



RESEARCH ARTICLE

Application of Lotka's law in Indian cytokine publications: A scientometric study based on web of science during 1998 TO 2022

J. Helan Shali Margret*, N. Amsaveni

Abstract

This study is descriptive type; the scientific term of "Cytokine" related publications were retrieved from the web science database from 1998 to 2022. Data were gathered on 28th November 2022, and a total of 5533 bibliography documents (including journal articles, conference proceedings, Book Chapters, Correction, etc) were retrieved and used for further study. Extraction of data was used through HistCite software and MS Excel, VOS viewer and Biblioshiny software were used to visualize the co-authorship network and mapping of the research productivity, local citation score (LCS) and global citation score (GCS) were identified. The main focus of this study is to find the year-wise authorship pattern, structure of co-authorship, trend of growth, different document types, most produced authors, contributing countries, most productive sources, most prolific institutions, co-authorship ratio, degree of collaboration, collaborative index; collaborative co-efficiency and testing the bibliometric law. A total of 5533 original research articles were retrieved from the Web of Science database for this study. Totally 35518 authors were contributed, among those single authored have contributed 74 (1.3%) articles. Four authored 842 (15.2%) collaborative contributions are higher than other co-authorship contributions. 2021 year have highest publications. 2016 earned the highest global citation scores. AIIMS and BHU were the most productive institutions. The USA and UK most collaborated with India.

Keywords: Cytokine, immune, Library science, Bibliometrics, Global citations, Relative growth rate, Authorship pattern, Lotka's law, Collaboration index.

Introduction

Cytokines are small proteins that are crucial for controlling the growth and functioning of immune system cells, including blood cells. They generate signals that instruct the immune system how to operate. All blood cells and other cells that support the body's immune and inflammatory responses are influenced by cytokines in their development. Although some nomenclature overlaps,

cytokines include lymphokines, interferons, chemokines, interleukins, and tumour necrosis factors but often do not include hormones or growth factors. Numerous cell types, including endothelial cells, fibroblasts, and different types of stromal cells, as well as immune cells, including mast cells, B lymphocytes, T lymphocytes, and macrophages, can create cytokines. Multiple cell types may produce a single cytokine. Cytokines are particularly significant in the immune system because they modify the balance between humoral and cell-based immune responses and control the development, proliferation, and reactivity of certain cell populations. They do this by acting through cell surface receptors. In complex ways, some cytokines may increase or decrease the effects of other cytokines. They are not the same as hormones, which are likewise significant chemicals involved in cell signaling. Hormones tend to be produced by particular cell types and circulate in larger amounts. In particular, cytokines play a crucial role in the host immune system's reactions to infection, inflammation, trauma, sepsis, cancer, and reproduction.

As far as we can observe, this was the first study that examined a scientometric study of cytokine publications.

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The purpose of this research was to analyze bibliometric aspects of cytokine and Indian cytokine publications that span the years 1998 to 2022. In addition to saving time for other crucial topics, we think that this work will direct future cytokine research and contribute to science by guiding such studies.

Review of Literature

Different bibliometric studies have been carried out on the subject of cytokines in various aspects; some of the most recent current ones are shown below to provide readers with a better idea of the methods and topics that these researchers are interested in this field.

The authors have derived that CAR-T cell therapy is effective against certain blood cancers but can cause adverse events like cytokine release syndrome (CRS). A comprehensive study analyzed CAR-T cell-induced CRS research from the Web of Science Core Collection, involving 6,623 authors, 295 institutions, and 1,001 publications across 49 countries. The United States, notably the University of Pennsylvania, leads in this research with highly cited figures like Carl H. June and Daniel W. Lee. Key research areas include CRS pathogenesis, serum biomarkers, management strategies, therapeutic drugs, neurotoxicity, and newer fields such as CRS treatment drugs, real-world clinical trial data, and CAR framework optimization. This analysis provides valuable insights for researchers in the field, Li, H., Huang, Q., & Zhang, Y. (2023).

The authors have highlighted that cytokines significantly influence the glioma tumor microenvironment, affecting tumor occurrence, development, and treatment response. Their strategic use in glioma immunotherapy holds promise for improved outcomes. Future research should use bibliometric mapping to identify key contributions and unexplored areas in this field. Quantitative mapping of glioma immunotherapy cytokine literature provides valuable insights for future studies, which will likely focus on the epidermal growth factor receptor, interleukin-13 receptor alpha 2, cancer vaccines, tumor microenvironment, macrophages and microglia biology, and resistance mechanisms, Zhang, H., *et al.*, (2023).

The authors have discussed that macrophages are key contributors to diabetes pathogenesis due to their production of inflammatory cytokines. This study uses bibliometric analysis to explore research trends and guide funding decisions for macrophage-related diabetes studies from 2000 to 2022. Key findings include increasing publication and citation trends, with Wu Yonggui and the University of Michigan being prominent contributors. China and the USA show strong collaboration. "Diabetologia" is the primary journal for related publications, with keywords like "inflammation," "diabetic nephropathy," "obesity," and "macrophage polarization" highlighted as significant research areas. The analysis offers a comprehensive overview

to shape future research and investment strategies, Wang S., *et al.*, (2023).

