Journal Productivity in Geology: Assessing the Applicability of Bradford's Law and Leimkuhler Model

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Abstract

The paper examines journal productivity in the field of Geology in India over a span of 32 years (1989-2020) utilizing the Web of Science (WoS) database.The list of journals based on the ranksrevealed that the *Journal of the Geological Society of India*is the most productive journal, followed by the *Journal of Earth System Science*. Both journals are published in India and are among the three core journals identified. Bradford's zones were calculated for overall productivity as well as for each block of an 8-year period. However, the distribution of journals did not adhere to Bradford's model, except during Block 1. Additionally, the Leimkuhler model was applied, but it did not align with the observed journal distribution. This was verified using the K-Sstatistical test, as the maximum difference between the observed and expected journal distribution (D_{max}=0.1953) was greater than the critical value ($D_{c.v.}$=0.1075).

Keywords: Journal productivity, Bradford's law, Leimkuhler model, K-S Test, Core Journals, Impact factor

Introduction

Journals are essential for disseminating the latest advancements and discoveries in all fields. They are the primary platforms where new ideas and findings are published, crucial for staying current and fostering innovation (Kumbar et al., 2007; Velmurugan & Radhakrishnan, 2015). Journals also play a key role in formalizing the exchange of information, which is vital for advancing and integrating knowledge across different disciplines (Boyer & Carlson, 2010). However, the proliferation of academic journals, the broad range of interdisciplinary research they cover, and increasing costs pose a challenge for librarians tasked with selecting the most relevant ones for specific fields.

In order to determine the key journals within a particular field, S.C. Bradford, Chief Librarian of the London Science Museum, examined the references quoted in the bibliographies of Applied

Geophysics and Lubrication. He ranked the journals by productivity, divided them into three zones with equal references, and observed a consistent pattern in the number of journals in each zone, concluding that the number of journals in each successive zone follows a specific pattern (Sudhier, 2010). Hence, the law states that when the journals on a specific subject are listed in descending order based on the number of articles they publish, they can be divided into a core group of periodicals highly devoted to the subject and successive zones of periodicals less devoted to the subject, each comprising the identical number of articles as in the core group. The number of periodicals in the core group and each subsequent zone will follow the ratio1: n: n^2…., where n denotes the Bradford multiplier. (Bradford,1948).

Bradford's law of declining productivity, formulated by Bradford in 1948, indicates that for a certain subject area, there are a limited number of journals that are highly productive, a larger number of moderately productive journals, and a still larger number of least productive journals (Nash-Stewart et al., 2012). This law allows us to assess how often articles on a specific subject appear in journals focused on different topics, while also considering the possibility that a journal dedicated to one subject might contain relevant articles for another subject area. (Alabi, 1979). Based on this law, it can be said that every individual subject exhibits an association with all other scientific disciplines, irrespective of the extent of their proximity (Zafrunnisha, 2012).

Review of Literature

Many studies have been done to assess the suitability of Bradford's law in various subject fields. **Pandey et al. (2024**) utilised Bradford's law to identify the core journals publishing articles on the application of AI and ML in Defence Technology and Military Operations that have been published. **Bapte and Nagpal (2023)** discovered that, with a small percentage error, the journal distribution of publications on 'plagiarism' follows Bradford's distribution, having 52 core journals. **Gupta and Singh (2023)** applied the Leimkuhler model for publications on artificial Intelligence for two groups, one having three zones and the other having five zones. **Borgohain et al. (2021)** concluded that the distribution of 213 sources belonging to Information Science literature, which were indexed in Scopus, did not follow the law. While it followed the Leimkuhler model.**Gayan and Singh (2019a, 2019b, 2021**) assessed the law on the citations extracted from the theses in the fields of Physics, Chemistry, and Mathematics. They found out that the zoning of citations did not obey the law, although the datasets follow the modified distribution as per the Leimkuhler model. **Desai et al. (2018)** applied the law to identify the core journals in paediatric surgery to assist surgeons in staying current with their reading.**Renjith and Shihab (2018)** examined journal indices of Geology journals. **Gourikeremath (2017)** investigated the law of scattering in the field of Microbiology. The law did not fit the sample theoretically, but was found to fit it verbally.**Kalita (2016)** examined the applicability of the law on the citations of the research articles published in the *Science* journal and found that it was not applicable. However, the Leimkuhler model was found to be suitable with only 0.045% error. The crop science literature failed to follow both Bradford's law and Leimkuhler's model, as analysed by **Tripathi and Sen (2016)**. **Joshi et al. (2015)** also found the non-applicability of the verbal formulation of the law for Stellar Physics. However, the graphical formulation and Leimkuhler model were found suitable. The study conducted by **Kumar (2014)** revealed that the verbal formulation of Bradford's law did not satisfy the articles published on Human-Computer Interaction, while the graphical formulation satisfied. On applying the Leimkuhler model, the values of D_{max} were found to be higher than the K-S test's values for all the data sets. **Ram and Paliwal (2014)** observed that the literature published on Psoriasis during 1960-2009 using the PubMed database did not follow Bradford's distribution, but followed the Leimkuhler model. **Singh and Bebi (2014)** found the law applicable to the journal distribution in 26 social sciences Ph.D. theses submitted to the University of Delhi. **Wardikar (2013)** conducted a comparable analysis of journal citation data from PhD theses submitted at Maharashtra State Universities, and with a very small percentage error of 0.048%, the Leimkuhler model was found to be applicable. **Sudhier (2010)** observed the trend of the journals collected from 79 IISc's Doctoral theses. A very small percentage error of 0.072% explained that the dataset followed Bradford's distribution.Many of the early attempts include studies by **Chakraborty (1970, 1971b)** to analyze the documentation pattern in Geology in India; by **Nag (1982, 1984)**; and **Kapoor (1984)** to document the data activities and databases in Earth Sciences in India. **Raina (1983)**tried to analyse geologists' communications published in the Journal of the Geological Society of India. **Gupta (1985)** studied periodical literature on Petroleum Geology. **Nijagunappa and Nijagunappa (1985)**; and **Parvathamma (1990)** attempted to find the core journals in the field of Earth Sciences during 1978-82 and 1978-88, respectively.

