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Activity and Growth of Literature in the Field of Geology

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ABSTRACT

Purpose: *This paper analyzes the growth of literature in the field of geology over 32 years (1989-2020) from India and the world. Using the Web of Science database, the analysis was conducted on 19,102 papers published by India and 486,686 papers produced worldwide.*

Methodology: *The measures used for analysis include relative growth rate, doubling time, and activity index. Three growth models, namely exponential, logistic, and power models, were also examined to find the best fit model. KS goodness-of-fit test was used to test the applicability of the exponential model.*

Findings: *The findings revealed that the relative growth rate of India is higher, while the doubling time is lower, as compared to that of the world. The values of the activity index show an increasing trend. On applying growth models, the power model was found to best fit the growth of the publications. On applying the KS test, the value of Dmax (0.050) was found to be greater than the critical value of Dα (0.0095) at the 5% level of significance, which shows that the growth of literature in the field of Geology does not follow the Exponential Growth Model.*

Originality: *Based on the literature analysis, this paper is the first attempt to study the growth of publications in the field of Geology from India.*

KEYWORDS: Growth Models, Exponential Model, Relative Growth Rate, Doubling time, Activity Index, KS Test

1. INTRODUCTION

The rapid advancement of science with new discoveries and inventions has resulted in a huge number of scientific publications. This necessitates a deeper understanding of how knowledge itself accumulates and evolves over time.[1] In terms of the advancements in science and technology, the term growth often refers to rise in the number of scientific organisations, researchers, grants, publications, impact, etc.[2] Specifically, 'Growth of Literature' refers to the quantitative change in the volume of literature over a defined time frame.[3] Applying growth models to the research literature that has already been published, applying curve fitting techniques to the data, and determining which curve best fits the data reveals specific literature growth patterns, forecasts the growth of literature, and helps the authorities and policymakers to track and encourage research activities.[4]

Geology involves the study of Earth, encompassing its materials, the physical and chemical processes occurring on its surface and within its interior, and the history of its life forms.[5] Education and research in the field of Geology are imperative in India because of its diverse geographical features, enabling a better understanding of Earth's processes and the creation of resources.[6] Many scientific principles have origins that can be traced back to the Vedas. Ancient Indian literature includes numerous references to fundamental concepts in Geology, Mineralogy, and Metallurgy. For example, Patanjali's treatise discusses metallurgy, Kautilya's Arthashastra covers mineralogy, Nagarjuna was a renowned metallurgist, Varahamihira mentions the preparation of cement, and so on.[7] The establishment of the Asiatic Society of Bengal in 1784 marked the beginning of formal geological research in India, which gained further momentum with the setting up of Geological Survey of India (GSI) at Calcutta in 1851.[8] However, it was only during the last quarter of the 19th century that modern geology and related subjects were introduced in few Indian universities, and Geology appeared as an independent academic discipline.[9] Apart from that, establishment of various organizations pre- and post-independence, like Council of Scientific and Industrial Research, Birbal Sahni Institute of Palaeosciences National Mineral Development Corporation, Oil and Natural Gas Corporation Limited, state departments of Mines and Geology, Indian Bureau of Mines, Indian Institutes of Technologies, Geological Society of India, **Indian Institute of Geomagnetism** and institutes under Ministry of Earth Sciences (MoES) resulted in an increased research in the field of Geology and hence enormous growth of geological publications.[10]

With an unswerving increase in the number of institutions offering research and development in the field of Geology in India, the productivity has also increased. Hence, the present study emphasizes analyzing the growth of research output in the field of geology in India.

2. REVIEW OF RELATED LITERATURE

Meera & Pooja[11] examined the growth models for bioinformatics literature resulting from Indo-US collaboration. They found that the growth was slow and steady, following a linear model as verified using the chi-square test. Thirunavukkarasu[12] *et al* observed a linear trend in the growth of seed technology publications over a span of 30 years. They found that the RGR was higher and the D_t was shorter. Verma[13] *et al* analysed the growth of funded research publications in the field of Scientometrics and bibliometrics at the global level. China was found to have the highest activity index. A study by Thattai[14] *et al* revealed that the global mangrove literature has grown exponentially. India's contribution to this field has also increased, with its activity index rising from 0.92 to 4.15. Wodeyar and Mulla[15] assessed the growth of Big Data research publications during 20 years using the Web of Science and Scopus databases. The overall RGR was found to be 0.521, and the doubling time was 2 years. Loan[16] *et al* observed RGR as 0.33 and D_t as 1.9 years for the literature of Cyber Security. Mohan & Kumar[17] examined India's growth in the field of planetary sciences from 1999-2018 using Web of Science. Linear and exponential models best fit the growth of publications. Pandey[18] *et al* analyzed the growth pattern of the publications on Artificial Intelligence indexed in the Scopus database. Doubling time increased from 0.47 to 4.26. Verma and Singh[19] looked at how the Food Science in India has grown from 1989 to 2018 by applying the approach recommended by Egghe and Rao. The values of RGR were 0.14, and the doubling time was 5 years. Verma[20] *et al* examined the trends in the growth of Biochemistry output from India indexed in the Scopus database. Nishavathi[21] tested the growth of publications produced by six AIIMS from 2007-2016, which revealed that the exponential growth model best represented the growth observed. This was further confirmed using the Chi-square and t-test. Rai[22] *et al* explored the growth of publications in the field of Deep Web from 1997 to 2019, indexed in the Scopus database using the Bibliometrix Package in RStudio. Teli and Dutta[23] examined 214 growth models applied across different subjects in 198 articles. Using the Chi-square test, they found that the majority of the papers followed exponential and logistic growth models. Verma and Shukla[24] investigated the performance of the ten most productive nations over 10 years in Information Literacy. Sangam[25] *et al* found that the doubling time for the world (5.13 years) was more than that of India (3.31 years) in the field of Genetics. Growth of India's literature is best represented by the exponential and logistic models, whereas the world's output is best depicted by linear and logarithmic models. Sangam[26] *et al* applied the models to analyze the progress in the Liquid Crystals literature of India and China using the approaches recommended by Rao and Egghe. The cumulative growth of India and China followed the power and growth models. Sangam[27] *et al* compared the growth of Chemical Science literature of India with that of the world using Chemical Abstract Online. On the basis of the values of R^2 and F, the exponential model was found to best fit the growth for both India and the world.

