Application of Bradford's Law of Scattering to the Solar Physics World Literature: A Scientometric Study

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Abstract

Bradford's law of scattering is one of the fundamental laws of bibliometric study, describes a quantitative relationship between journals and the papers they publish in any given subject field. This paper deals with the applicability of Bradford law of scattering, study include 80 journals publishing 1,28,003 articles, in the world solar physics literature published during 1991-2015. Ranked list of journals prepared, Astrophysical journal alone publish with 25% of the articles in solar physics field, followed by Astronomy and Astrophysics with 20% articles. The applicability of Bradford's law was tested. The journal distribution pattern of the solar physics literature does not fit the Bradford's distribution pattern. The applicability of Egghe's model (modification of Leimkuhler's model) was also tested and here also the dataset does not fit the Bradford's distribution pattern.

Keywords: *Bradford's law, Leimkuhler's model, Egghe's model, Solar, Physics.*

Introduction

Research journals are the chief means of primary sources of information; they publish original and unfiltered ideas and serve as the main communication channel to the researchers in the field of study. Some journals which are referred and cited by most of the authors because of the resemblance of the

subject scope of the journal and areas of research work i.e. they identify and forecast of existing new concepts, approaches, techniques and growth and developments in the subject in order to keep the researchers well informed. The concept of core journals was derived from the 'Bradford's law of scattering', formulated by S. C. Bradford in 1934, and Eugene Garfield in 1960s while selecting the journals in different subject fields for the preparation of *Science Citation Index*.

Bradford's law explains how the literature on a particular subject field scattered or distributed in the journals. It was first reported in 1934 in the journal *Engineering* by Bradford and, subsequently, in book titled *Documentation* by the same author in 1948 where the verbal formulation and graphical representation of his law is explained. The present paper examines the application of Bradford's law of scattering to Solar Physics literature published worldwide during 1991-2015.

Objective of the study

To apply Bradford's law of scattering to Solar Physics literature and verify if the law holds good.

Methodology

Citations and cited references are the prime data elements for conducting the scientometric analytic studies. The citation indexing database provides such data and it is a technique of detecting the relationship of documents through citation, as they exhibit some association of ideas between citing and cited paper.

The present study focused on the verification of Bradford's law of scattering to the research outcome of worldwide solar physicspublished during 1991-2015. The data for this study was collected from the Science Citation Index- Expanded (SCI-E) of Web of Science, a comprehensive citation indexing database containing almost all subjects of science and technology.The study identified the journals and their corresponding frequency of articles for the verification of Bradford's law of scattering suggested by Bradford and Egghe's model i.e. modification of the Leimkuhler's model.(Wardikar, 2013).

Results and discussion

Publication Productivity

Quantifying the growth of publications in a subject and different subject fields is an interest to scientometrics. The publication productivity reefers to increase of research activities in terms of publications in different forms and languages over a period of time. Scientometric inferences on study of growth of publications regarded as one of the most objective and reliable method of assessment.

Table 1 : Year-wise contributions in the field of Solar Physics.

Year	No. of Articles	Cum-Articles	%	Citations	Cum-Citations	Cit./ Article	Ref.	Cum-Ref.	Ref./ year
1991	3997	3997	2.52	130284	130284	32.6	120142	120142	30.06
1992	3457	7454	2.18	131020	261304	37.9	107433	227575	31.08
1993	4166	11620	2.63	138557	399861	33.26	123032	350607	29.53
1994	4635	16255	2.92	152537	552398	32.91	135234	485841	29.18
1995	4763	21018	3.00	171118	723516	35.93	144798	630639	30.40
1996	4663	25681	2.94	163927	887443	35.15	151243	781882	32.43
1997	5524	31205	3.48	179883	1067326	32.56	161065	942947	29.16
1998	4673	35878	2.95	187995	1255321	40.23	143606	1086553	30.73
1999	6201	42079	3.91	193964	1449285	31.28	200417	1286970	32.32
2000	6328	48407	3.99	205702	1654987	32.51	211033	1498003	33.35
2001	6734	55141	4.25	203096	1858083	30.16	230731	1728734	34.26
2002	6230	61371	3.93	191174	2049257	30.69	213295	1942029	34.24
2003	7008	68379	4.42	211499	2260756	30.18	244086	2186115	34.83
2004	6730	75109	4.24	197222	2457978	29.3	243684	2429799	36.21
2005	7317	82426	4.61	189447	2647425	25.89	256276	2686075	35.02
2006	7007	89433	4.42	187618	2835043	26.78	269685	2955760	38.49
2007	7101	96534	4.48	181400	3016443	25.55	277925	3233685	39.14
2008	7408	103942	4.67	168618	3185061	22.76	288976	3522661	39.01
2009	7696	111638	4.85	170714	3355775	22.18	324415	3847076	42.15
2010	7979	119617	5.03	146449	3502224	18.35	335222	4182298	42.01
2011	7997	127614	5.04	134229	3636453	16.78	359642	4541940	44.97
2012	8376	135990	5.28	115412	3751865	13.78	391081	4933021	46.69
2013	7397	143387	4.66	87220	3839085	11.79	387962	5320983	52.45
2014	7438	150825	4.69	56958	3896043	7.66	397786	5718769	53.48
2015	7744	158569	4.88	28662	3924705	3.7	424449	6143218	54.81
	158569			**3924705**			**6143218**		