Objectives

i. To identify the Bradford zones and assess Bradford's Law of scattering.
ii. To compile a list of journals based on their ranks and identify the core journals in the field of Geology during 1989-2020.
iii. To test the applicability of Leimkuhler's Model using the K-S Test.

Hypothesis

Null Hypothesis (H_0): There is no significant difference between the observed and expected journal productivity in the field of Geology.
Alternate Hypothesis (H_a): There is a significant difference between the observed and expected journal productivity in the field of Geology.

Methodology

A total of 19,102 papers in the field of Geology from India during 1989-2020 were downloaded using the Advanced Search option of the Web of Science database. The search is performed using the field tags SU (Research Area), CU (Country), and PY (Year). The results obtained are further refined by the document types (Article, Proceeding Paper, Review) and indexes (SCI-

EXPANDED OR CPCI-S) covered by the database. The data of 32 years was divided into four blocks of eight years each, viz. **Block 1**(1989-1996),**Block 2**(1997-2004), **Block 3 (**2005-2012), **Block 4 (**2013-2020). Analysis was conducted using MS Excel. The impact factors of the journals were determined using the Journal Citation Report (JCR) for the year 2021.

Research articles are publications that present new results, while reviews aim at reviewing the literature on a specific topic, and, on the other hand, conference papers in general present intermediate results of in-progress research (Abramo& D'Angelo, 2015). According to Garg et al. (2010), these document types are peer reviewed and constitute the core of the communication channel. These three document types, namely article, proceeding paper, and review, are the most citable items among all the types of documents as observed by Joshi et al. (2010). Therefore, out of the 17 types of documentsthat contained the geology literature, only Article, Proceedings Paper, and Review have been selected for the analysis.

Results

Journal Productivity in the field of Geology (1989-2020)

Total output in the field of Geology from India accounts for 19,102 publications. These are found to be scattered in 230 journals, including series titles that include proceeding papers, but have been listed under the name of the parent journal for the analysis. Few journals changed their names during the course of study; for the sake of uniformity, the current names of the journals have been used.

The 230 journals are ranked from 1 to 98 based on the number of publications published by them. From Table 1, the *Journal of Geological Society of India* (TP=3,696) ranks first, followed by the *Journal of Earth Science* (TP=1,799), and *Advances in Space Research* (TP=759). In terms of total citations received, *Journal of the Geological Society of India* (TC=20,090), *Geophysical Research Letters* (TC=17,840), and *Journal of Earth System Science* (TC=13,439) are found as the top three journals. In terms of impact, *Annual Review of Earth and Planetary Sciences* (CPP=237.5), *Nature Geoscience* (CPP=178.8), and *Journal of Geophysical Research-Solid Earth and Planets* (CPP=136) are found to be the top 3 journals. Figure 1 depicts the citation impact of zone 1 and 2 journals. The journals, *Nature Geoscience* (IF=16.908), *Annual Review of Earth and Planetary Sciences* (IF=12.81), and *Earth System Science Data* (IF=11.333), have the highest impact factor rankings in JCR 2021, but exhibit minimal publication output of geology literature from India.

Only four (1.74%) out of 230 journals published from India are found to be indexed in the Web of Science database. These four journals are *the Journal of the Geological Society of India, the Journal of Earth System Science, the Himalayan Geology,* and *Disaster Advances* (Table 1).

Top Journals

Among the core journals, the *Journal of the Geological Society of India (JGSI)*, India, is found to be the most productive one, containing 3,696 (19.35%) articles. It has been published by the Geological Society of India since 1959 and is one of India's leading Earth Science journals. It has a citation impact of 5.4 and an impact factor of 1.459. The journal was also found to be the topmost journal among the core journals in the field of *Earth Sciences* by Parvathamma et al. (1991). It has also been listed as the ninth most cited journal in Earth Sciences by the scholars at Manipur University (Yumnam&Phuritsabam, 2019) and the fourth most cited journal in *Geology* by the researchers at Andhra University (Prasad et al., 2007). The journal was the second most productive journal in the field of *Himalayan R&D* (Gupta & Gupta, 2014). The publications of this journal have been subjected to bibliometric analysis by Raina (1983) and Renjith &Pradeepkumar (2021). It has also been found to be the most preferred journal by the researchers from the University of Delhi for publishing their research (Azmi, 2016). This shows the importance of the journal.

