



RESEARCH ARTICLE

APPLICATION OF BRADFORD'S LAW OF SCATTERING TO THE LIGHT POLLUTION LITERATURE IN INDIA

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Abstract

The present study deals with the application of Bradford's law of scattering for the literature related to 'Light Pollution' research in India during the period of 2005 to 2024 as reflected in the Web of Science. A total of 1831 articles related to Light Pollution research published in 526 journals during the study period. The study analysed the year wise publication productivity, ranking of most preferred journals and time series analysis is also used to predict the future growth of literature. It was observed that Environmental Science and Pollution Research ranked 1st with a total of 355 (19.39%) publications, followed by Environmental Pollution ranked 2nd with 66 (3.60%) publications and Journal of Environmental Chemical Engineering ranked 3rd with 35 (1.91%) publications. The result shows that verbal formulation 1: n : n^2 has fits well with the data on Light Pollution and verification of Bradford's law and it fits with 8:79:439 geometric series with 3.91% of error. Furthermore, the Bradford law includes examined using graphical formulation through the creation of a graph, indicating that all three characteristics are viable.

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Introduction:-

Light is a vital resource for preserving visible atmospheres, dividing between day and night. Light is a vital resource for preserving visible atmospheres, dividing between day and night activities, amplifying some critical procedures like photosynthesis, and assisting in rehabilitating and restoring organisms. It also provides information that Photoperiodism and circadian clocks assist in spatial orientation and visual perception. Light pollution is the excessive, inadequately directed or invasive artificial light from homes and towns, which interferes with wildlife, stargazing, sleep habits, and professional astronomy and wastes a vast amount of energy (Gallaway et al., 2010). It is particularly prominent when the night sky becomes more visible, which makes it challenging to see planets and stars. Excessive illumination, glare, light trespass, and skyglow are the four primary types of light pollution (Rodrigo-Comino et al., 2023). Light pollution is a major environmental issue that is difficult to control and continues to grow towards an increase exponentially. Consequently, the scientific community has focused on this

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Bradford's Law of Scattering is one of the bibliometric laws which is used in bibliometric/scientometric studies. This method assists in determining the highly-cited journals listed as nucleus journals of the subject. The Bradford's Law of scattering and the idea of core journals were identified by Samuel Clement Bradford in 1934. Bradford's law describes how research articles on any given subject field are scattered or spread across different journals. According to a specific mathematical function, a growth in articles on a subject requires increasing the number of journals/information sources. The number of groups of journals to produce nearly an equal number of articles is roughly in proportion to $1: n: n^2 \dots$, where n is called the Bradford multiplier (Bradford's 1934). The present study analyses the application of Bradford's law to the light pollution literature in India during the period of 2005 to 2024.

Objectives of the Study:-

The specific objectives of this study are:

1. To prepare the rank list of journals and study the phenomenon for the scattering of journals in India light pollution publications;
2. To test the appropriateness of verbal and graphical formulation of Bradford's Law of Scattering in the field of light pollution research publications.

Methodology:-

For the present study focused on the verification of Bradford's law of scattering in the Light Pollution research in India. The data was retrieved from the Web of Science database. The database has been searched with the keyword as 'Light Pollution' in the 'Title' AND 'CU=India' during the period of 2005 to 2024. A total of 1831 articles published in 526 journals were taken for study. The following are the test Bradford's law and indicators used to analyse and evaluate data on Light Pollution.

Data Analysis of Interpretation:-

Year Wise Distribution of Articles:

Table 1 reveals the year-wise distribution of published articles. As per data, the highest publications i.e., 351 (19.71%) were published in the year 2024. Data reveals continuous growth in publications. The highest citations were received in 2021 with 13.63% of the total citations received by 8040 articles. The highest average citations per article in the year 2009 (108.50) and the average citation per year is 402.0. A total of 1831 articles received 58993 citations. Despite slight dips, the overall trend suggests consistent and strong citation performance over time.

