals	Total Citations share	cumulative no of citations	% Share to total citations
1	5	5	507	507	33.78
2	41	46	455	962	30.31
3	312	358	539	1501	35.91

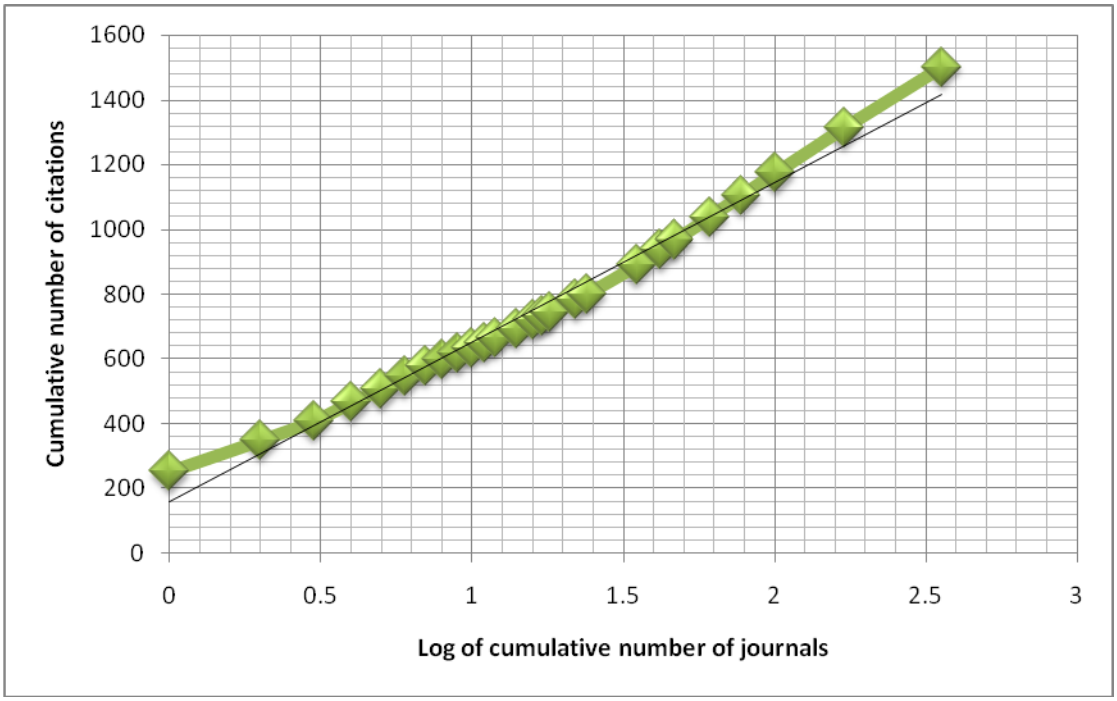

Figure 1: Graphical formulation of Bradford's distribution

Figure 1 gives a graphical formulation of the Bradford's law, when we put the log of cumulative number of journals in the X axis and cumulative no of citations in Y axis. In the graph we see there is a step rise initially which contains the core group of journals then it becomes linear and sloping part of the graph starts towards the end. So, the graph in figure 1 satisfies the criteria of Bradford's distribution graph given by Brookes[20].

Rank list of journals in Mathematics

A rank list of journals is prepared based on number of citations received and it is reported in table 7. It is found that out of total 1501 journal citations, "Fuzzy Sets & Systems" received highest 254 number of citations with a share of 16.92%; and stands in the first position in the rank list. It is published by Elsevier BV from Netherlands and it comes under the Scimago subject area of Computer Science.

Table 7: Rank list of journals in Mathematics

Rank	Book name	Number of citations	Percentage	Country	Publisher	Scimago Subject area
1	Fuzzy Sets & Systems	254	16.92	Netherlands	Elsevier BV	Computer Science
2	Journal of Mathematical Analysis and Applications	96	6.40	United States	Elsevier Inc.	Mathematics
3	Bulletin of Calcutta Mathematical Society	60	4.00	India	Calcutta Mathematical Society	N.I.S.*

4	The Journal of Fuzzy Mathematics	57	3.80	USA	International Fuzzy Mathematics Institute	N.I.S.
5	Journal of Tripura Mathematical Society	40	2.66	India	Tripura Mathematical Society	N.I.S.
6	Indian Joumal of Applied Physics	39	2.60	India	iScienceIn Publishing	N.I.S.
7	Computers and Mathematics with Applications	33	2.20	United Kingdom	Elsevier Ltd.	Computer Science
8	Information Sciences	21	1.40	Netherlands	Elsevier BV	Computer Science
9	International Journal of Mathematics and Mathematical Sciences	18	1.20	Egypt	Hindawi Publishing Corporation	Mathematics
10	Information and Control	17	1.13	China	Science Press	Computer Science

* **N.I.S.:** Not indexed in Scimago

"Journal of Mathematical Analysis and Applications" stands on the second position with 96 citations having a share of 6.40%. It is published by Elsevier Inc. from USA under the category of Mathematics. "Bulletin of Calcutta Mathematical Society" stands on third position with 60 citations having 4.00% share. It is published by Calcutta Mathematical Society from India.

Discussion and Conclusion:

A citation alone may look insignificant but when accumulated and analysed in bulk they can provide very useful and interesting insights about a discipline. In this study, citations in the field of Mathematics are analysed by using various scientometric techniques. The study, when applied different collaborative measures showed that that collaborative research activities are noticed in Mathematics literature.

Journals were found to be the most cited type of documents in the field of Mathematics which accounted for 82.07% of total share. "Fuzzy set theory and its Application" from Kluwer Academic Publisher was found to be the most cited book. On checking with library holdings it was found that 8 copies are available in the library. However, the library can purchase a few more copies in terms of better collection development. Fuzzy Sets & Systems published by Elsevier BV was found to be the most cited journal from the study. The library subscribe to this particular database and they can continue with the subscription in future as it is very useful. It was also found that foreign publications are more preferred by the scholars than that of domestic publications.

It can be concluded that no significant difference can be observed between CC values and MCC values, and also this variation narrows down when the number of authorship increases. It is quite evident that single authors remained dominant until 1950 but gradually increased number authorships since then and now trend is growing towards multiple authorship. Bradford's law was tested against

the dataset but did not fit the dataset very well as a result Leimkuhler's model was applied and it fitted the dataset.

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