The second journal in the nucleus zone is the Journal of Earth System Science (JESS), published by the Indian Academy of Sciences, India. 1,799 papers have been published in this journal, which received 13,439 citations with CPP=7.5. Its impact factor is 1.371. The journal was formerly a part of the *Proceedings of the Indian Academy of Sciences-Section A*, which was first published in 1934. Later, it was published as *Proceedings-Earth and Planetary Sciences* beginning in 1978, and it remained under that name until 2005, when it was rebranded as the *Journal of Earth System Sciences*.

Advances in Space Research, published by Elsevier, is the third journal in the nucleus with 759 articles and 4,513 citations and a CPP value of 5.9. It is published from the UK and has an impact factor of 2.152.

The journal, *Himalayan Geology* (HG), published by the Wadia Institute of Himalayan Geology, is the third Indian journal that is among the topmost journals with 11th rank (TP=315). It ranks 208th in terms of citation impact (CPP=2.1), which is very low as compared to other journals.

Also, the journal *Gondwana Research (GR)*has the highest Impact Factor (6.051) among the 230 journals. The journal is in zone 2 and ranks 12th in terms of total publications (TP=287) and 6th in terms of citation impact (CPP=20.7).

It is also observed that the highest citation impact (37.9) is received by the 274papers published in the journal *Precambrian Research (PR)*, published by Elsevier. The journalis in zone 2 and ranks 13th in total number of papers (TP=274) and 5th in Impact Factor(IF = 4.725).
The journal *Environmental Geology (EG)*, which ranks 14th in zone 2, was last published in the year 2009, and hence its impact factor is not available in the JCR 2021.

Table 1

Rank List of Journals in Geology (1989-2020)

S. No.	Journal	TP	TC	CPP	JCR-IF 2021	Publisher	Country	*Rank*
				ZONE 1				
1.	**Journal of the Geological Society of India (JGSI)**	**3696**	**20090**	**5.4**	**1.459**	**Geological Society of India**	**India**	***1***
2.	**Journal of Earth System Science (JESS)**	**1799**	**13439**	**7.5**	**1.371**	**Indian Academy of Sciences**	**India**	***2***
3.	Advances in Space Research (ASR)	759	4513	5.9	2.152	Elsevier	UK	*3*
				ZONE 2				
4.	Environmental Earth Sciences (EES)	729	5952	8.2	2.784	Springer	Germany	*4*
5.	Natural Hazards (NH)	724	6085	8.4	3.102	Springer	Netherlands	*5*
6.	Geophysical Research Letters (GRP)	651	17840	27.4	4.72	American Geophysical Union	US	*6*
7.	Arabian Journal of Geosciences (AJG)	641	2774	4.3	1.827	Springer	Germany	*7*
8.	Journal of Asian Earth Sciences (JAES)	619	8127	13.1	3.449	Elsevier	UK	*8*
9.	Journal of Hydrology (JH)	499	12294	24.6	5.722	Elsevier	Netherlands	*9*
10.	Annales Geophysicae (AG)	367	5372	14.6	1.88	Copernicus Publications	Germany	*10*
11.	**Himalayan Geology (HG)**	**315**	**655**	**2.1**	**1.293**	**Wadia Institute of Himalayan Geology**	**India**	***11***
12.	Gondwana Research (GR)	287	5944	20.7	6.051	Elsevier	US	*12*
13.	Precambrian Research (PR)	274	10372	37.9	4.725	Elsevier	Netherlands	*13*
14.	Environmental Geology* (EG)	265	7991	30.2	NA	Springer	US	*14*
15.	Quaternary International (QI)	235	2620	11.1	2.13	Elsevier	UK	*15*
16.	Geocarto International (GI)	232	1305	5.6	4.889	Taylor & Francis	UK	*16*
17.	Journal of Coastal Research (JCR)	222	1552	7.0	0.854	Coastal Education & Research Foundation	USA	*17*
18.	PalaeogeographyPalaeoclimatologyPalaeoecology (PPP)	188	3907	20.8	3.318	Elsevier	Netherlands	*18*
19.	Journal of Geotechnical and Geoenvironmental Engineering (JGGE)	179	3448	19.3	4.012	American Society of Civil Engineers	US	*19*
				ZONE 3				
20.	The remaining 211 journals	6412	96491	15	16.908 to 0.202	89 publishers	-	20 to 98
	Total	**19102**	**230819**	**12.1**				

(**Environmental Geology* was last published in the year 2009, and hence its impact factor is not available in the JCR 2021)