Table 1: Year Wise Distribution of articles and Received Citations

Year	Articles	% of 1831	Cum. Art.	Cum. Art %	TCR	TCR %	ACPA	ACPY
2005	3	0.16	3	0.16	217	0.37	72.33	10.85
2006	4	0.22	7	0.38	50	0.08	12.50	2.5
2007	7	0.38	14	0.76	188	0.32	26.86	9.4
2008	12	0.66	26	1.42	484	0.82	40.33	24.2
2009	14	0.76	40	2.18	1519	2.57	108.50	75.95
2010	11	0.60	51	2.79	706	1.20	64.18	35.3
2011	25	1.37	76	4.15	842	1.43	33.68	42.1
2012	19	1.04	95	5.19	716	1.21	37.68	35.8
2013	23	1.26	118	6.44	1112	1.88	48.35	55.6
2014	32	1.75	150	8.19	1919	3.25	59.97	95.95

2015	43	2.35	193	10.54	2196	3.72	51.07	109.8
2016	49	2.68	242	13.22	2842	4.82	58.00	142.1
2017	54	2.95	296	16.17	2375	4.03	43.98	118.75
2018	83	4.53	379	20.70	5397	9.15	65.02	269.85
2019	107	5.84	486	26.54	5691	9.65	53.19	284.55
2020	144	7.86	630	34.41	6933	11.75	48.15	346.65
2021	211	11.52	841	45.93	8040	13.63	38.10	402.00
2022	302	16.49	1143	62.42	7890	13.37	26.13	394.5
2023	337	18.41	1480	80.83	5477	9.28	16.25	273.85
2024	351	19.17	1831	100	4399	7.46	12.53	219.95
Total	1831	100			58993	100	32.22	2949.65

Cum. Art.= Cumulative Articles, TCR-Total Citations Received; ACPA-Average Citations Per Article, ACPY= Average Citations Per Year

Time series analysis:-

Time series are analysed to understand the processes and underlying structure that produce the observations. A mathematical model allowing prediction, monitoring, or control can be created by understanding the mechanisms of a time series. This analysis also includes forecasting and prediction are common in business and economics. Monitoring the surrounding environment or an input is a regular procedure in both research and industry. A time series data set contains at least one systematic pattern. The seasonality and trends are the most prominent patterns. The seasons and trends are the most prominent patterns. Generally, trends are regarded as quadratic or linear. Regression analysis and moving averages are frequently used to identify trends. A total of 1831 publications in the field of light pollution research during the period of 2005 to 2024. In this study, time series analysis is applied to forecast the growth of the light pollution literature in India.

Table 2:Time series analysis of Light Pollution Research

Sl. No.	Year	Publications (Y)	X	X ²	XY
1	2005	3	-10	100	-30
2	2006	4	-9	81	-36
3	2007	7	-8	64	-56
4	2008	12	-7	49	-84
5	2009	14	-6	36	-84
6	2010	11	-5	25	-55
7	2011	25	-4	16	-100
8	2012	19	-3	9	-57
9	2013	23	-2	4	-46
10	2014	32	-1	1	-32
11	2015	43	1	1	43
12	2016	49	2	4	98
13	2017	54	3	9	162
14	2018	83	4	16	332
15	2019	107	5	25	535
16	2020	144	6	36	864
17	2021	211	7	49	1477
18	2022	302	8	64	2416
19	2023	337	9	81	3033
20	2024	351	10	100	3510
		1831	0	770	11890

The Straight line equation is applied under the Time series analysis to enable the formulation of assessments for future growth.

Straight Line equation $Y_c = a + bx$
Where,
Y = Trend value to be computed (dependent variable)
X=Unit of time (Independent variable)
a= Constant to be calculated
b= Constant to be calculated
Application of straight line equation to the Light Pollution
Since $\Sigma x = 0$
$a = \Sigma Y / N = 1831 / 20 = 91.55$ $b = \Sigma XY / \Sigma x^2 = 11890 / 770 = 15.44$
Estimated literature in 2034 is, when $X = 2034 - 2014 = 20$ years
$= 91.55 + 15.44 * 20 = 91.55 + 308.8 = 400.35$
Estimated literature in 2039 is, when $2039 - 2014 = 25$ years
$= 91.55 + 15.44 * 25 = 91.55 + 386 = 477.55$