3. METHODOLOGY

The present study consists of 19,102 research contributions from India and 4,86,686 research publications from the world, found in the Web of Science for 32 years, from January 1989 to December 2020. The data was collected using the Advanced Search option of the Web of Science database, using the field tags SU (Research Area), CU (Country), and PY (Year of Publication). The results were limited to SCI-Expanded (Science Citation Index-Expanded), and CPCI-S (Conference Proceedings Citation Index- Science). The document types chosen for analysis include only articles, conference proceedings, and reviews, as these document types are peer reviewed, constitute the core of the communication channel, and are the most citable items among all the types of documents.[28,29] The data was divided into four blocks of eight years each, viz. **Block 1** (1989-1996), **Block 2 (**1997-2004), **Block 3**(2005-2012), and **Block 4(**2013-2020). The results were saved in text files and imported into MS-Excel for analysis. Analysis has been conducted using MS-Excel and SPSS 25.

4. OBJECTIVES AND HYPOTHESIS

4.1 Objectives

1. To examine the relative growth rate and doubling time of research productivity.
2. To examine the trends in the values of the activity index of India.
3. To explore the applicability of select Growth Models.
4. To test the applicability of the exponential growth model using the KS test.

4.2 Hypothesis:

Null Hypothesis (H_0): There is no significant difference between the observed and expected growth of literature based on the Exponential Growth Model.

Alternate Hypothesis (H_a): There is a significant difference between the observed and expected growth of literature based on the Exponential Growth Model.

5. RESULTS

The block-wise as well as year-wise total output of the World and India in the field of Geology is depicted in Table 1 along with the values of Relative Growth Rate (RGR) and Doubling Time (D_t). The table also mentions the Activity Index of India with respect to the World. Mean Relative Growth Rate (RGR_{mean}) and Mean Doubling Time ($D_{t\ mean}$) for the growth of world and Indian output are also calculated.

It can be noted that in the year 1989, only 207 papers were published in the field of Geology from India in the journals that are indexed in the Web of Science database. While the World produced 6,513 publications in the same year. The number of publications went up to 1,410 in the year 2020 for India, whereas for the World it is observed to be 30,069. The year 2020 also recorded the highest number of publications from India and the World. Figure 1 depicts the cumulative growth of publications from India and the World.

5.1 Relative Growth Rate (RGR) and Doubling Time (D_t)

The term Relative Growth Rate (RGR) denotes the comparison of the current year's growth to the growth observed in the preceding year. This concept, originally developed by Blackman and referred to as the efficiency index, emerged from his work in plant growth analysis.[27,28] RGR is calculated by the following formula

$$RGR = \frac{W_2 - W_1}{T_2 - T_1}$$

Where, W_1 = $Ln\ W_1$ = Log_e (of number of publications at the start);

W_2 = $Ln\ W_2$ = Log_e (of number of publications at the end);

$T_2 - T_1$ = Difference between final and initial time.

There is a direct association between the relative growth rate and the amount of time required by a body of literature to double its size. Therefore, if the total number of publications pertaining to a topic double over the course of a specific time period, at that juncture, the change in the logarithms of the amounts at the start and closure of this time period must be equal to the value of the logarithm of the number 2 i.e., 0.693 and D_t can hence be evaluated as[25]:

$$D_t = \frac{0.693}{RGR}$$

Relative Growth Rate (RGR) and corresponding Doubling Time (D_t) are calculated for India and the World for each year and block-wise. The trend in RGR and Dt shows a different picture, which is visible from Figures 2 and 3.

From Table 1 and Figure 2, the mean relative growth rate (RGR) of India and the World in Block 1 (1989-1996) was observed to be 0.32 and 0.31, respectively, signifying growth rates of 32% and 31%, respectively. During Block 2 (1997-2004), the mean RGR was calculated as 0.11 for India and 0.12 for the World. During Block 3 (2005-2012), the mean RGR for both India (0.09) and the World (0.08) depicts a further decrease. In Block 4 (2013-2020), the mean RGR was found to be the lowest for both India (0.08) and the World (0.07). Although the number of publications recorded for the World was higher than for India each year, and overall, the relative growth rate for India was observed to be greater than that of the World. The overall mean RGR value for India was 0.15, while for the World it was 0.14.

Doubling time (Dt) is the time taken for the quantity of literature to double compared to the present value. According to the block-wise doubling time mentioned in Table 1, Block 1 (1989-1996) records the doubling time for India as 2.67 years and for the World as 2.80 years. The doubling time increased to 8.72 years for India and 10.25 years for the World during Block 4 (2013-2020). The overall doubling time for India was recorded as 6.51 years, while for the World it was 7.12 years. The block-wise trend for India and the world is depicted in Figure 3.

In the domain of Earth sciences, Parvathamma[33] found the average values of RGR and D_t to be 0.23 and 4.8 years, respectively, during 1978-1988. Similarly, Mahapatra & Das[34] stated that the discipline of geology has reached a fairly advanced stage of development, which explains the low growth rate figures despite increased collaboration. They observed average values of RGR and D_t as 0.28 and 4.7 years, respectively, during 1987-1996. This is further supported by the present study, where the RGR is 0.15 and D_t is 6.5 years. Over time, there has been a decline in growth rates, accompanied by an increase in doubling time.
A similar trend of India's RGR being more than the World's RGR and doubling time being less than the World's doubling time is in symmetry with the results obtained in the field of *Global Genetics Literature*[25]; in *Indian Chemical Science Literature*[27]; in *Indian Physics Literature*[35]; in *Astronomy and Astrophysics*[36]; in *Indian Engineering.*[37] This indicates that the rate of growth of literature is related to the level of maturity of the field of research.