The year-wise number of articles, the impact of these articles in the form of citations received and the cited references quoted in the articles are tabulated in the above table and depicted in the figure-1.

The sum of 158569 publications published by the world wide scholars in the field of solar physics during 1991-2015.Theyear 2012 witnessed the most productive year having 8376 (5.28 %) papers published, followed by 7997 (5.04%) in the year 2011 and 7979 (5.03%) papers in 2010, the mean of number of papers per year was 6343.

A great deal of (3924705) citations been received for the articles published solar physics during 1991-2015. It was observed that the largest number 211499 (5.39 %) of citations received in the year 2003. The maximum citation/article/ year was 40.23 observed in the year1998 and the mean citation/article/year was 26.4. Similarly, significant number (16143218) of cited references was quoted in all the articles published during the period of study in the world solar physics filed. There was gradual regular increase in the number of cited references observed during the period of study.

It was observed that the largest number 42449 (7 %) of cited references quoted in the year 2015. The maximum citation/article/year was 54.81 observed in the year 2015 and the mean citation/article/year was 37.44.

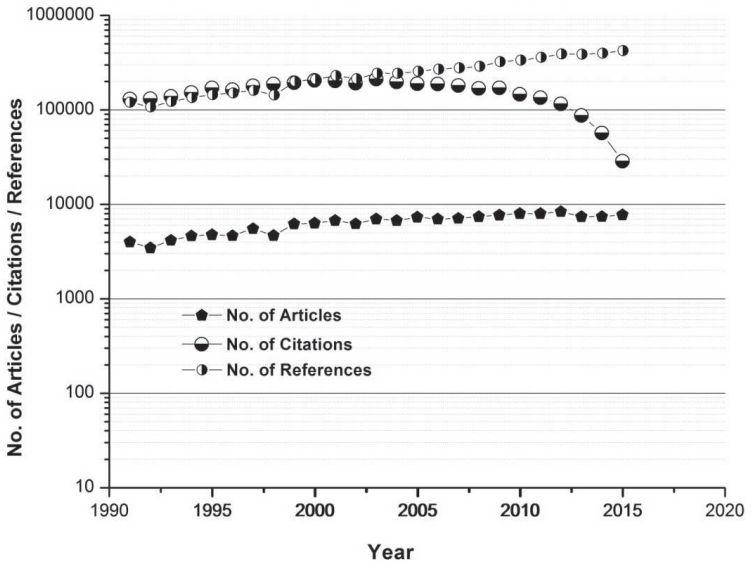


Figure 1 : Publication productivity of solar physics research.

Ranked List of Cited Journals in Solar physics world Literature

The ranked list of journals tabulated in the Table-2. The total 80 journal ranks were awarded, all these journals published as many as 1,28,003 articles in solar physics subject during 1991-2015. Among these journals, *Astrophysical journal* tops the journal ranking list by publishing the highest number of articles (32705 26%), followed by *Astronomy and Astrophysics*(25886 20%) articles and *Mon. Not. Roy. Astron. Soc.*occupied third rank with (16053 13%). *Astronomical Journal* with (6298 5%) articles took the fourth rank and *J. Geophys. Res-Space Phys.*(5818 5%) fifth rank, and so on.

The top three ranked journals in the ranked list contributed to nearly 60% of the total articles and the first eight journals contributed to more than 75% of the total journals literature. This clearly indicates that the substantial research output of solar physics research concentrated in the small list of journals.