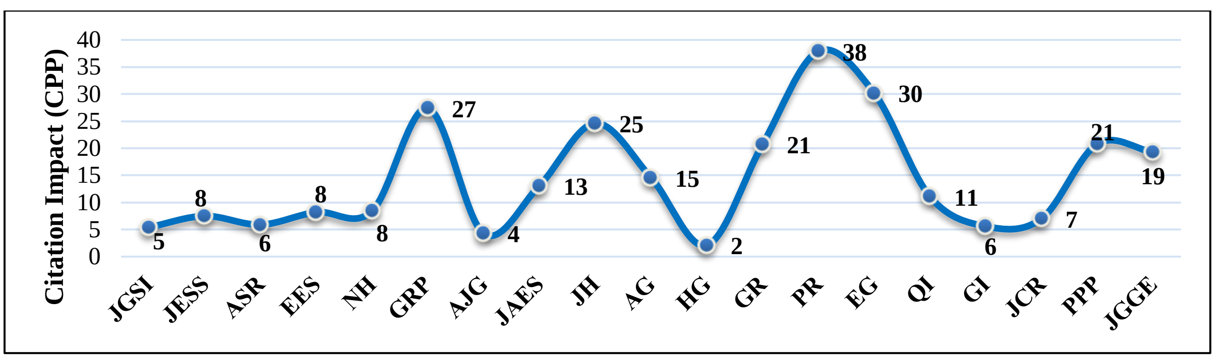

Fig. 1: Citation Impact of Journals of Zone 1 & 2 in Geology (1989-2020)

Application of Bradford's Law of Scattering of Journals

In order to assess the law, the journals have been arranged into three zones. Ideally, each zone should contain roughly the same number of articles, which would be close to one-third of the total number of articles across all the journals. Since the total number of publications is 19,102, each zone must contain approximately 6,367 publications. From tables 1 and 2, the first zone (nucleus zone) contains only 3 (1.3%) journals, which cover 6,254 (32.74%) publications. The second zone (allied journals) contains 16 (6.9%) journals with 6,427 (33.64%) publications. The remaining 211 (91.41%) journals in the third zone (alien journals) contain 6,412 (33.61%) publications. The Bradford multiplier, denoted by k, is derived by dividing the number of journals in a specific zone by the number of journals in the previous zone. The Bradford multiplier for zone 2 is calculated as 5.33, while for zone 3 is calculated as 13.19. The mean Bradford multiplier is obtained by taking the average of the two values of each zone. Hence, the mean Bradford multiplier is$(5.33 + 13.18)/2 = 9.26$.

Bradford Zones:

According to Bradford's Law of Scattering, the identified zones will approximately follow a geometric series in the form of 1: n: n^2. The series is expressed as:

$$1: n: n^2 \sim 3: 3 \text{ x } 9.26: 3 \text{ x } (9.26)^2 \sim 3: 27.78: 257.24 = 288.02 \sim 288$$

The relationship of each zone in the case of Geology literature comes out to be 3:28:257. Here, 3 denotes the number of core journals.

$$\text{Percentage error} = \frac{288-230}{230} \times 100 = 25.22\%$$

Cline (1981) stated that if any group of data which have a low percentage error can adhere to the Bradford law. Based on the calculation, it is found that the percentage error is very high (25.22%), and hence, the data from the Geology literature does not fit the Bradford expression. Therefore, to verify Bradford's law in the field of Geology, it is decided to check the compatibility with the Leimkuhler model.

Table 2
Distribution of zones in Geology (1989-2020)

Zones	Number of Journals in each zone	Journals (%)	Number of Publications in each zone	Publications (%)	Bradford Multiplier
1	3	1.3	6254	32.74	
2	16	6.9	6427	33.64	5.33
3	211	91.7	6421	33.61	13.19
All Zones	**230**		**19102**		**9.26**

Application of Leimkuhler Model

If the scattering ofjournals doesn't follow the pattern predicted by Bradford's law, the Leimkuhler model is used to verify the law (Gupta & Singh, 2023), which is expressed as (Leimkuhler, 1967):

$\boldsymbol{R(r) = a\, log\,(1 + br)}$……………………. (1)

Where *R(r)* denotes the cumulative number of publications contributed by journals of rank 1, 2, up to *r*. The constants *a* and *b* given in equation (1) can be calculated using the equations given by Egghe (1990):

$$\boldsymbol{a = y_0/\ln k} \text{……………………. (2)}$$

$$\boldsymbol{b = (k-1)/r_0} \text{……………………. (3)}$$

$r_0$is the number of journals in the first zone;
$y_0$is the number of publications in each zone of equal size; and
*k*isthe Bradford multiplier.
To find out k:

$$\boldsymbol{k = e^{\gamma}.{y_m}^{1/p} = 1.781.{y_m}^{1/p}} \text{……………. (4)}$$

The value ofγ (Euler's number) is 1.781. The variable*p* denotes the number of zones, which is equal to 3.