The authors have focused on the bibliometric study of regulatory T (Treg) cells in neurological diseases, using data from the Web of Science Core Collection, analyzed 2,739 documents from 85 countries and 2,811 organizations. Harvard Medical School was notably prominent, with Howard E. Gendelman as a key author. "Frontiers in Immunology" was the leading journal. Key research areas included "multiple sclerosis," "inflammation," and "neuroinflammation," with "gut microbiota" emerging as a new focus. Treg cell-based immunomodulation, enhancing Treg cell functions through cytokine regulation and gut microbiota modulation, holds promise for treating neurological diseases. The study highlights the importance of Treg cell research and identifies key future research directions, Gao, Q. *et al.*, (2023).

The authors have provided a comprehensive bibliometric study of regulatory T (Treg) cells in neurological diseases, using data from the Web of Science Core Collection, analyzed 2,739 documents from 85 countries and 2,811 organizations. Harvard Medical School was notably prominent, with Howard E. Gendelman as a key author. "Frontiers in Immunology" was the leading journal. Key research areas included "multiple sclerosis," "inflammation," and "neuroinflammation," with "gut microbiota" emerging as a new focus. Treg cell-based immunomodulation, enhancing Treg cell functions through cytokine regulation and gut microbiota modulation, holds promise for treating neurological diseases. The study highlights the importance of Treg cell research and identifies key future research directions, Sahin, H. H. K. *et al.*, (2022).

The authors have discussed the tumor necrosis factor (TNF) holds crucial research value in post-stroke neuroinflammation (PSN). A bibliometric analysis of 1,391 articles from 2003 to 2021 identified a notable upward trend in publications. The research contributions primarily came from 57 countries and 1,446 institutions, with China leading in the number of publications and the US in citations. TNF plays a vital role in PSN through multiple immune mechanisms and may serve as a potential target for neuroprotective therapeutics after stroke. Future research may focus on identifying key therapeutic targets in the TNF pathway, Zhao, Y., *et al.*, (2022).

The authors have focused on the comprehensive bibliometric study that analyzed 4,381 entries on T cells and atherosclerosis (AS) from the Web of Science™ Core Collection using CiteSpace and VOSviewer. The study filled a gap in bibliometric research on AS, revealing insights into subject categories, authorship, and spatiotemporal distribution. Over the past decade, the field has stabilized, with current research focusing on AS cytokines, associated illnesses, and immunological and inflammatory pathways.

Emerging areas of study include monocytes, mortality, inhibition, and B cells. The study aims to promote clinical applications and research in AS and T cells while identifying potential collaborators for researchers, Wei N., *et al.*, (2022).

The authors have highlighted A bibliometric study that analyzed 1,481 records on macrophage-associated osteoarthritis (OA) research from 1991 to 2021, revealing an upward trend in annual publications. China and the USA contributed over 44% of publications. Key tools used included CiteSpace, VOSviewer, and the R package "bibliometrix." The League of European Research Universities was the most active institution, with "Arthritis and Rheumatism" and "Osteoarthritis and Cartilage" as popular journals. Prominent authors included Koch AE and Bondeson J. Research focused on rheumatology, orthopedics, and immunology, with keyword clusters on rheumatoid arthritis, clinical symptoms, regeneration mechanisms, pathological features, and surgical interventions. This study highlights research frontiers and guides future scholarly efforts, Yang Z., *et al.*, (2022).

The authors have explained A bibliometric study examined the intersection of schizophrenia (SCZ) and inflammation by analyzing articles from the Web of Science Core Collection. Using the R package "bibliometrics," the study identified key findings, top keywords, and collaboration networks among countries. VOSviewer and CiteSpace tools were used for co-authorship and citation burst analyses. With 3,596 publications included, the study found the USA, China, and Germany as major contributors. Prominent keywords included "schizophrenia," "inflammatory," "bipolar disorder," "brain," and "meta-analysis." The study provides a comprehensive view of SCZ and inflammation research over the past three decades, Sun, H. L., *et al.*, (2022).

The authors have concentrated on the COVID-19 pandemic has underscored the urgent need to understand its impact on the human body, particularly through cytokine storm syndrome triggered by elevated cytokine and chemokine levels in patients. This syndrome illustrates the severe consequences of immune system dysregulation and emphasizes the necessity for an effective immune response. Scientometric analysis plays a crucial role in tracking evolving patterns of cytokine storms, aiding in the comprehension of their pathophysiology and management across various disorders, including those induced by infections, iatrogenic causes, autoimmune disorders, and monogenic diseases. The study comprehensively explores clinical manifestations, pathophysiological features, and therapeutic strategies related to cytokine storms, providing valuable insights for researchers aiming to understand and mitigate their impact, Wang, K. T., *et al.*, (2022).

The authors have focused on the study using citation networks to evaluate cytokines' impact on ocular health.

Spanning from 1990 to October 2021, it identified 3127 publications in the Web of Science database using keywords like "cytokine," "inflammatory," and "eye disease." Citation Network Explorer and CiteSpace software facilitated analysis, revealing 8955 citations, peaking in 2018. Notably, Peizeng Yang (1.4%), Aize Kijlstra (1.3%), and Stephen C. Pflugfelder (1.2%) were the top authors. This approach provided an in-depth exploration of cytokine influence in ocular inflammatory diseases, Galvez B. G. *et al.*, (2022).