5.2 Activity Index (AI)

The sheer enormity of the country and the extensiveness of the subject specialties render raw counts of research output meaningless, and in order to solve this problem, the Activity Index was proposed by Frame in 1977 and further developed by Schubert & Braun in 1986. The index evaluates the extent to which a country gives priority to research in a particular field of study and ranks the countries accordingly[38], and is calculated as follows:

$$AI = \frac{Share\ of\ country\ in\ world's\ publication\ output\ in\ a\ given\ field}{Share\ of\ country\ in\ world's\ publication\ output\ in\ all\ subject\ fields}$$

If the value is 1, then the research effort of a country resembles accurately to the world's average in the given field of study; if the value is more than 1, then the research effort of a country is greater than the world's average in the given field of study; and if the value is less than 1, then the research effort of a country is less than the world's average in the given field of study.

In the present context, the Activity Index for India is calculated for each of the 32 years as well as for all four blocks. The values of Activity Index indicate research efforts of India in the field of Geology with respect to the efforts done in the same field in the rest of the world during the same time period. Considering the block-wise values of the Activity Index from Table 1, it is noticed that the activity is below the world's average during the first two blocks. During Block 1 (1989-1996), the AI was 90.04, while during Block 2 (1997-2004), it was found to be the lowest at AI=83.58. The activity of India in the field of Geology started to increase, becoming slightly above the world's average during Block 3 (2005-2012), with an AI of 101.29. By the end of the last block, the activity had increased above average, with an AI of 115.21. The trend of the Activity Index is shown in Figure 4.

It is also observed that the activity of India was highest in the year 2019 (AI=122.9) and lowest in the year 1990 (AI=77.78). The activity remained below average consistently from 1989 to 2006, which could be attributed to the Asian Economic Crisis of 1997. This crisis led to the failure of the full implementation of the liberalization reforms of 1991, which could have opened up India to foreign investments. However, the crisis made it difficult to expose the nation on a global level. After the crisis, when India started to rebuild, the Activity Index of India matched the world's average level precisely in 2007 (AI=100.13) and was slightly above the world's average in 2008 (AI=105.76). In 2009, a dip in activity was observed, with an AI of 95.48, possibly due to another economic crisis that began in 2007 in the US and started affecting India by 2008, lasting until 2009. However, from 2010 through 2020, the activity of India remained consistently above average.[39,40,41,42,43]

Table 1: RGR, D_t, and Activity Index (AI) of India and the World in the field of Geology (1989-2020)

Year	World Output	Cumulative World Output (Wo)	Ln (Wo)	RGR	Dt	Indian Output	Cumulative Indian Output (Io)	Ln (Io)	RGR	D_t	AI
1989	6513	6513	8.78			207	207	5.33			83.21
1990	7237	13750	9.53	0.75	0.9	215	422	6.05	0.71	1.0	77.78
1991	6658	20408	9.92	0.39	1.8	223	645	6.47	0.42	1.6	87.69
1992	6564	26972	10.2	0.28	2.5	225	870	6.77	0.3	2.3	89.74
1993	7336	34308	10.44	0.24	2.9	280	1150	7.05	0.28	2.5	99.92
1994	7744	42052	10.65	0.20	3.4	289	1439	7.27	0.22	3.1	97.7
1995	8246	50298	10.83	0.18	3.9	266	1705	7.44	0.17	4.1	84.45
1996	8894	59192	10.99	0.16	4.3	316	2021	7.61	0.17	4.1	93.02
1989-1996	**59192**	**253493**		**0.31**	**2.8**	**2021**	**8459**		**0.32**	**2.6**	**90.04**
1997	9991	69183	11.14	0.16	4.4	344	2365	7.77	0.16	4.4	90.14
1998	10122	79305	11.28	0.14	5.1	329	2694	7.9	0.13	5.3	85.09
1999	10314	89619	11.4	0.12	5.7	308	3002	8.01	0.11	6.4	78.18
2000	10737	100356	11.52	0.11	6.1	326	3328	8.11	0.10	6.7	79.49
2001	11313	111669	11.62	0.11	6.5	342	3670	8.21	0.10	7.1	79.14
2002	11697	123366	11.72	0.1	7.0	357	4027	8.3	0.09	7.5	79.9
2003	12225	135591	11.82	0.09	7.3	393	4420	8.39	0.09	7.4	84.16
2004	13490	149081	11.91	0.09	7.3	477	4897	8.5	0.10	6.8	92.57
1997-2004	**89889**	**858170**		**0.12**	**6.2**	**2876**	**28403**		**0.11**	**6.5**	**83.58**
2005	13803	162884	12	0.09	7.8	470	5367	8.59	0.09	7.6	89.14
2006	15038	177922	12.09	0.09	7.9	564	5931	8.69	0.10	6.9	98.19
2007	15740	193662	12.17	0.08	8.2	602	6533	8.78	0.10	7.2	100.13
2008	16660	210322	12.26	0.08	8.4	673	7206	8.88	0.10	7.1	105.76

Year	World Output	Cumulative World Output (Wo)	Ln (Wo)	RGR	Dt	Indian Output	Cumulative Indian Output (Io)	Ln (Io)	RGR	D_t	AI
2009	17138	227460	12.33	0.08	8.9	625	7831	8.97	0.08	8.3	95.48
2010	17012	244472	12.41	0.07	9.6	680	8511	9.05	0.08	8.3	104.65
2011	18401	262873	12.48	0.07	9.6	753	9264	9.13	0.08	8.2	107.13
2012	19756	282629	12.55	0.07	9.6	829	10093	9.22	0.09	8.1	109.86
2005-2012	**133548**	**1762224**		**0.08**	**8.7**	**5196**	**60736**		**0.09**	**7.7**	**101.29**
2013	22327	304956	12.63	0.08	9.1	937	11030	9.31	0.09	7.8	109.87
2014	22462	327418	12.7	0.07	9.8	999	12029	9.4	0.09	8.0	116.44
2015	24517	351935	12.77	0.07	9.6	1001	13030	9.48	0.08	8.7	106.89
2016	25102	377037	12.84	0.07	10.1	1048	14078	9.55	0.08	9.0	109.30
2017	24390	401427	12.9	0.06	11.1	1115	15193	9.63	0.08	9.1	119.68
2018	26539	427966	12.97	0.06	10.8	1154	16347	9.7	0.07	9.5	113.84
2019	28651	456617	13.03	0.06	10.7	1345	17692	9.78	0.08	8.8	122.9
2020	30069	486686	13.1	0.06	10.9	1410	19102	9.86	0.08	9.0	122.76
2013-2020	**204057**	**3134042**		**0.07**	**10.3**	**9009**	**118501**		**0.08**	**8.7**	**115.21**
1989-2020				**0.14**	**7.1**				**0.15**	**6.5**	**97.31**