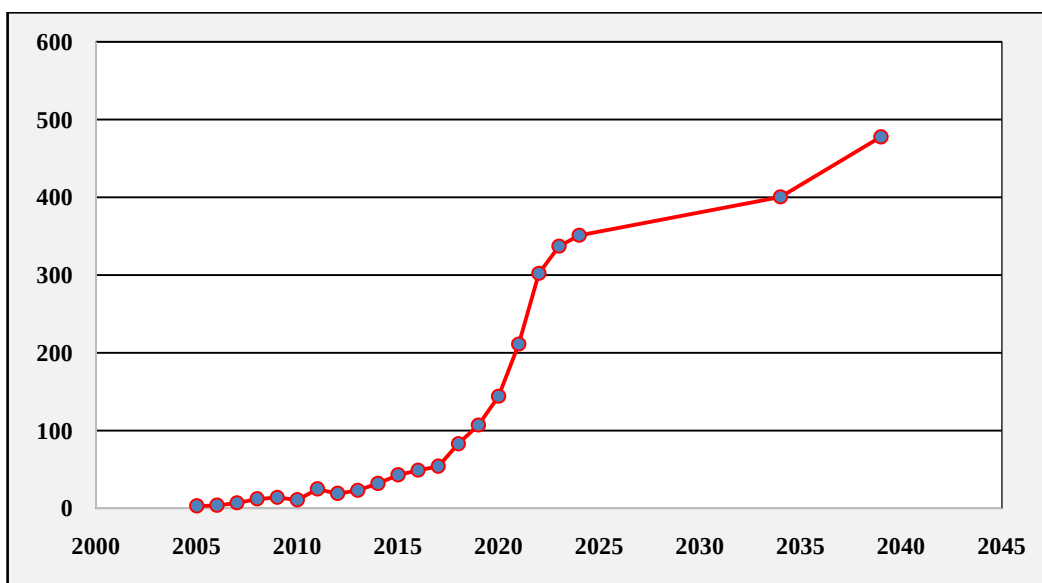


Fig. No. 1: Time Series Analysis Future Growth

From the above results, it is observed that the calculations the estimated future growth of Indian Light Pollution research will be increased from 91.55 in the year 2024 to 400.35 in the year 2034 and in the year 2039 to 477.55, the tableno.2 and Fig. no.1 reveal the same. The increasing trend continued up to the estimated year. So, it can be assumed that the rate of growth is positive in relation by the year-wise publications.

Ranking of Journals:

The table 3 reveals the top 20 ranking of journals which are preferred by scientists in the field of Light Pollution research. Environmental Science and Pollution Research ranked 1st with a total of 355 (19.39%) publications share, followed by Environmental Pollution ranked 2nd with 66 (3.60%) publications, Journal of Environmental Chemical Engineering ranked 3rd with 35 (1.91%) publications, Science of the Total Environment ranked 4th with 35 (1.91%) publications and Water Air and Soil Pollution ranked 5th with 35 (1.91%) publications. The highest citations

received by the preferred journal is Environmental Science and Pollution Research with 9115 citations. The highest average citation per article received by the Journal of Environmental Management is 81.81.

Table 3 : Top 20 Most Preferred Journals in the field of Light Pollution research in India

Rank	Source Title	Articles	% of 1831	TCR	% of 58993	ACPA	IF	Country
1	Environmental Science and Pollution Research	355	19.39	9115	15.45	25.68	5.8	Germany
2	Environmental Pollution	66	3.60	2070	3.51	31.36	7.3	Netherlands
3	Journal of Environmental Chemical Engineering	35	1.91	2193	3.72	62.66	7.2	United Kingdom
4	Science of the Total Environment	35	1.91	1186	2.01	33.89	8.0	Netherlands
5	Water Air and Soil Pollution	35	1.91	538	0.91	15.37	3.0	Germany
6	Chemosphere	32	1.75	1667	2.83	52.09	8.1	Netherlands
7	Atmospheric Pollution Research	31	1.69	460	0.78	14.84	3.5	Netherlands
8	Environmental Research	27	1.47	724	1.23	26.81	8.431	Netherlands
9	Environmental Monitoring and Assessment	22	1.20	447	0.76	20.32	3.0	Netherlands
10	Inorganic Chemistry Communications	22	1.20	245	0.42	11.14	5.4	Netherlands
11	Journal of Environmental Management	21	1.15	1718	2.91	81.81	8.910	Netherlands
12	Atmospheric Environment	20	1.09	767	1.30	38.35	4.012	United Kingdom
13	Marine Pollution Bulletin	19	1.04	344	0.58	18.11	7.001	United Kingdom
14	Chemistryselect	15	0.82	104	0.18	6.93	2	Germany
15	New Journal of Chemistry	15	0.82	185	0.31	12.33	3.3	France
16	Atmospheric Chemistry and Physics	14	0.76	785	1.33	56.07	6.133	Germany
17	International Journal of Environmental Science and Technology	14	0.76	175	0.30	12.5	2.860	Germany
18	Ceramics International	13	0.71	604	1.02	46.46	5.6	Netherlands
19	Colloids and Surfaces A Physicochemical and	13	0.71	235	0.40	18.08	5.41	Netherlands