The variable y_m is the number of publications in the journal of rank 1; hence, from Table 1, $y_m = 3696$.Therefore,

$$\boldsymbol{k = (1.781.y_m)^{1/p} = \{1.781.(3696)\}^{1/3} = (6582.576)^{1/3} = 18.74} \sim 19$$

Furthermore,$y_0 = A/p$. The value of A is given by the total number of publications in the dataset. Hence,

$$\boldsymbol{y_0 = A/p = 19102/3 = 6367.33}$$

Also, the value of r_0 is calculated using following equation,$r_0 = T(k-1)/(k^p - 1)$, where, *T*=230 is the total number of journals.Therefore,

$$\boldsymbol{r_0 = 230(19-1)/(19^3 - 1) = 230(18)\,/6859 - 1) = 0.6036}$$

By putting the values of y_0, *k*, and r_0, in the equations (2) and (3), we can determine the values of the constants *a* and *b*, as shown below

$$\boldsymbol{a = y_0/\ln k = 6367.33/\ln(19) = 6367.33/2.944 = 2162.81}$$

$$\boldsymbol{b = (k-1)\,/\,r_0 = (19-1)\,/\,0.6036 = 29.82 \sim 30}$$

Then equation (1) is used to calculate the expected number of publications in all the journal ranks. For journals ranked 1, 2, and 3:

$\boldsymbol{R}(\mathbf{1}) = 2162.81\log\big(1 + 30(1)\big) = 2162.81\log(31) = 2162.81(3.434) = 7427.06$
$\boldsymbol{R}(\mathbf{2}) = 2162.81\log\big(1 + 30(2)\big) = 2162.81\log(61) = 2162.81(4.111) = 8891.04$
$\boldsymbol{R}(\mathbf{3}) = 2162.81\log\big(1 + 30(3)\big) = 2162.81\log(91) = 2162.81(4.511) = 9756.13$

Application of Kolmogorov-Smirnov (K-S) Test for Goodness of Fit

The validity of the Leimkuhler model is confirmed using the Kolmogorov-Smirnov Test for Goodness of Fit, commonly called theK-Stest, which compares cumulative frequencies of observed and expected journal productivity distribution (Massey, 1951). The maximum absolute deviation between the cumulative proportions of the observed and expected frequency is determined as $D_{max}=|f_o- f_e|$, *w*here, $f_o$is the fraction of the observed journal productivity; and $f_e$is the fraction of expected journal productivity (Kumar, 2014).

The expected number of publications for all journal ranks is shown in Table 3 using the Leimkuhler model mentioned in equation (1). This table also lists the fractionalized observed journal productivity distribution and the fractionalized expected journal productivity distribution. The fractionalization is done by dividing each value by the total number of publications, which is 19,102. Further, the difference in the fractionalized cumulative observed values and the fractionalized cumulative expected values is also mentioned in the table.

The K-S test depends on a critical value at a certain level of significance, and in the present study, the critical value (Dc.v) is calculated at the 5% level of significance, as shown below. If the value of D_{max}exceeds the value of $D_{c.v}$, then the null hypothesis is rejected. The critical value is $D_{c.v}$is given by(Massey, 1951):

$$D_{c.v}= \frac{1.36}{\sqrt{n}} = \frac{1.36}{\sqrt{\text{total number of journals}}} = \frac{1.36}{\sqrt{230}} = \frac{1.36}{15.166} = 0.1075$$

Now, for the present study, the maximum absolute difference D_{max}, as indicated in Table 3, is equal to 0.1953. Also, the critical value $D_{c.v}$is equal to 0.1075. As the maximum deviation exceedsthe K-S critical value (D_{max} =0.1953 > $D_{c.v}$ =0.1075) at the 5% level of significance, the alternate hypothesis is accepted, that ‘there is a significant difference between the observed and expected journal productivity in the field of Geology’. Therefore, the Leimkuhler model does not adequately explain the distribution of journal productivity in the field of Geology literature.From Table 4, the value of r_0 is 0.6036, which means that the nucleus zone of the Leimkuhler model contains 0.6036 (~1) journals.

Similarly, using the values of k and $r_o$from Table 4,the number of journals in each zone is given as follows:

First group $\boldsymbol{r_0}$= 0.60 ~ 1
Second group $\boldsymbol{r_0 \times k}$ = 0.60×18 = 10.8
Third group$\boldsymbol{r_0 \times k^2}$ = 0.60×18×18 = 194.4

Thus, the modified distribution based on Leimkuhler's model of Bradford's law (Leimkuhler,1980) can be expressed as:

$$r_0: r_0 \times k: r_0 \times k^2 = 0.60: 0.60(18): 0.60(18)(18) = 0.60:10.8:194.4 = 205.8$$

Based on the Leimkuhler Model, the total number of journals in which the Geology literature must have been scattered must be 205.8~206, instead of 230 journals.

$$\text{Percentage Error} = \frac{230-205.8}{230} \times 100 = 10.52\ \%$$

From the above equation, the percentage error is not acceptable. This is also in accordance with the results of the K-S Test. Therefore, the Geology literature does not conform to the modified distribution proposed by Leimkuhler.