(RGR=Relative Growth Rate, D_t=Doubling Time, AI=Activity Index)

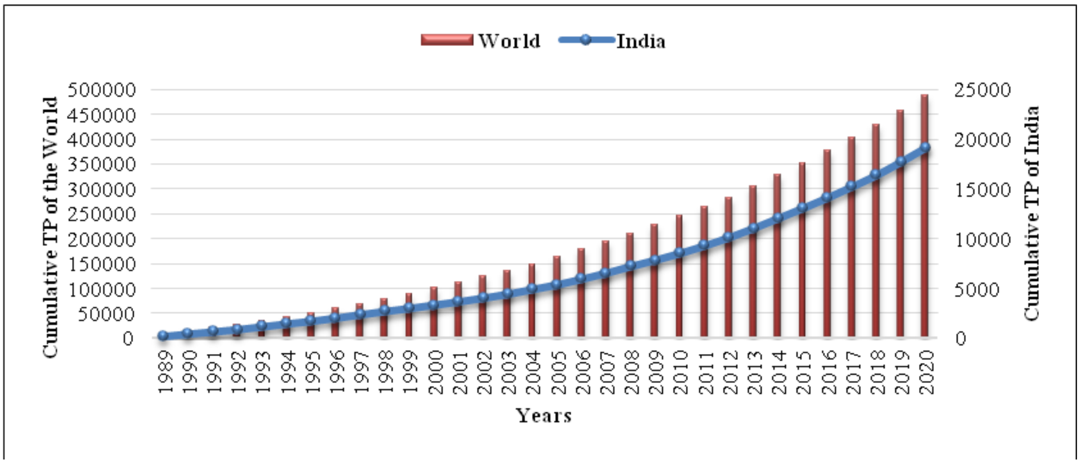

Figure 1: Cumulative Growth of Literature in the field of Geology (1989-2020)

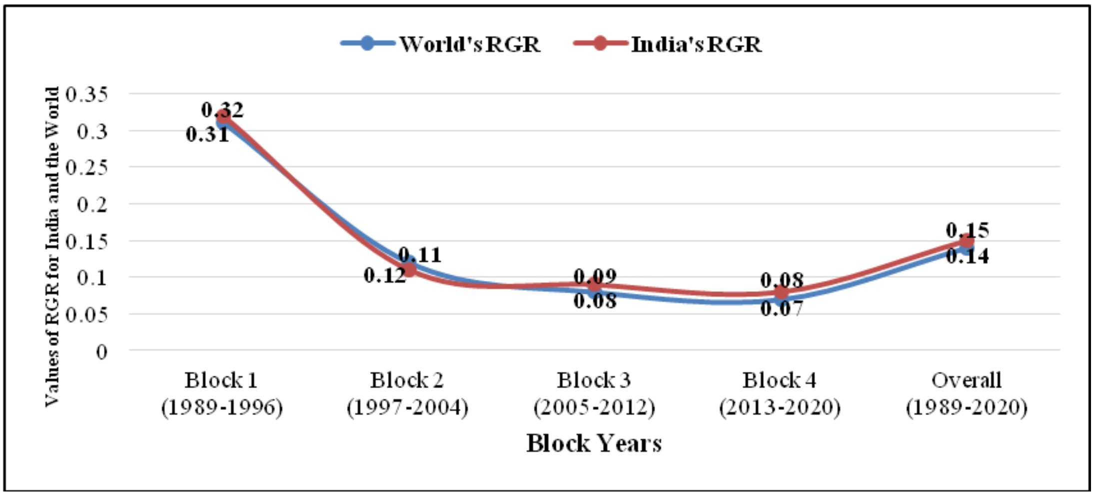

Figure 2: Trends in Relative Growth Rate (RGR) in the field of Geology (1989-2020)

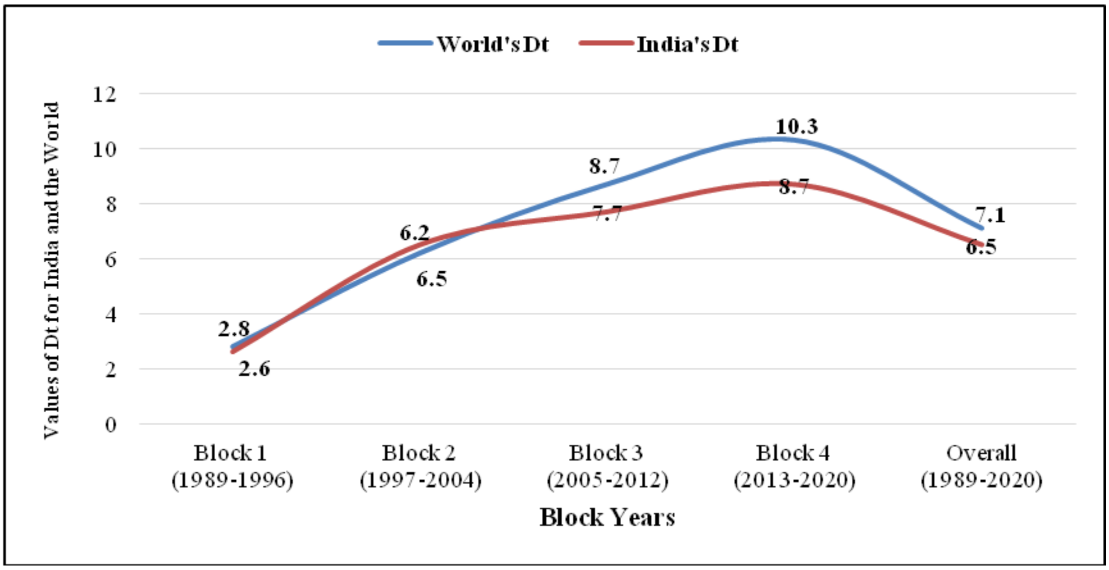

Figure 3: Trend in Doubling Time (D_t) in the field of Geology (1989-2020)