	Engineering Aspects							
20	Journal of Cleaner Production	12	0.66	778	1.32	64.83	10.1	Netherlands
Truncated								

TP-Total publications; TCR-Total Citations Received; ACP- Average Citations per Paper; IF: Impact Factor

Bradford's Law of Scattering:-

Bradford's Law of Scattering is one of the bibliometric laws which is used in bibliometric/scientometric studies. This method assists to determine the highly-cited journals are listed as nucleus journals of the subject. Bibliometric Law of scattering was formulated by Samuel Clement Bradford (1934). He carryout a study in Applied geophysics research. He noticed that the scattered of scientific journal papers followed a common pattern. He describes a quantitative relationship between journals and published papers which the papers be found (Bradford, 1934). Application of Bradford's Law of Scattering shows the three productive zones so that each zone produces 1/3 of the total relevant papers. Bradford (1950) defined Bradford law as "If the scientific periodicals are arranged in order of decreasing productivity of articles on a given subject, they may be divided into a nuclear of periodicals more particularly devoted to the subject and different groups or zones containing the same number of papers as the nucleus when the number of periodicals in the nucleus and succeeding zone will be as 1: n: n². The first nucleus zone comprises a small number of highly productive journals say n₁, the second zone has a larger number of temperately productive journals say n₂, and the third zone has still larger number of journals of low productivity say n₃. He enunciated his law 1: n: n², where 'n' is a multiplier

In the present study depicts the Bradford law has been tested for journal articles of Light Pollution research during 2005 to 2024. For testing the Bradford's law in the Light Pollution, 1831 publications dispersed in the 526 journals are divided into three zones and listed by rank order. The beginning core journals contributed the highest number of publications. It is defined that the journals structured in descending order of journal productivity and it exposes that most productive journal publications appeared first as well as low productive journal publications appeared last in the table 4.

Table 4: Parameter value for the Bradford's distribution in Light Pollution Journals

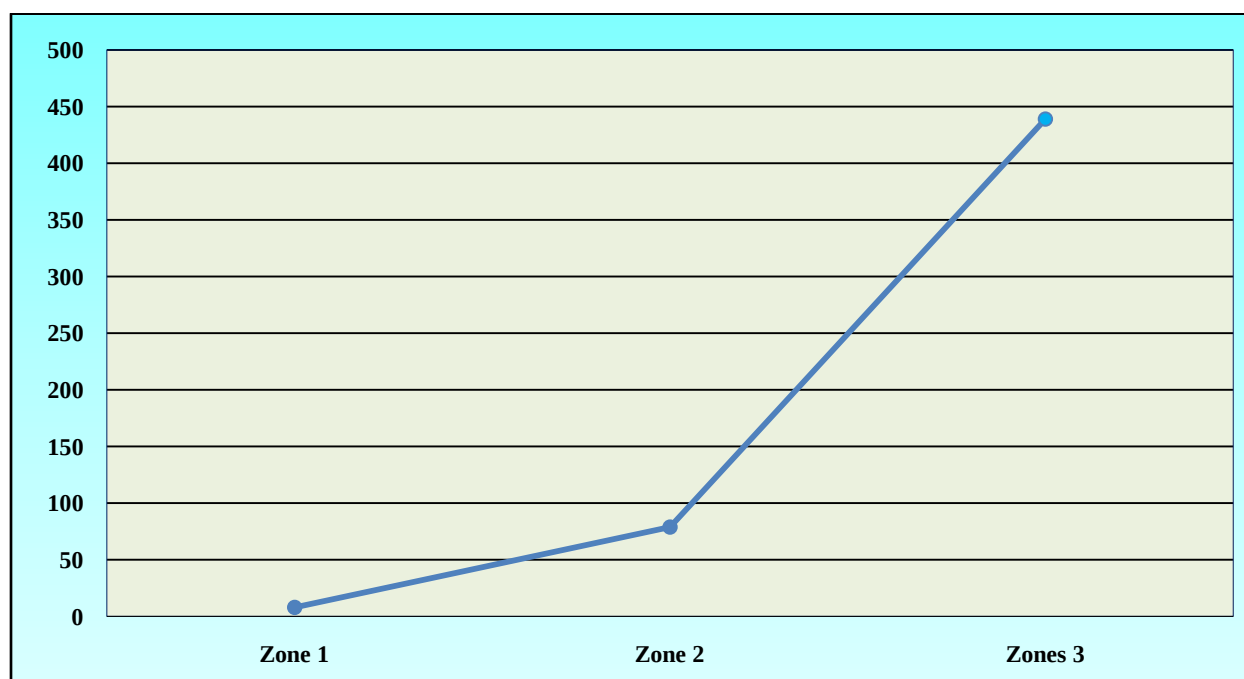
Rank	Number of Journals	Cumulative number of Journals	Number of Articles	Cumulative number of Articles	Log(n)
1	1	1	355	355	0.00
2	1	2	66	421	0.69
3	3	5	105	526	1.61
4	1	6	32	558	1.79
5	1	7	31	589	1.95
6	1	8	27	616	2.08
7	2	10	44	660	2.30
8	1	11	21	681	2.40
9	1	12	20	701	2.48
10	1	13	19	720	2.56
11	2	15	30	750	2.71
12	2	17	28	778	2.83
13	2	19	26	804	2.94
14	2	21	24	828	3.04
15	2	23	22	850	3.14
16	6	29	60	910	3.37