Bibliometrics plays a crucial role in assessing trends in health sciences, notably in cancer research, and guiding cytokine studies. The focus on cytokines, particularly during the SARS-CoV-2 pandemic, underscores their impact in global viral infections. A bibliometric analysis of 232,606 articles highlighted the U.S. as the leading contributor, with Harvard University prominent in publications. The analysis emphasizes the need for increased research from developing countries. Cytokine studies are pivotal in understanding disease pathology and variability, offering insights for new medical strategies, especially in managing global viral infections like SARS-CoV-2, Sahin, M., & Senel, E. (2020).

Objectives

- To analyze the degree of collaboration.
- To find out the year-wise degree of collaboration for the cytokine research
- To find out the most frequently collaborated countries with India on cytokine publications.
- To find out the most contributed authors on cytokine publications.
- To analyze the growth trends, exponential growth rate and number of cited references on cytokine publications.
- To find out the doubling time and collaborative index from 1998 to 2022.
- To find the collaborative pattern of authorship pattern in cytokine research.
- To evaluate that Lotka's law of scientific author productivity applies to publications on cytokine research

Methodology

This study is a descriptive type approach and the data was selected through a stratified sampling method for a Scientometric study. The necessary sample data of this research has taken bibliographical data indexed by the ISI Web of Science (WOS) database on 28th November 2022 based on the search term "Cytokine" publication year 1998 to 2022 only Indian publications. And to determine the most common individuals, institutions, universities, and academic institutions associated with the development of research in the area of interest. There were 5533 items (including journal articles, papers from conference proceedings, reviews,

meeting abstracts, editorial materials, letters, book chapters, etc.) were retrieved. The retrieved data were extracted using HistCite and MS Excel software to identify the further analysis data for tabulation. The scientific community consists of producers, consumers, and scientific sources. The goal of this study was to conduct a scientometric analysis of scientific products, as well as to visualize and analyze co-authorship networks in cytokine publications from 1998 to 2022. The results of this study provide enlightenment on collaboration, provide a tool for strategically planning future research in this particular subject, and offer insight into potential development. Used by some software the Scientometric studies visualize the co-authorship network for further information. This network shows information about authors, and the authors' collaborative patterns, as well as the authors' status belongs to their publication.

Analysis And Interpretation

Degree of collaboration

This paper traces the year-wise degree of collaboration in cytokine publications from 1998-2022. The collected data were analyzed and interpreted. Various approaches have been the degree methods given to calculate the degree of research collaboration. Here in this study, the formula suggested has been applied, Subramanyam (1983).

$$\text{The degree of collaboration } C = \frac{Nm}{Nm + Ns}$$

Hence, C = Degree of collaboration; Nm = total number of articles in the multiple authors; Ns = total number of single papers in the discipline.

Here, Nm = 4161, Ns = 66, and C = 0.98. As a result, the total 25 years (1998-2022) degree of collaboration (C) is 0.98). However, the results change when we calculate the degree of collaboration for a twenty-five period year by year.

Totally 5533 publications were produced by 35518 researchers and the overall Degree of Collaboration (DC) value is 0.98. Indian researcher produced and indexed by the Web of Science (WOS) database. The sample duration is 1998 to 2022, according to Table 1 represents the data year-wise publications. Only 150 authors published 33 (0.60%) articles and DC was 0.95 were at the year of 1998 increased to 681 (12.31%) in the year 2021 DC is 0.98. This result shows more than twelve times the fold developed. The publications were increased by more than 100 after the year of 2007. Previous years had less numbers of publications. The highest publications are in the year of 2021, followed by the years 2022, 2020 and 2016.

Most Frequently Collaborating Countries with India

The analysis of documents indexed in ISI showed that cytokine researchers collaborated from various 117

countries. Table 2 shows that the most frequent countries participating in scientific production with Indian Scientists. Out of 117 countries, USA collaborated 759 (13.7%) of articles with 26755 TGCS, followed by UK collaborated 166 (3.0%) of articles with 9150 TGCS, Saudi Arabia collaborated 159 (2.9%) of articles with 5225 TGCS, Germany collaborated 111 (2.0%) of articles with 6830 TGCS, and Australia collaborated 108 (2.0%) of articles with 5868 TGCS respectively. The remaining countries have collaborated below 100 articles with India in the subject of cytokine.

Most Frequent Authors

Table 3 analysis results suggested that from 1998 to 2022, 5533 publications were indexed in the Web of Science in the field of cytokine. Totally 35518 authors were identified but the actual authors are 18405. The top twenty (above 50 publications) researchers were arranged by ranking based on their highest contributions and according to their indices values. Kumar Anjani, Umea University, Sweden (185 titles) among those 26 articles, was the mentioned author as first-authored contribution with 28 h-index, 9547 total global citation scores, followed by Kumar Sathish, Christian Medical College & Hospital, Vellore, Tamilnadu (165 titles) among those 18 articles have been as first-authored contribution with 23 h-index, 5133 total global citation scores; Sharma Anjay, CSIR, Mathura, India (120 titles) among those 13 articles have been as first-authored contribution with 23 h-index, 2082 total global citation scores; Singh Shailza, NCCS, SP Pune University campus, Maharastra (115 titles) among those 12 articles have been as first-authored contribution with 26 H-index, 2469 total global citation scores respectively. The remaining authors contributed below 100 articles in cytokine publications during the sample periods.