Table 3

Application of Kolmogorov-Smirnov (K-S) Test for Goodness of Fit

Number of Journals	Corresponding Number of Papers	Cumulative Number of Publications	Rank of Journals (r)	Fraction of the Observed Journal Productivity (f_o)	Cumulative Number of Expected Publications by Application of Leimkuhler model	Fraction of the Expected Journal Productivity (f_e)	Absolute Difference $\lvert f_o - f_e \rvert$
Zone 1 1	3696	3696	1	0.1935	7427.06	0.3888	**0.1953**
1	1799	5495	2	0.2877	8891.04	0.4655	0.1778
1	759	6254	3	0.3274	9756.13	0.5107	0.1833
Zone 2 1	729	6983	4	0.3656	10372.38	0.5430	0.1774
1	724	7707	5	0.4035	10851.42	0.5681	0.1646
1	651	8358	6	0.4375	11243.36	0.5886	0.1511
1	641	8999	7	0.4711	11575.05	0.6060	0.1349
1	619	9618	8	0.5035	11862.57	0.6210	0.1175
1	499	10117	9	0.5296	12116.32	0.6343	0.1047
1	367	10484	10	0.5488	12343.40	0.6462	0.0973
1	315	10799	11	0.5653	12548.88	0.6569	0.0916
1	287	11086	12	0.5804	12736.52	0.6668	0.0864
1	274	11360	13	0.5947	12909.18	0.6758	0.0811
1	265	11625	14	0.6086	13069.07	0.6842	0.0756
1	235	11860	15	0.6209	13217.94	0.6920	0.0711
1	232	12092	16	0.6330	13357.23	0.6993	0.0662
1	222	12314	17	0.6446	13488.08	0.7061	0.0615
1	188	12502	18	0.6545	13611.47	0.7126	0.0581
1	179	12681	19	0.6639	13728.20	0.7187	0.0548
Zone 3 1	166	12847	20	0.6725	13838.95	0.7245	0.0519
1	155	13002	21	0.6807	13944.30	0.7300	0.0493
1	148	13150	22	0.6884	14044.76	0.7353	0.0468
1	147	13297	23	0.6961	14140.75	0.7403	0.0442
1	141	13438	24	0.7035	14232.67	0.7451	0.0416
2	140	13718	25	0.7181	14320.84	0.7497	0.0316
1	135	13853	26	0.7252	14405.56	0.7541	0.0289

1	134	13987	27	0.7322	14487.08	0.7584	0.0262
1	128	14115	28	0.7389	14565.64	0.7625	0.0236
1	127	14242	29	0.7456	14641.45	0.7665	0.0209
1	125	14367	30	0.7521	14714.69	0.7703	0.0182
1	118	14485	31	0.7583	14785.53	0.7740	0.0157
1	117	14602	32	0.7644	14854.12	0.7776	0.0132
1	113	14715	33	0.7703	14920.61	0.7811	0.0108
1	111	14826	34	0.7761	14985.11	0.7845	0.0083
1	109	14935	35	0.7819	15047.74	0.7878	0.0059
1	104	15039	36	0.7873	15108.62	0.7909	0.0036
1	101	15140	37	0.7926	15167.82	0.7940	0.0015
1	97	15237	38	0.7977	15225.45	0.7971	0.0006
1	96	15333	39	0.8027	15281.58	0.8000	0.0027
1	95	15428	40	0.8077	15336.29	0.8029	0.0048
1	88	15516	41	0.8123	15389.65	0.8057	0.0066
1	87	15603	42	0.8168	15441.73	0.8084	0.0084
1	73	15676	43	0.8206	15492.58	0.8110	0.0096
1	72	15748	44	0.8244	15542.26	0.8136	0.0108
1	71	15819	45	0.8281	15590.83	0.8162	0.0119
1	70	15889	46	0.8318	15638.33	0.8187	0.0131
1	69	15958	47	0.8354	15684.81	0.8211	0.0143
2	66	16090	48	0.8423	15730.32	0.8235	0.0188
2	61	16212	49	0.8487	15774.88	0.8258	0.0229
2	60	16332	50	0.8550	15818.55	0.8281	0.0269
1	56	16388	51	0.8579	15861.35	0.8304	0.0276
1	54	16442	52	0.8607	15903.32	0.8325	0.0282
2	53	16548	53	0.8663	15944.49	0.8347	0.0316
3	52	16704	54	0.8745	15984.89	0.8368	0.0376
2	51	16806	55	0.8798	16024.55	0.8389	0.0409
1	50	16856	56	0.8824	16063.50	0.8409	0.0415
2	48	16952	57	0.8874	16101.76	0.8429	0.0445
1	46	16998	58	0.8899	16139.35	0.8449	0.0450
2	45	17088	59	0.8946	16176.30	0.8468	0.0477
1	44	17132	60	0.8969	16212.63	0.8487	0.0481
1	43	17175	61	0.8991	16248.36	0.8506	0.0485
1	40	17215	62	0.9012	16283.51	0.8525	0.0488
4	39	17371	63	0.9094	16318.10	0.8543	0.0551
2	37	17445	64	0.9133	16352.14	0.8560	0.0572
3	35	17550	65	0.9188	16385.66	0.8578	0.0610
1	33	17583	66	0.9205	16418.66	0.8595	0.0610
5	32	17743	67	0.9289	16451.17	0.8612	0.0676
3	31	17836	68	0.9337	16483.20	0.8629	0.0708
1	30	17866	69	0.9353	16514.76	0.8646	0.0707
2	29	17924	70	0.9383	16545.86	0.8662	0.0721
1	28	17952	71	0.9398	16576.53	0.8678	0.0720
1	27	17979	72	0.9412	16606.76	0.8694	0.0718
4	26	18083	73	0.9467	16636.58	0.8709	0.0757
1	25	18108	74	0.9480	16665.99	0.8725	0.0755
1	24	18132	75	0.9492	16695.01	0.8740	0.0752
1	23	18155	76	0.9504	16723.65	0.8755	0.0749
2	22	18199	77	0.9527	16751.91	0.8770	0.0758
2	21	18241	78	0.9549	16779.80	0.8784	0.0765
3	20	18301	79	0.9581	16807.34	0.8799	0.0782
2	19	18339	80	0.9601	16834.54	0.8813	0.0788
4	18	18411	81	0.9638	16861.39	0.8827	0.0811
1	17	18428	82	0.9647	16887.92	0.8841	0.0806
2	16	18460	83	0.9664	16914.12	0.8855	0.0809
3	15	18505	84	0.9687	16940.02	0.8868	0.0819