17	4	33	36	946	3.50
18	6	39	48	994	3.66
19	3	42	21	1015	3.74
20	8	50	48	1063	3.91
21	15	65	75	1138	4.17
22	22	87	88	1226	4.47
23	41	128	123	1349	4.85
24	84	212	168	1517	5.36
25	314	526	314	1831	6.27
	526		1831		

Table No 5: Scattering of Journals and Publicationsover Bradford's zones

Zones	Journals	Journals %	Publications	Publications %	Bradford Multiplier (k)
1	8	1.52	616	33.64	0
2	79	15.02	610	33.32	9.88
3	439	83.46	605	33.04	5.56
Total	526	100	1831	100	7.72*

Mean value of Bradford multiplier *

**Fig. No.2: Scattering of Journals and Publications over Bradford's zones**

For testing of Bradford's law, the Light Pollution research articles, the 526 journals are divided into three zones. The distribution of journals and a corresponding number of articles in the three zones along with the value of Bradford multiplier are shown in table 5 & figure 2. In the present dataset, the first 8 journals covered 616 (33.64%) articles, followed by 79 journals covered 610 (33.32%) articles and the next 439 journals covered 605 (33.04%) articles. It can be noticed that the three zones are almost exactly the 1/3rd of the total articles as suggested by Bradford. According to Bradford's law, of scattering, zone wise distribution will form an approximately geometric series in

the form $1: n: n^2$. The relationship of each zone in the present study is 8:79:439. Here, The Bradford multiplier between the number of references in zone 1 and zone 2 is 9.88 while it is 5.56 between zone 2 and 3. The average multiplier value is 7.72.

Therefore, $1: n: n^2$
 $= 8: 8 \times 7.72: 8 \times (7.72)^2$
 $= 8: 61.76: 476.7872$
 $= 546.5472$

Percentage error=	Value of $1: n: n^2$ - Total no. of journals	X100
	Total no. of journals	

Therefore,

Percentage error =	$[(546.5472 - 526) / 526] \times 100$
=	$546.5472 - 526 = 20.5472$
=	$20.5472 / 526 = 0.039063$
=	$0.039063 \times 100 = 3.91\%$
Percentage error =	3.91%

Since the percentage of error is negligible (3.91%) here, the data fits well Bradford's law of scattering.

Graphical Formulation:-

The Graphical formulation is just the experimental verification of the verbal formulation which observes certain regularity in the distribution of scientific publications (Sudhler 2010). The graphical formulation approach was developed by Brookes which tries to verify the Verbal formulation of the Bradford's Law of scattering (Brookes, 1969). If the distribution confirms to Bradford's law, it will show the characteristics in the 3 distinct regions:

1. the graph may have sharp rise at beginning which shows the core journals;
2. a major portion of linear relation between two variables,
3. a 'droop' at the tail end indicating incompleteness of the bibliography.