Trends of Growth Rate, Doubling Time and Collaborative Index of Cytokine Publications from 1998 To 2022

The number of articles or pages that increased per unit of time is the only factor that contributes to the relative growth rate (RGR). "The RGR and Dt model, proposed by Mahapatra in 19949, has been used to calculate the growth rate of publications." At the same time, doubling time refers to how many times required to simply double the current quantity at a specific growth rate. This application is used to determine how long it will take to double the current volume of publications, citations, pages, etc. It is closely connected with the RGR.

Relative growth rate calculated using the formula below:

$$RGR = W2 - W1 / T2 - T1.$$

Where, RGR is the growth rate for the specific interval's time. W1 = Loge (the natural log of the starting contribution count).

W2 = Loge (the natural log of the total number of contributions)

Table 1: Year-wise degree of collaboration

<i>Year</i>	<i>Total no. of article</i>	<i>Total no. of authors</i>	<i>Single authors articles</i>	<i>% of single authors</i>	<i>Multiple authors articles</i>	<i>% of multiple authors</i>	<i>DC</i>	<i>TGCS</i>
1998	33	150	1	0.02	20	0.36	0.95	779
1999	38	180	1	0.02	24	0.43	0.96	1310
2000	24	100	0	0.00	13	0.23	1.00	862
2001	35	132	1	0.02	17	0.31	0.94	1061
2002	37	139	1	0.02	24	0.43	0.96	1101
2003	47	238	1	0.02	32	0.58	0.97	1809
2004	59	261	1	0.02	31	0.56	0.97	2625
2005	70	349	3	0.05	47	0.85	0.94	2789
2006	89	435	3	0.05	58	1.05	0.95	3158
2007	124	619	0	0.00	88	1.59	1.00	4952
2008	164	841	1	0.02	106	1.92	0.99	5742
2009	165	882	2	0.04	114	2.06	0.98	5155
2010	189	991	1	0.02	131	2.37	0.99	6312
2011	224	1235	2	0.04	181	3.27	0.99	7687
2012	231	1286	1	0.02	172	3.11	0.99	7610
2013	256	1385	6	0.11	185	3.34	0.97	6833
2014	335	1983	6	0.11	254	4.59	0.98	9119
2015	317	2037	2	0.04	252	4.55	0.99	7344
2016	387	2176	5	0.09	278	5.02	0.98	10236
2017	315	1956	0	0.00	239	4.32	1.00	5407
2018	384	4958	1	0.02	313	5.66	1.00	5887
2019	328	2067	2	0.04	267	4.83	0.99	4272
2020	483	3217	9	0.16	368	6.65	0.98	7483
2021	681	4618	9	0.16	528	9.54	0.98	5063
2022	518	3283	7	0.13	419	7.57	0.98	704
Total	5533	35518	66	1.19	4161	75.20		115300

DC – Degree of Collaboration; TGCS – Total Global Citation Score

Table 2: Most frequent collaborating countries with Indian scientists on cytokine

<i>Country</i>	<i>Recs.</i>	<i>%</i>	<i>TLCS</i>	<i>TGCS</i>	<i>Country</i>	<i>Recs.</i>	<i>%</i>	<i>TLCS</i>	<i>TGCS</i>
USA	759	13.7	524	26755	Malaysia	53	1.0	20	4084
UK	166	3.0	109	9150	Canada	52	0.9	10	5327
S.Arabia	159	2.9	33	5225	Sweden	45	0.8	57	4263
Germany	111	2.0	22	6830	Switzerland	41	0.7	5	4676
Australia	108	2.0	47	5868	Brazil	40	0.7	12	4056
S.Korea	79	1.4	64	5616	Egypt	37	0.7	3	608
France	69	1.2	51	5672	Iran	33	0.6	12	4208
Japan	66	1.2	11	4988	Russia	33	0.6	35	4352
China	60	1.1	38	4830	Singapore	32	0.6	7	4155
Italy	54	1.0	47	5250	UAE	31	0.6	4	3738

Recs. – Records; TLCS – Total Local Citation Score; TGCS – Total Global Citation Score