Table 2 : Ranking of journals publishing solar physics literature

Ranking	Journal Name	No. Articles	% of Articles	No. of Citations	% of Citations
1	Astrophys. J.	32705	25.55	1402840	36.50
2	Astron. Astrophys.	25886	20.22	749577	19.50
3	Mon. Not. Roy. Astron. Soc.	16053	12.54	462667	12.04
4	Astron. J.	6298	4.92	261439	6.80
5	J. Geophys. Res-Space Phys.	5818	4.55	154405	4.02
6	Sol. Phys.	3671	2.87	81074	2.11
7	Astrophys. J. Lett.	3252	2.54	70824	1.84
8	Astrophys. Space Sci.	3117	2.44	16807	0.44
9	Phys. Rev. D	2296	1.79	66601	1.73
10	IAU Symposium Proc. Series	2286	1.79	1844	0.05
11	Publ. Astron. Soc. Pac.	1711	1.34	57612	1.50
12	Astrophys. J. Suppl. Ser.	1704	1.33	122751	3.19
13	Publ. Astron. Soc. Jpn.	1618	1.26	26804	0.70
14	Astron. Astrophys. Suppl. Ser.	1538	1.20	60457	1.57
15	Astro. Nachr.	1459	1.14	11137	0.29
16	Space Sci. Rev.	1431	1.12	46108	1.20

17	Ann. Geophys.	1149	0.90	16483	0.43
18	Adv. Space Res.	1138	0.89	6962	0.18
19	Astron. Lett.-J. Astron. Space Astrophys.	1098	0.86	6333	0.16
20	Astron. Rep.	904	0.71	4674	0.12
21	Planet Space Sci.	879	0.69	12399	0.32
22	Icarus	806	0.63	24776	0.64
23	New Astron.	755	0.59	7521	0.20
24	Phys. Lett. B	552	0.43	18796	0.49
25	Acta Astron.	498	0.39	11393	0.30
26	Res. Astron. Astrophys.	493	0.39	2615	0.07
27	Balt. Astron.	447	0.35	1606	0.04
28	Class. Quantum Gravity	442	0.35	9715	0.25
29	Rev. Mex. Astron. Astrofis.	430	0.34	3339	0.09
30	Astrophysics	421	0.33	708	0.02
31	Chin. J. Astron. Astrophys.	416	0.32	2788	0.07
32	Publ. Astron. Soc. Aust.	408	0.32	4565	0.12
33	J. Astrophys. Astron.	365	0.29	1776	0.05
34	Int. J. Mod. Phys. D	343	0.27	2786	0.07
35	New Astron. Rev.	342	0.27	4547	0.12
36	Astron. Zhurnal	339	0.26	967	0.03
37	Ann. Geophys.-Atmos. Hydrospheres Space Sci.	313	0.24	6289	0.16
38	Observatory	275	0.21	1044	0.03
39	J. Cosmol. Astropart. Phys.	272	0.21	4935	0.13
40	Earth Moon Planets	260	0.20	1790	0.05
41-80	Other (40) journals	3815	2.98	91691	2.39
	Total	**128003**		**3843445**	

Bradford's Law of Scattering

Ranking of journals in a subject field is an important aspect of scientometric studies especially the Bradford's law of scattering, has its application in the acquisition policy of journals in libraries and assessing the important of one or more journals in a particular subject field.

Bradford law of scattering describes how the literature on a particular subject is scattered or distributed in various journals, and he formulated that,"if a scientific periodicals are arranged in an order of decreasing productivity of articles on a given subject, i.e., the journal that yields the most relevant articles coming first and the most unproductive last, then the journals will be grouped into three zones, each zone containing one third of the total number of articles, when the number of periodicals in the first (nucleus zone) and succeeding zones will be as *1: n : n*^{2}where 'n' is a multiplier"(Bradford, 1934).

Bradford did not give a mathematical model for his law. Models were suggested later by Brookes(1969a, 1969b), Vickery and Leimkuhler (1967), Wilkinson (1972), Egghe (1985, 1986, 1990), Basu (1992), Ravichandra Rao (1998). Several authors, while explaining the scattering of articles in journals, have formulated many different models of Bradford's Law (Sudhier, 2010).

Brookes model (1969)

$$F(x) = a + b \log x \qquad (1)$$

where *F*(*x)* is the cumulative number of referencescontained in the first *x* most productive journals, and *a*and *b* are constants. This is the most widely usedformulation of Bradford's Law.