In this study, Graphical formulation has been used as a visual formulation for the verbal formulation of the law of scattering

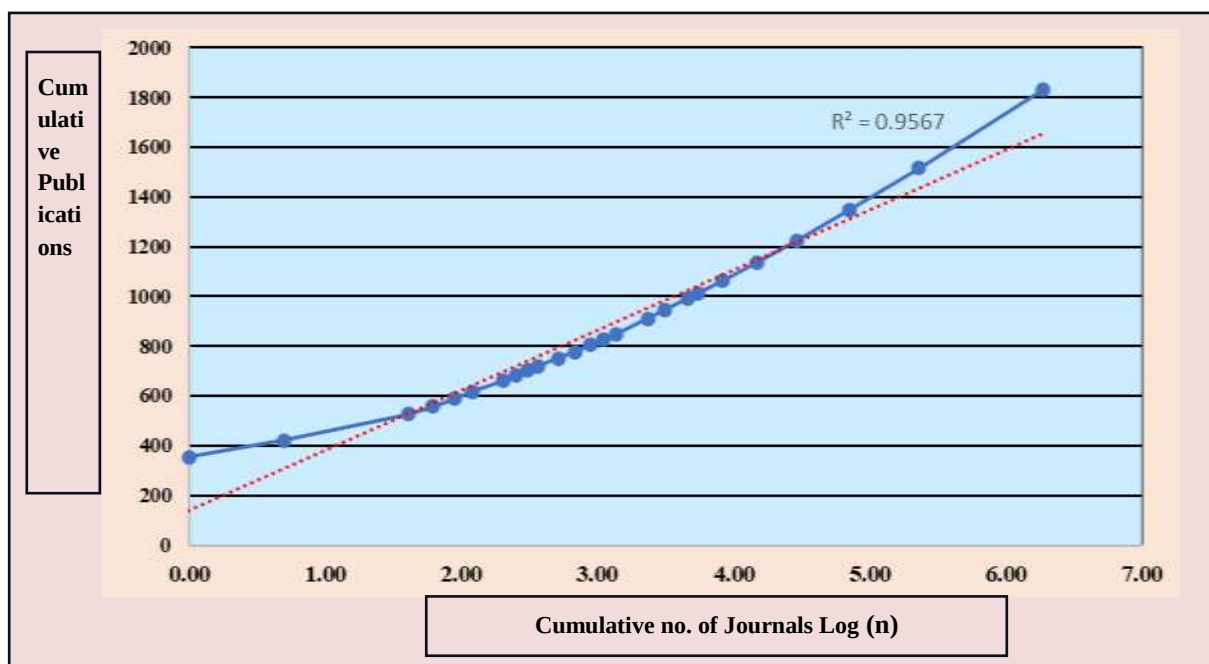


Figure 3: Bradford's Bibliograph for Journals Distribution

The graph in the Fig 3 shows the logarithmic plot of cumulative publications on the horizontal (X) axis and the log of cumulative number of journals on the vertical (Y) axis. In this study Bradford curve with a Groos droop. The Bradford's curve with a Groos droop, where the journals are plotted against their productivity.

Conclusion: -

The present study analyses the test of Bradford's Law and the growth of literature on light pollution by researchers in India from 2005 to 2024 based on the data extracted from the Web of Science (WOS). Bradford's Law of Scattering is a bibliometric law that helps select core journals in a research field. In this study, theoretical aspects of Bradford's Law of Scattering are tested, and it is found that the data fit well in the present data set in the field of Light Pollution research publications during the period. The Journal distribution pattern of Light Pollution literature fits well with Bradford's distribution, i.e., 1: n: n². Bradford's law of scattering states that articles in each zone should be equal, as witnessed in the present study.

The percentage of error is found to be the most negligible (3.91%) and therefore, the law is found to be valid for the data set. Research in Light Pollution is gradually increasing, and there is an upward trend in India; however, there is some fluctuation in the trends of publications. India ranks third in worldwide publication share among the highest twenty most efficient countries in the field of Light Pollution. Nevertheless, there is scope for improvement, and India can contribute much more, considering India's potential in Light Pollution research. Indian science research funding agencies, including the government, should provide sufficient funding and other infrastructure facilities for the causes of Light Pollution. This study can help forecast the trends of Indian research in light pollution and its related fields. Further, it can give a state-of-the-art report on the field to the government and other research agencies to form policies, and it is valuable for understanding the framework of scientific literature. It also has implications for research evaluation, information retrieval, and science policy.

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