Table 3: Most frequent authors on cytokine publications

<i>R</i>	<i>Author</i>	<i>Address</i>	<i>Recs.</i>	<i>%</i>	<i>TGCS</i>	<i>1st authored</i>	<i>H-index</i>	<i>DC</i>
1	Kumar Anjani	Umea Univ, Sweden	185	3.3	9547	26	28	0.86
2	Kumar Sathish	Christian Med Coll, Vellore	164	3.0	5133	18	23	0.89
3	Sharma Abhay	CSIR, Mathura, India	120	2.2	2082	13	23	0.89
4	Singh Shailza	NCCS, SP Pune Univ, Maharashtra	115	2.1	2469	12	26	0.90
5	Sharma Swati	CSIR, New Delhi	96	1.7	4889	17	25	0.82
6	Babu Subash	Natl Inst Hlth, Chennai, Tamilnadu	95	1.7	1776	9	24	0.91
7	Das Sulagna	Natl Brain Res Ctr, Haryana, India	92	1.7	1356	21	19	0.77
8	Kumar Rajesh	Inst Pathol ICMR, New Delhi	85	1.5	4800	20	24	0.76
9	Kumar P	All India Inst Med Sci, New Delhi	74	1.3	1344	19	20	0.74
10	Singh Ranjana	Sanjay Gandhi PG IMS, UP	66	1.2	4757	9	21	0.86
11	Gupta Shalini	Pune Univ Campus, Maharashtra	64	1.2	1066	14	18	0.78
12	Saha Banishree	IISc, Bangalore, Karnataka	63	1.1	1829	7	20	0.89
13	Kumar Vijay	Panjab Univ, Chandigarh, India	60	1.1	817	12	14	0.80
13	Roy Subhrajyoti	Univ N Bengal, W Bengal, India.	60	1.1	1270	13	20	0.78
14	Singh Shanker K	Indian Vet Res Inst, UP, India	59	1.1	4073	2	14	0.97
15	Singh Amit	Banaras Hindu Univ, UP, India	58	1.0	1364	13	19	0.78
16	Gupta Amit	IIIM, Pharmacol, Jammu, India.	53	1.0	858	8	15	0.85
17	Banerjee S	Sree Chitra T IMS & T, Kerala	51	0.9	896	6	19	0.88
18	Kumar Dinesh	Indian Council Med Res, Chennai	50	0.9	7659	7	19	0.84
18	Singh Meghna	Cent Drug Res Inst, Lucknow, UP	50	0.9	1147	10	16	0.80

TGCS- Total Global Citation Score; DC – Degree of Collaboration

Table 4: Growth rate, doubling time and collaborative index on cytokine publications

<i>Year</i>	<i>No. of articles</i>	<i>Cum. No. of articles</i>	<i>Log1e (W1)</i>	<i>Log2e (W2)</i>	<i>RGR (P)</i>	<i>Dt (p)</i>	<i>Exp. GR</i>	<i>CI</i>
1998	33	33	-	3.5	0	0	-	4.6
1999	38	71	3.5	4.26	0.76	0.91	1.15	4.7
2000	24	95	4.26	4.55	0.29	2.39	0.63	4.2
2001	35	130	4.55	4.87	0.32	2.17	1.46	3.8
2002	37	167	4.87	5.12	0.25	2.77	1.06	3.8
2003	47	214	5.12	5.37	0.25	2.77	1.27	5.1
2004	59	273	5.37	5.61	0.24	2.89	1.26	4.4
2005	70	343	5.61	5.84	0.23	3.01	1.19	5
2006	89	432	5.84	6.07	0.23	3.01	1.27	4.9
2007	124	556	6.07	6.32	0.25	2.77	1.39	5
2008	164	720	6.32	6.58	0.26	2.67	1.32	5.1
2009	165	885	6.58	6.79	0.21	3.30	1.01	5.4
2010	189	1074	6.79	6.98	0.19	3.65	1.15	5.2
2011	224	1298	6.98	7.17	0.19	3.65	1.19	5.5
2012	231	1529	7.17	7.33	0.16	4.33	1.03	5.6
2013	256	1785	7.33	7.49	0.16	4.33	1.11	5.4
2014	335	2120	7.49	7.66	0.17	4.08	1.31	5.9

2015	317	2437	7.66	7.8	0.14	4.95	0.95	6.4
2016	387	2824	7.8	7.95	0.15	4.62	1.22	5.6
2017	315	3139	7.95	8.05	0.1	6.93	0.81	6.2
2018	384	3523	8.05	8.17	0.12	5.78	1.22	12.9
2019	328	3851	8.17	8.26	0.09	7.70	0.85	6.3
2020	483	4334	8.26	8.37	0.11	6.30	1.47	6.7
2021	681	5015	8.37	8.52	0.15	4.62	1.41	6.8
2022	518	5533	8.52	8.62	0.1	6.93	0.76	6.3
Total	5533	42381			5.12	3.8		6.4

RGR – Relative Growth Rate; DT- Doubling Time; Exp. GR – Exponential Growth Rate; CI – Collaborative Index