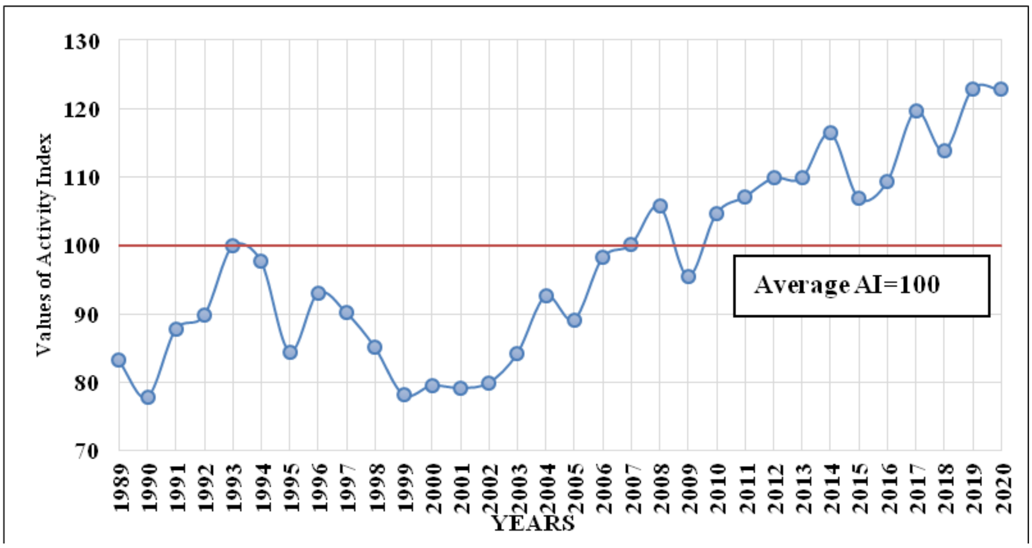

Figure 4: Activity Index of India in the field of Geology (1989-2020)

5.3 Growth Models based on Growth Rate Functions

Egghe and Rao[44] presented two growth rate functions as a means of determining which models, if any, may be a good fit to explain the growth of a given set of data pertaining to a particular field of study. These two different growth rate functions are defined as follows:

$$\alpha 1(x) = f(x+1)/f(x)$$
$$\alpha 2(x) = f(2x)/\ f(x)$$

for x = 1, 2, 3, 4...

For time/year x, the first growth rate function is denoted by the symbol $\alpha 1(x)$ or $\alpha 1$ while the second growth rate function is denoted by the symbol $\alpha 2(x)$ or $\alpha 2$.

The growth rate function α1 analyses the progression of the number of publications from one year to the next (the period x to $x+1$). On the other hand, the growth rate function α2 relates the growth over a time period that is twice the present year (from x to $2x$ period). The equation that describes the relationship between α1 and α2 may be written as follows:

$$\alpha 2(\mathrm{x}) = \alpha 1\ (2\mathrm{x} - 1) \times \alpha 1\ (2\mathrm{x} - 2) \times \ldots\ldots \times \alpha 1\ (\mathrm{x}) \ldots$$

If there are N observations in total, then there will be N-1 values for α1 (x=0, 1, 2, N-1) and $N/2$ values for α2 (x =1, 2, N-2). For particular growth models like the Exponential, Logistic, Power, etc., Egghe and Rao have also computed and displayed graphs of α1 and α2. Without resorting to calculations or statistical fits, they have also provided plots of both of the growth rate functions for the various models according to the following classification:

i) when α1 is increasing it is Type 1;
ii) when α1 is constant, it is Type 2;
iii) when α1 is decreasing, it is Type 3;
iv) when α1 is increasing first and then decreasing, it is Type 4.

There is no need to determine the values of α2 when α1 is of type 1, 2, or 4. Only when α1 is steadily declining, that is, when Type 3 is being followed, is it necessary to determine the values of α2. Based on the above, the growth of literature follows the following models:

i) When α1 is Type 2 and α2 is Type 1, the growth follows an exponential model.
ii) When α1 is Type 3 and α2 is Type 4, the growth follows the Logistic or Gompertz model.
iii) When α1 is Type 3 and α2 is Type 1, the growth follows the Power ($C > 0$, $0 < b \leq 1$) model.
iv) When α1 is Type 4 and α2 is Type 1, the growth follows the Power ($C > 0$, $b > 0$) model.
v) When α1 is Type 3 and α2 is Type 2, the growth follows the Power (C=0) model.

Based on the criteria mentioned and the trends observed from plotting the growth rate functions in Figure 5, it is evident that in all instances, α1 is decreasing and aligns with Type 3. The decreasing trend in the plots of α1 suggests the option of using either a Logistic model or a Power model. Given that the first growth rate function revealed a declining trend, it is now necessary to plot the second growth rate function, α2, to identify the exact model that may fit the available literature.

From Table 2 and Figure 6, the second growth rate function is observed to be growing, indicating that Type 1 is being followed.

Thus, due to the decreasing trend of α1 (Type 3) and the increasing trend of α2 (Type 1), the Power model with parameters ($C > 0$, $0 < b \leq 1$) is deemed suitable for the current study, following the methodology outlined by Egghe and Rao.