3	14	18547	85	0.9709	16965.60	0.8882	0.0828
3	13	18586	86	0.9730	16990.89	0.8895	0.0835
7	12	18670	87	0.9774	17015.88	0.8908	0.0866
4	11	18714	88	0.9797	17040.59	0.8921	0.0876
9	10	18804	89	0.9844	17065.02	0.8934	0.0910
2	9	18822	90	0.9853	17089.18	0.8946	0.0907
2	8	18838	91	0.9862	17113.07	0.8959	0.0903
9	7	18901	92	0.9895	17136.70	0.8971	0.0924
5	6	18931	93	0.9910	17160.07	0.8983	0.0927
7	5	18966	94	0.9929	17183.19	0.8995	0.0933
9	4	19002	95	0.9948	17206.07	0.9007	0.0940
18	3	19056	96	0.9976	17228.71	0.9019	0.0957
15	2	19086	97	0.9992	17251.12	0.9031	0.0961
16	1	19102	98	1.0000	17273.29	0.9043	0.0957

Table 4
Value of the Parameters of Leimkuhler Model in Geology (1989-2020)

Time Period	**Parameters of the model**					D_{max}	$D_{c.v}$
	k	r_0	y_0	**a**	**b**		
1989-2020	19	0.6036	6367.33	2162.81	30	0.1953	0.1075

Block-wise Application of Bradford's Law of Scattering

i. **Block 1(1989-1996)**:During Block 1 (1989-1996), a total of 2,021 publications were published in 116 journal titles. Therefore, each zone must contain approximately 674 publications. The data in Table 5 shows that the first zone contains 1 (0.86%) journal, which covers 759 (37.56%) publications; the second zone contains 10 (8.62%) journals with 674 (33.35%) publications; and third zone contains the remaining 105 (90.52%) journals with 588 (29.09%) publications. Hence, the mean Bradford multiplier is (10+10.5)/2=**10.3**. The relationship of each zone in the case of Geology literature during the first block is in the ratio **1:10:105**. The total number of journals in Block 1 is expected to be 117, whereas the actual number is 116. Based on this, the percentage error is found to be negligible (**0.86%**), and hence, the data in the field of Geology during Block 1 (1989-1996) fits Bradford's expression for journal productivity.

ii. **Block 2 (1997-2004):** During this block, a total of 2,876 publications were published in 193 journals. Therefore, each zone must contain approximately 959 papers. The data in Table 5 shows that the first zone contains 1 (0.52%) journal, which covers 877 (30.49%) publications; the second zone contains 9 (4.66%) journals with 966 (33.59%) publications; and the third zone containremaining 181 (93.78%) journals with 1,033 (35.92%) publications. Hence, the mean Bradford multiplier is ((9+20.1)/2) = **14.6**. The relationship of each zone in the case of Geology literature during the second block comes out to be in the ratio **1:9:181**. The total number of journals in Block 2 is expected to be 229, whereas the actual number is 193. Based on this, the percentage error is found to be **18.65%,** and hence, the data in the field of Geology during Block 2 (1997-2004) does not fit Bradford's expression for journal productivity.