Table 5: Authorship pattern

Year		1 st author	2 nd author	3 rd author	4 th author	5 th author	6 th author	7 th author	8 th author	9 th author	10 + authors	artl. (autrs.)
1998	Artls	1	3	9	9	4	4	1	2	-	1	33 (150)
	Autrs	1	6	27	36	20	24	7	16	-	13	
1999	Artls	1	7	6	6	7	3	2	2	2	2	38 (180)
	Autrs	1	14	18	24	35	18	14	16	18	22	
2000	Artls	0	2	9	7	1	1	2	2	-	-	24 (100)
	Autrs	0	4	27	28	5	6	14	16	-	-	
2001	Artls	1	8	9	6	7	1	1	2	-	-	35 (132)
	Autrs	1	16	27	24	35	6	7	16	-	-	
2002	Artls	1	4	8	9	7	2	1	2	-	-	37 (139)
	Autrs	1	8	24	36	35	12	7	16	-	-	
2003	Artls	1	6	8	8	2	10	5	4	1	2	47 (238)
	Autrs	1	12	24	32	10	60	35	32	9	23	
2004	Artls	1	11	16	9	3	11	3	4	1	1	59 (261)
	Autrs	1	22	48	36	15	66	21	32	9	11	
2005	Artls	3	7	13	11	10	10	8	3	3	3	70 (349)
	Autrs	3	14	39	44	50	60	56	24	27	32	
2006	Artls	3	12	16	16	10	17	4	5	3	4	89 (435)
	Autrs	3	24	48	64	50	102	28	40	27	49	
2007	Artls	0	17	19	26	19	14	12	8	4	6	124 (619)
	Autrs	0	34	57	104	95	84	84	64	36	61	
2008	Artls	1	26	31	27	34	12	13	2	5	14	164 (841)
	Autrs	1	52	93	108	170	72	91	16	45	193	
2009	Artls	2	19	30	36	20	14	16	7	8	14	165 (882)
	Autrs	2	38	90	144	100	84	112	56	72	184	
2010	Artls	1	27	30	39	27	17	16	10	9	14	189 (991)
	Autrs	1	54	90	156	135	102	112	80	81	180	

2011	Artls	2	30	26	30	37	67	28	15	12	17	224 (1235)
	Autrs	2	60	78	120	185	162	196	120	108	204	
2012	Artls	1	24	34	35	32	37	23	16	14	16	231 (1286)
	Autrs	1	48	102	140	160	222	161	128	126	198	
2013	Artls	6	27	38	44	43	26	24	16	7	25	256 (1385)
	Autrs	6	54	114	176	215	156	168	128	63	305	
2014	Artls	6	31	44	62	53	41	32	22	9	40	335 (1983)
	Autrs	6	62	132	248	265	246	224	176	81	543	
2015	Artls	2	28	35	51	41	43	28	22	17	52	317 (2037)
	Autrs	2	56	105	204	205	258	196	176	153	682	
2016	Artls	5	41	63	48	62	49	36	24	23	37	387 (2176)
	Autrs	5	82	189	192	310	294	252	192	207	453	
2017	Artls	0	34	42	41	44	38	35	26	17	42	315 (1956)
	Autrs	0	68	126	164	220	228	231	208	153	558	
2018	Artls	1	31	39	49	72	45	32	29	25	65	384 (4958)
	Autrs	1	62	117	196	360	270	224	232	225	3271	
2019	Artls	2	27	32	38	63	45	43	20	19	47	328 (2067)
	Autrs	2	54	96	152	315	270	301	160	171	546	
2020	Artls	11	44	60	75	62	62	49	31	26	78	483 (3217)
	Autrs	11	88	180	300	310	372	343	248	234	1131	
2021	Artls	15	68	70	91	78	84	60	45	45	127	681 (4618)
	Autrs	15	136	210	364	380	504	420	360	405	1824	
2022	Artls	7	35	57	69	50	53	33	41	34	101	518 (3283)
	Autrs	7	70	171	276	250	318	231	328	306	1326	
Total	Artls	74 (1.3)	569 (10.3)	744 (13.5)	842 (15.2)	786 (14.2)	666 (12)	505 (9.1)	360 (6.5)	287 (5.2)	708 (12.8)	5533 (35518)
	Autrs	74 (0.2)	1138 (3.2)	2232 (6.3)	3368 (9.5)	3930 (11.1)	3996 (11.3)	3535 (10)	2880 (8.1)	2583 (7.3)	11809 (33.3)	

Autrs – Authors; Artls – Articles

T1 is the first-time unit.

T2 is the final time unit.

Doubling Time (Dt)

There is a clear correlation between the doubling time and the relative growth rate.

Here, the usual natural logarithm of 0.693 is used to calculate Doubling Time.

The formula for the Doubling time = $0.693 / R$ (R is for the relative growth rate)

The relative growth rate [R(P)] and doubling time [Dt(P)] of publication values are indicated in Table 4. It could be observed that the relative growth rate of publication [R(P)] collaborative index (CI) values is 6.4, in 2018, the highest value of CI is 12.9. Having a declining trend means the growth of the publication rate is having slight variations. The mean relative growth of all years showed a growth rate of 0.2. The

corresponding Doubling Time for different years [Dt(P)] gradually increased from 0.91 in 1998 to 6.93 in 2022. The mean doubling time is 3.8 years. Thus, as the rate of growth of publication was increased, the corresponding doubling time were decreased. The exponential growth rate values show the same of declined trends, but its suddenly increased highest publication year is 2020.

In order to calculate the trend of growth of the scientific products in cytokine, the following formula was used: $PR = \frac{V_{Present} - V_{Past}}{V_{Past}} * 100$. Where PR = percent rate, $V_{Present}$ = present or future value and V_{Past} = past value. To calculate collaborative index formula was used: $CI = \sum_{j=1}^A j f_i / N$

Authorship Pattern for the Cytokine Publication

Totally 5533 publications were produced by 35518 researchers Year wise result is 150 authors were contributed 33 articles at 1998, 180 authors were contributed 38 articles