Table 2: Values of α1 and α2 for the growth of Geology (1989-2020)

Year (t)	Total Publications	Cumulative Total Publications (y)	α1	α2
1989	207	207		
1990	215	422	2.04	2.04
1991	223	645	1.53	
1992	225	870	1.35	2.06
1993	280	1150	1.32	
1994	289	1439	1.25	2.23
1995	266	1705	1.18	
1996	316	2021	1.19	2.32
1997	344	2365	1.17	
1998	329	2694	1.14	2.34
1999	308	3002	1.11	
2000	326	3328	1.11	2.31
2001	342	3670	1.10	
2002	357	4027	1.10	2.36
2003	393	4420	1.10	
2004	477	4897	1.11	2.45
2005	470	5367	1.10	
2006	564	5931	1.11	2.51
2007	602	6533	1.10	
2008	673	7206	1.10	2.67
2009	625	7831	1.09	
2010	680	8511	1.09	2.84
2011	753	9264	1.09	
2012	829	10093	1.09	3.03
2013	937	11030	1.09	
2014	999	12029	1.09	3.28
2015	1001	13030	1.08	
2016	1048	14078	1.08	3.50
2017	1115	15193	1.08	
2018	1154	16347	1.08	3.70

2019	1345	17692	1.08	
2020	1410	19102	1.08	3.90
Total	**19102**			

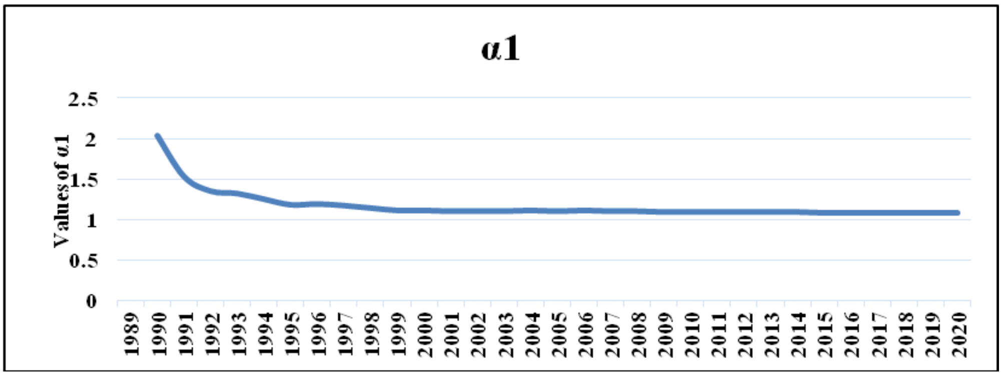

Figure 5: First Growth Rate Function (α1)

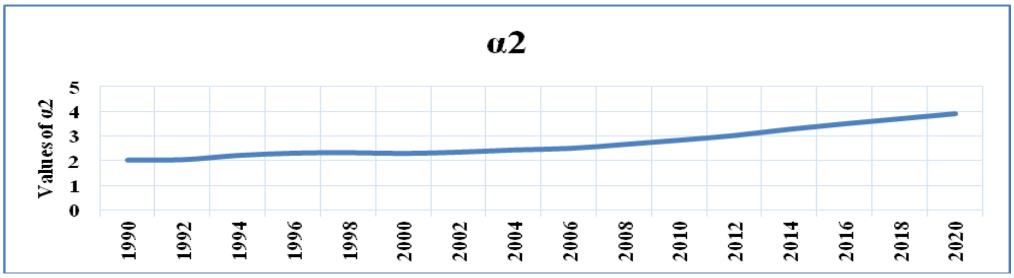

Figure 6: Second Growth Rate Function (α2)

5.4.1 Logistic Model

The logistic growth model assumes that the growth rate is proportional to the product of the current size and future growth. The cumulative curve of this model follows an S-curve pattern, starting modestly, then undergoing rapid expansion, followed by an extended period of saturation, while the shape of the non-cumulative curve is symmetrical around its point of inflection.[45] The logistic function is characterized by a lower size of knowledge, usually beginning with no publications, and a highest size beyond which knowledge in a specialty cannot grow anymore. The equation for the logistic growth function is given as;

$$y = \frac{k}{1 + ae^{-bx}}$$

Where *y* represents the size at time *x*, and *k* is the highest number of years. The shape of the curve is symmetrical about the point of inflection at $x = log\ a/b = x'$. If $x < x'$, the growth rate is increasing; if $x > x'$, the growth rate is decreasing. Figure 7 is plotted with the help of SPSS 25, using the values of years and the cumulative number of total publications from Table 2. The values of parameters for constants *a* and b are *a* =0.0016, b =0.889. Based on the values of parameters obtained for this model, the logistic equation suitable for the growth of Geology literature is:

$$y = \frac{k}{1 + 0.0016e^{-0.889x}}$$

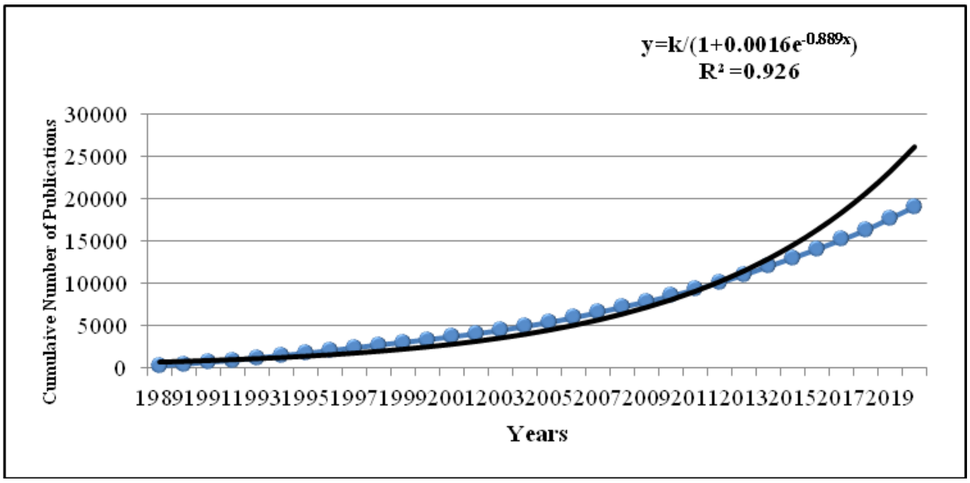

Figure 7: Logistic Model Fit in the field of Geology (1989-2020)