Vickery (1948) extended the verbal formulation to show that it can be applied to any number of zones of equal yield.

Leimkulher (1967) model

$$R(r) = a \log(1 + br) (2)$$

where *R* (*r)* is the cumulative number of articles contributed by journals ranked 1 through *r*, and *a* and *b* are parameters. Where *r = 1, 2, 3 ….*

Egghe model (1985,1986)- modifications for calculating the Bradford's Multiplier based on Leimkulher's model

$k = (e^{\gamma} \times Y_m)^{1/p(3)}$

Where γ is Euler's number ($e^{\gamma} = 1.781$) , p = Number of zones i.e. 3.

y_m = Number of items in the most productivity sources.

r_0 = Number of journals in the nucleus of Bradford is calculated as:

$$r_0 = \frac{T\,(k-1)}{(k^p - 1)}$$

where T = Total number of journals

Application of Bradford's Law

Table 3 presents details of frequency of journal articles arranged in decreasing order of the articles to test the Bradford's law.

For testing the Bradford's law, the 80 journal titles were divided into three zones. The distribution of journals and corresponding number of articles in the three zones along with the value of Bradford multiplier are shown in the Table 4.

In the present dataset, the first single journal covered 32705 articles, next 4 journals covered 54055 articles and next 75 journals covered 41243 articles. It can be noticed that the three zones are not exactly the 1/3rd of the total articles as suggested by Bradford. The first zone has less articles as compared to the second zone and the third zone is similar to 1/3rd of articles i.e. 32.2%.

Table 4 : Scattering of journals and Articles over Bradford Zone

Zone	No. of Journals	No. of Articles	Bradford Multiplier
1st	1	32705	---
2nd	4	54055	4
3rd	75	41243	18.75
Total	**80**	**128003**	

The identified zones arranged in the geometric series in the form of ***1:n:n²*** as given by Bradford. We found that, the relationship of each zone in the present study is 1:11:129. This does not fit into the Bradford's distribution.

Here, 1 represent the number of journals in the nucleus zone and the mean value of multiplier is n=11.38.

Therefore, $1 : (1 \times 11.38) : (1 \times 11.38^2) :: 1 : n : n^2$

$1 : 11 : 129$

$$The\ percentage\ of\ error = \frac{129}{80}\ x\ 100 = 61.25\ \%$$

Since the percentage of error is very high here, the data will not fit well the Bradford's law.

Application of Egghe's model

As the data set does not fit into Bradford's model, therefore the Egghe's model i.e. modification of Leimkuhler is employed for the verification of Bradford's law of scattering. For application of Bradford's law, three zones were selected, p=3, $y_m = 32705$.Then by using mathematical formula (3), the value of the Bradford's multiplier *k* is calculated as:

$k = (1.781 \times Y_m)^{1/p}$

$k = (1.781 \times 32705)^{1/3} = 38.76$

$$y_0 = \frac{A}{P} = \frac{128003}{3} = 42667.66$$

and r_0 = number of journals in the nucleus of Bradford is calculated as:

$$r_0 = \frac{T(k-1)}{(k^p - 1)}$$

Where T = total number of journals

$$r_0 = \frac{80(38.76 - 1)}{(38.76^3 - 1)} = 0.0518$$

The No. of Journals in the nucleus zone is 0.0518, which is practically not possible. The number of journals in the nucleus should be one or more than one. If we consider =1and Bradford Multiplier is 38.76.Therefore, the distribution is written as:

1: (1x38.76) : (1x38.76^2) :: 1 : k : k^2

i.e 1:39: 1502

Here the journals exceeding the existing journal range. This study identified only one journal in the nucleus zone and 39 journals in the second zone and in the third zone the number of journals exceeding the 80 which is not true. Hence we can infer that, when the Egghe's model applied for the testing the Bradford's law, it is found that the selected data set does not fit into the Bradford's law.

Conclusion

The journal distribution pattern of the world wide solar physics literature published during 1991-2015 does not fit the Bradford distribution pattern, i.e. 1: n: n^2. Similarly when the Egghe's model applied for same data set for the verification of Bradford's law and it is found that the data set does not fit Bradford's distribution pattern.

The data also revealed that out of 80 journal titles, only one journal 'Astrophysical Journal' in the nucleus zone would ensure 26 % of the journal literature. This indicates that the majority of solar physics literature concentrated on very few core journals in the subject.

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