Table 6: Distribution of publications and application of Lotka's law in cytokine publications

papers (X)	Authors		Total		$\sum (yx/\sum yx)$		$1/x^n$	$f = C(1/x^n)$	Σ	D	$\Sigma X = \log X$	$\Sigma Y = \log Y$	ΣXY	ΣX^*X
	(Yx)	%	(XY)	$yx/\sum yx$										
1	13485	73.26	13485	37.97	0.3797	1	0.6154	0.6154	-0.2357	0	4.130	0	0	0
2	2342	12.72	4684	13.19	0.5116	0.25	0.1539	0.7693	-0.2577	0.301	3.370	1.014	0.091	0.091
3	944	5.13	2832	7.97	0.5913	0.1111	0.0684	0.8376	-0.2463	0.477	2.975	1.419	0.228	0.228
4	458	2.49	1832	5.16	0.6429	0.0625	0.0385	0.8761	-0.2332	0.602	2.661	1.602	0.362	0.362
5	287	1.56	1435	4.04	0.6833	0.04	0.0246	0.9007	-0.2174	0.699	2.458	1.718	0.489	0.489
6	202	1.1	1212	3.41	0.7174	0.0278	0.0171	0.9178	-0.2004	0.778	2.305	1.794	0.606	0.606
7	130	0.71	910	2.56	0.743	0.0204	0.0126	0.9304	-0.1874	0.845	2.114	1.786	0.714	0.714
8	99	0.54	792	2.23	0.7653	0.0156	0.0096	0.9400	-0.1747	0.903	1.996	1.802	0.816	0.816
9	65	0.35	585	1.65	0.7818	0.0123	0.0076	0.9475	-0.1657	0.954	1.813	1.730	0.911	0.911
10	57	0.31	570	1.6	0.7979	0.01	0.0015	0.9491	-0.1512	1.000	1.756	1.756	1.000	1.000
11	44	0.24	484	1.36	0.8115	0.0083	0.0006	0.9496	-0.1381	1.041	1.643	1.711	1.084	1.084
12	46	0.25	552	1.55	0.827	0.0069	0.0003	0.9499	-0.1229	1.079	1.663	1.794	1.165	1.165
13	40	0.22	520	1.46	0.8417	0.0059	0.0001	0.9500	-0.1083	1.114	1.602	1.785	1.241	1.241
14	34	0.18	476	1.34	0.8551	0.0051	0.0031	0.9532	-0.0981	1.146	1.531	1.755	1.314	1.314
15	14	0.08	210	0.59	0.861	0.0044	0.0027	0.9559	-0.0949	1.176	1.146	1.348	1.383	1.383
16	11	0.06	176	0.5	0.8659	0.0039	0.0024	0.9583	-0.0924	1.204	1.041	1.254	1.450	1.450
17	17	0.09	289	0.81	0.8741	0.0035	0.0022	0.9604	-0.0863	1.230	1.230	1.514	1.514	1.514
18	15	0.08	270	0.76	0.8817	0.0031	0.0019	0.9624	-0.0807	1.255	1.176	1.476	1.576	1.576
19	14	0.08	266	0.75	0.8952	0.0028	0.0017	0.9641	-0.0689	1.279	1.146	1.466	1.635	1.635
20	12	0.07	240	0.68	0.9019	0.0025	0.0015	0.9656	-0.0637	1.301	1.079	1.404	1.693	1.693
21	11	0.06	231	0.65	0.9084	0.0023	0.0014	0.9670	-0.0586	1.322	1.041	1.377	1.748	1.748
22	7	0.04	154	0.43	0.9128	0.0021	0.0013	0.9683	-0.0555	1.342	0.845	1.134	1.802	1.802
23	9	0.05	207	0.58	0.9186	0.0019	0.0012	0.9695	-0.0509	1.362	0.954	1.299	1.854	1.854
24	3	0.02	72	0.2	0.9206	0.0017	0.0010	0.9705	-0.0499	1.380	0.477	0.659	1.905	1.905
25	2	0.01	50	0.14	0.922	0.0016	0.0010	0.9715	-0.0495	1.398	0.301	0.421	1.954	1.954