5.4.2 Power Model

According to the power model, the growth rate is not constant with time, but rather a function of time. The power growth model is given by the equation:

$$y = C + ax^b$$, where *C*, *a*, and *b* > 0

The eexponent *b* determines the shape of the power model curve as when the value of *b* is between 0 and 1, a concave shape curve (reverse j) is created; when *b* equals 1, the power model becomes a linear growth model and the curve takes the shape of a straight line; and when *b* exceeds 1, a convex shape curve, *j* shape, is observed.[46]

On plotting the graph between the years and the cumulative number of total publications as listed in Table 2, the graph in Figure 8 is obtained. Using the trend line in MS Excel, the equation for the power model the values of constants as ***C*=0, *a*=142.8, *b*=1.329,** and depicts the relationship between time and number of publications as

$$y=142.8x^{1.329}$$

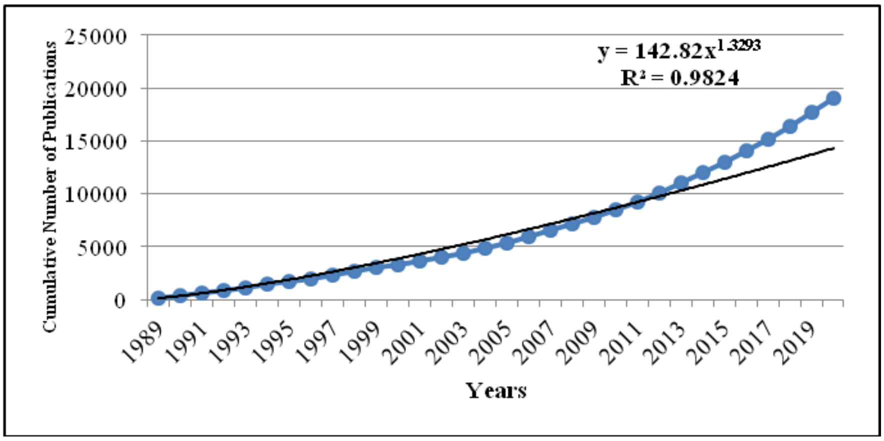

Figure 8: Power Model Fit in the field of Geology (1989-2020)

5.4.3 Exponential Model

When the growth of knowledge follows a compound interest rate, i.e., it increases at a fixed percentage on the previously accumulated knowledge, this kind of growth is ascribed to an exponential function. Mathematically, it is expressed as

$$y = ae^{bx},$$

where *y* is the number of publications at time *x*.[47] On plotting the graph between the years and the cumulative number of total publications as listed in Table 2, the graph in Figure 9 is obtained. Using the trend line in MS Excel, the values of constants were found as a =605.9, and b =0.117, and the equation for the exponential model is obtained, which reflects the relationship between the time and number of publications as

$$y = 05.9e^{0.117x}$$

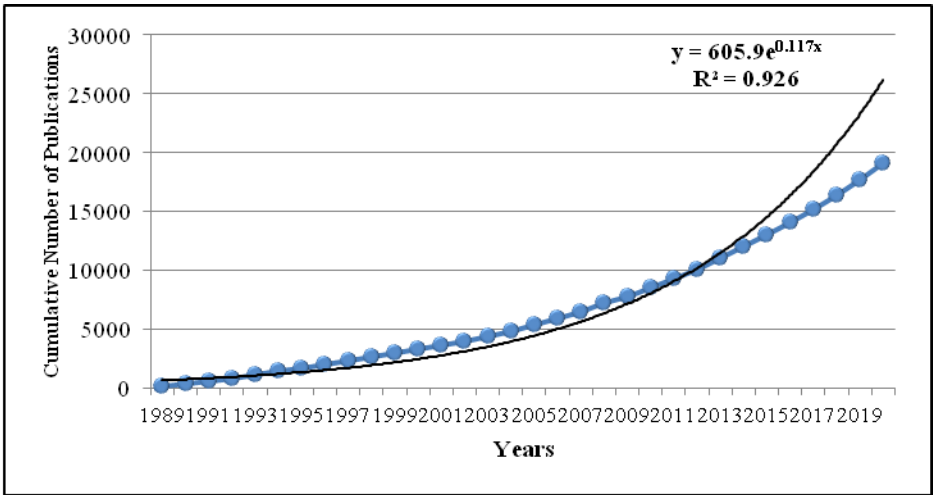

Figure 9: Exponential Model Fit in the field of Geology (1989-2020)

The values of fit statistics, namely the coefficient of determination (R2) and F-test (F), were obtained using SPSS 25 for each model and listed in Table 3. From the values of fit statistics, the following can be inferred:

(i) For the Logistic Growth Model, the R^2 value is found to be 0.926 and F is 75.517 (Figure 7), which shows that the Logistic Model explains 92.6% of the variance in the growth of Geology literature.

(ii) For the Power Model, the R^2 value is 0.927 and F is 375.517 (Figure 8), which indicates that the power model explains 92.7% variance in the growth of Geology literature.

(iii) For the Exponential Growth Model, the value of R^2 is 0.926 and F is 375.517 (Figure 9). It indicates that the exponential model explains 92.6 of % variance in the growth of geology literature.

Hence, based on the above values, the Power model is found to best fit the growth of literature in the field of Geology.

Also, based on the methodology defined by Egghe and Rao, the Power model is found to best fit the growth of Geology literature. Therefore, it can be concluded that the Power model provides the best explanation for the growth of Geology literature compared to other models considered in the study. The Logistic and Exponential models, with negligible variations in R2 and F values, are identified as the second-best models for explaining the growth of Geology literature.