iii. **Block 3 (2005-2012):** During this block, a total of 5,196 publications were published in 186 journals. Therefore, each zone must contain approximately 1,732 publications. The data in Table 5 shows that the first zone contains 3 (1.61%) journals, which cover 1,751 (33.70%) publications; the second zone contains 14 (7.53%) journals with 1,724 (33.18%) publications; and third zone contain the remaining 169 (90.86%) journals in 1,721 (33.12%) publications. The mean Bradford multiplier is$(4.7 + 12.1)/2 = \mathbf{8.4}$. The relationship of each zone in the case of Geology literature comes out to be in the ratio**3: 14: 169.** The total number of journals in Block 3 is expected to be 240, whereas the actual number is 186. Based on this, the percentage error is found to be **29.03%**, and hence, the data in the field of Geology during Block 3 (2005-2012) does not fit Bradford's expression for journal productivity.

iv. **Block 4 (2013-2020):** During this block, a total of 9,009 publications were published in 209 journals. Therefore, each zone must contain approximately 3003 publications. The data in Table 5indicatethat the first zone has 4 (1.9%) journals covering 3,074 (34.12%) publications;the second zone has 17 (8.1%) journals with 3,069 (34.06%) publications; and the third zone has the remaining 188 (89.9%) journals with 2,866 (31.81%) publications. The mean Bradford multiplier is$(4.25 + 11.06)/2 = \mathbf{7.65}$. The relationship of each zone in the case of Geology literature comes out to be in the ratio **4:17:188**. The total number of journals in Block 4 is expected to be **269,** whereas the actual number is 209. Based on this, the percentage error is found to be very high (**28.70%**), and hence, the data in the field of Geology during Block 4 (2013-2020) also does not fit Bradford's expression.

On applying the Bradford Law of the journal scattering to the journals in each of the four blocks, it is found that the percentage error for the Block 1 (1989-1996) is 0.86%, for Block 2 (1997-2004) is 18.65%, for Block 3 (2005-2012) is 29.03%, and for Block 4 (2013-2020) is 28.7%. Hence, except for the first block, the law is found to be inapplicable to the remaining three blocks.

Table 5

Bradford's Zonesfor Geology Research Output during all the four Block Periods

Blocks	Zones	Number of Journals	Journals (%)	Number of Publications	Publications (%)	Bradford Multiplier	Number of Journals as per the Bradford's Law	Percent age error
Block 1 (1989-1996)	**1**	1	0.86	759	37.56		1	0.86%
	2	10	8.62	674	33.35	10	10.3	

	3	105	90.52	588	29.09	10.5	106.9	
	All Zones	**116**		**2021**		**10.3**	**117**	
Block 2 (1997-2004)	**1**	1	0.52	877	30.49		1	18.65%
	2	9	4.66	966	33.59	9	14.6	
	3	181	93.78	1033	35.92	20.1	213.16	
	All Zones	**193**		**2876**		**14.6**	**229**	
Block 3 (2005-2012)	**1**	3	1.61	1751	33.70		3	29.03%
	2	14	7.53	1724	33.18	4.7	25.2	
	3	169	90.86	1721	33.12	12.1	211.68	
	All Zones	**186**		**5196**		**8.4**	**240**	
Block 4 (2013-2020)	**1**	4	1.9	3074	34.12		4	28.70
	2	17	8.1	3069	34.06	4.25	30.62	
	3	188	89.9	2866	31.81	11.06	234.36	
	All Zones	**209**		**9009**		**7.65**	**269**	

Conclusion

From the results, it can be concluded that the journal distribution pattern in this study does not align with Bradford's law over the entire 32-year period. Additionally, Bradford's law failed to explain the journal distribution in Blocks 2, 3, and 4, due to high percentage errors. However, during Block 1, the journal distribution followed Bradford's distribution, with a negligible percentage error of 0.86%. The study also applied the Leimkuhler model, which was further confirmed using the K-S test. This law also failed to explain the scattering of journals in the field of Geology from 1989 to 2020.

According to the trend, applying Bradford's law helps identify core journals in a specific field. This study has also aimed to categorize the most productive, moderately productive, and journals with diminishing productivity where authors have published their research over the past 32 years. The study observed an increase in the number of core journals from 1 to 4 over the four block periods, along with a rise in the total number of journals. This implies that, for the purpose of publishing, the scattering of journals has increased over time. In other words, along with publishing in fundamental journals, authors tend to publish their research in multidisciplinary journals as well. This trend could explain the non-applicability of the law, which suggests that papers should be scattered across a smaller number of journals as compared to the findings of the current study. Another possible reason is the concentration of publications in a few journals, as we can see, 19% of the literature is published in the Journal of the Geological Society of India (Kumar, 2014).

The finding is that out of the 230 journals having a total output of 19,102 publications from India, only four journals are found to be published in India. This clearly shows that the journals published from India in the field of Geology must work on their quality in order to qualify the criteria to be indexed in the database, which will further lead to better representation of Indian output in the database. In addition, three journals, namely The Journal of Geological Society of India, the Journal of Earth System, and Disaster Advances, have not been classified under the Web of Science Category 'Geology' but under 'Geosciences, Multidisciplinary'. This clearly shows the need and scope of how these journals must improve in order to get reclassified under the Geology domain. The journal 'Himalayan Geology' is the only journal out of the four journals that is classified under the domain of Geology.

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