Power model has also been found to best fit the growth of literature in the field of *Economics, Sociology, History, Political Science,* and *Psychology;*[1] *Food Science and Technology;*[19] Liquid *Crystals Research;*[26] in *Physics, Chemistry,* and *Electrical & Electronics Engineering;*[45] and *Theoretical Population Genetics.*[48]

Table 3: Fit statisics for Growth Models in the field of Geology Literature (1989-2020)

Model	Parameters values		Fit Statistics		Doubling Time
	a	***b***	R^2	***F***	
Logistic	0.0016	0.889	0.926	375.517	5.9 years
Power	142.8	1.329	0.927	380.383	
Exponential	605.9	0.118	0.926	375.517	

5.5 Testing of Exponential Growth Model with K-S Test

The K-S Goodness-of-fit test was used to assess whether the growth of literature in the field of Geology adheres to an exponential growth model. This test compares the observed literature productivity with the expected literature productivity. The expected literature productivity is computed using the equation of the exponential growth model as formulated in section 5.4.3:

$$y= 605.9e^{0.117x}$$

Table 4 mentions the number of years (t), observed number of publications (y_x), fraction of observed number of publications (f_o), expected number of publications, fraction of expected number of publications (f_e), and the difference between the fraction of observed (f_o) and expected (f_e) number of publications.

The K-S test evaluates whether the observed literature productivity is different from expected literature productivity by comparing the maximum absolute difference with the critical value of the K-S Test at the 5% level of significance

At the 5% level of significance, the critical value is calculated as follows:

$$D_{c.v} = \frac{1.36}{\sqrt{\sum y_x}} = \frac{1.36}{\sqrt{19102}} = \frac{1.36}{138.21} = 0.0098$$

Here, y_x represents the total number of publications, which is 19,102 for this study. From Table 4, the maximum difference between observed and expected values, D_{max} = 0.050, which exceeds the critical value of the Kolmogorov-Smirnov Test, Dα =0.0098, at the 5% level of significance.

Thus, the null hypothesis is rejected, indicating a notable difference between the observed and expected productivity of literature. This leads to the acceptance of the alternate hypothesis (H_a) that 'there is a significant difference between the observed and expected growth of literature based on the Exponential Growth Model.' Consequently, the growth of literature in the field of Geology does not follow the Exponential Growth Model.

Table 4: Exponential Growth Model and K-S Goodness-of-fit Test (K-S Test)

Year	Number of Years (x)	Observed		Expected		Absolute Difference $\lvert f_o - f_e \rvert$
		Number of Publications (y_x)	Fraction of Publications (f_o)	Number of publications $y=605.9e^{0.117x}$	Fraction of of publications (f_e)	
1989	1	207	0.011	681.104	0.036	-0.025
1990	2	422	0.022	765.642	0.040	-0.018
1991	3	645	0.034	860.673	0.045	-0.011
1992	4	870	0.046	967.500	0.051	-0.005
1993	5	1150	0.060	1087.585	0.057	0.003
1994	6	1439	0.075	1222.575	0.064	0.011
1995	7	1705	0.089	1374.321	0.072	0.017
1996	8	2021	0.106	1544.901	0.081	0.025
1997	9	2365	0.124	1736.653	0.091	0.033
1998	10	2694	0.141	1952.205	0.102	0.039
1999	11	3002	0.157	2194.512	0.115	0.042
2000	12	3328	0.174	2466.894	0.129	0.045
2001	13	3670	0.192	2773.083	0.145	0.047
2002	14	4027	0.211	3117.276	0.163	0.048
2003	15	4420	0.231	3504.191	0.183	0.048
2004	16	4897	0.256	3939.129	0.206	**0.050**
2005	17	5367	0.281	4428.052	0.232	0.049
2006	18	5931	0.310	4977.659	0.261	**0.050**
2007	19	6533	0.342	5595.483	0.293	0.049
2008	20	7206	0.377	6289.991	0.329	0.048
2009	21	7831	0.410	7070.701	0.370	0.040
2010	22	8511	0.446	7948.313	0.416	0.029
2011	23	9264	0.485	8934.853	0.468	0.017
2012	24	10093	0.528	10043.842	0.526	0.003
2013	25	11030	0.577	11290.478	0.591	-0.014
2014	26	12029	0.630	12691.845	0.664	-0.035
2015	27	13030	0.682	14267.150	0.747	-0.065
2016	28	14078	0.737	16037.980	0.840	-0.103
2017	29	15193	0.795	18028.605	0.944	-0.148
2018	30	16347	0.856	20266.305	1.061	-0.205
2019	31	17692	0.926	22781.748	1.193	-0.266
2020	32	19102	1.000	25609.405	1.341	-0.341

CONCLUSION

In the present study, the values of RGR and D_t signify that the focus of research in the field of geology has shifted from basic or theoretical research to applied or field research aimed at solving complex problems, which necessitates increased collaborations. When the subject is in the initial stage of development, more theoretical research is conducted to formulate the theories or laws that will govern the subject. Once fundamental concepts and theories are established, the research then involves the application of theories to solve the complex problems, which is time-consuming, and hence, the outcome takes time. Therefore, typically, the growth rate is higher during the initial stage of development and slows down as the subject reaches an advanced stage of development.

In the initial years, due to various economic crises faced by India in the past, India's productivity in the field of geology remained low compared to global productivity. However, increased government funding for Science and Technology (S&T)—which grew from Rs. 760.5 crores in 1980-1981 to Rs. 1,23,847.71 crores in 2018-2019[49]—along with the signing of Memorandums of Understanding (MoUs) among various organizations working in geology research and development at national and international levels have elevated India's productivity to match that of the world.

This growth can also be attributed to the establishment of separate geology departments in various central and state universities, as well as national-level research and development (R&D) organizations over the years. The implementation of post-independence policies such as the Scientific Policy Resolution in 1958, the Technology Policy Statement in 1983, the Science and Technology Policy in 2003, and the Science Technology Innovation Policy in 2013 has consistently prioritized research and development in various fields of science and technology.[50] The recent Science, Technology, and Innovation Policy of 2020 is also aligned with these policies, further strengthening research activities overall. All these factors have collectively enhanced research productivity in the field of geology over time, as reflected in the findings of the present study.

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