26	4	0.02	104	0.29	0.925	0.0015	0.0009	0.9724	-0.0474	1.415	0.602	0.852	2.002
27	4	0.02	108	0.3	0.928	0.0014	0.0009	0.9733	-0.0453	1.431	0.602	0.862	2.049
28	1	0.01	28	0.08	0.9288	0.0013	0.0008	0.9741	-0.0453	1.447	0.000	0.000	2.094
29	2	0.01	58	0.16	0.9304	0.0012	0.0007	0.9748	-0.0444	1.462	0.301	0.440	2.139
30	2	0.01	60	0.17	0.9321	0.0011	0.0007	0.9755	-0.0434	1.477	0.301	0.445	2.182
31	4	0.02	124	0.35	0.9356	0.001	0.0006	0.9761	-0.0405	1.491	0.602	0.898	2.224
33	3	0.02	99	0.28	0.9384	0.0009	0.0006	0.9767	-0.0383	1.519	0.477	0.725	2.306
35	2	0.01	70	0.2	0.9404	0.0008	0.0005	0.9772	-0.0368	1.544	0.301	0.465	2.384
37	2	0.01	74	0.21	0.9425	0.0007	0.0004	0.9776	-0.0351	1.568	0.301	0.472	2.459
38	3	0.02	114	0.32	0.9457	0.0007	0.0004	0.9780	-0.0323	1.580	0.477	0.754	2.496
39	1	0.01	39	0.11	0.9468	0.0007	0.0004	0.9785	-0.0317	1.591	0	0	2.531
40	1	0.01	40	0.11	0.9479	0.0006	0.0004	0.9788	-0.0309	1.602	0	0	2.567
41	1	0.01	41	0.12	0.949	0.0006	0.0004	0.9792	-0.0302	1.613	0	0	2.601
42	1	0.01	42	0.12	0.9502	0.0006	0.0004	0.9796	-0.0294	1.623	0	0	2.635
43	1	0.01	43	0.12	0.9514	0.0005	0.0003	0.9799	-0.0285	1.633	0	0	2.668
45	2	0.01	90	0.25	0.954	0.0005	0.0003	0.9802	-0.0262	1.653	0.301	0.498	2.733
46	1	0.01	46	0.13	0.9553	0.0005	0.0003	0.9805	-0.0252	1.663	0.000	0	2.765
47	2	0.01	94	0.26	0.9579	0.0005	0.0003	0.9808	-0.0229	1.672	0.301	0.503	2.796
48	1	0.01	48	0.14	0.9593	0.0004	0.0002	0.9811	-0.0218	1.681	0	0	2.827
50	2	0.01	100	0.28	0.9621	0.0004	0.0002	0.9813	-0.0192	1.699	0.301	0.511	2.886
51	1	0.01	51	0.14	0.9635	0.0004	0.0002	0.9816	-0.0181	1.708	0	0	2.916
53	1	0.01	53	0.15	0.965	0.0004	0.0002	0.9818	-0.0168	1.724	0	0	2.973
58	1	0.01	58	0.16	0.9666	0.0003	0.0002	0.9820	-0.0154	1.763	0	0	3.110
59	1	0.01	59	0.17	0.9683	0.0003	0.0002	0.9822	-0.0139	1.771	0	0	3.136
60	2	0.01	120	0.34	0.9717	0.0003	0.0002	0.9824	-0.0107	1.778	0.301	0.535	3.162
63	1	0.01	63	0.18	0.9735	0.0003	0.0002	0.9825	-0.0090	1.799	0	0	3.238

64	1	0.01	64	0.18	0.9753	0.0002	0.0001	0.9827	-0.0074	1.806	0	0	3.262
66	1	0.01	66	0.19	0.9771	0.0002	0.0001	0.9828	-0.0057	1.820	0	0	3.311
74	1	0.01	74	0.21	0.9792	0.0002	0.0001	0.9829	-0.0037	1.869	0	0	3.494
85	1	0.01	85	0.24	0.9816	0.0001	0.0001	0.9830	-0.0014	1.929	0	0	3.723
92	1	0.01	92	0.26	0.9842	0.0001	0.0001	0.9830	0.0012	1.964	0	0	3.856
95	1	0.01	95	0.27	0.9869	0.0001	0.0001	0.9831	0.0038	1.978	0	0	3.911
96	1	0.01	96	0.27	0.9896	0.0001	0.0001	0.9832	0.0064	1.982	0	0	3.929
115	1	0.01	115	0.32	0.9928	0.0001	0.0001	0.9832	0.0096	2.061	0	0	4.246
120	1	0.01	120	0.34	0.996	0.0001	0.0001	0.9833	0.0127	2.079	0	0	4.323
164	1	0.01	164	0.46	1.0007	0	0.0000	0.9833	0.0174	2.215	0	0	4.906
185	1	0.01	185	0.52	1.01	0	0.0000	0.9833	0.0227	2.267	0	0	5.140
	18406		35518	100		1.6250	0.9833		-99163	89.0702	47.624	42.9794	140.513

at 1999, 100 authors were contributed 24 articles at 2000, 132 authors were contributed 34 articles at 2001, 139 authors were contributed 34 articles at 2002, 238 authors were contributed 47 articles at 2003, 261 authors were contributed 60 articles at 2004, 349 authors were contributed 71 articles at 2005, 435 authors were contributed 90 articles at 2006, 619 authors were contributed 125 articles at 2007, 841 authors were contributed 165 articles at 2008, 882 authors were contributed 166 articles at 2009, 991 authors were contributed 190 articles at 2010, 1235 authors were contributed 264 articles at 2011, 1286 authors were contributed 232 articles at 2012, 1385 authors were contributed 256 articles at 2013; 1983 authors were contributed 335 articles at 2014, 2037 authors were contributed 317 articles at 2015, 2176 authors were contributed 387 articles at 2016.

In 1956 authors contributed 315 articles in 2017, 4958 authors contributed 384 articles in 2018, 4958 authors contributed 384 articles in 2018, and 2067 authors contributed 328 articles in 2019. About 3217 authors contributed 483 articles in 2020, 4618 authors contributed 681 articles in 2021, and 3283 authors contributed 518 articles in 2022. 74 (1.3%) of articles were by single-authored 74 (0.21%); 569 (10.3%) of articles were by two authored 1138 (3.2%); 744 (13.5%) of articles were by three authored 2233 (6.3%); 842 (15.23%) of articles were by four authored 3368 (9.5%); 786 (14.2%) of articles were by five authored 3930 (11.1%); 666 (12.0%) of articles were by six authored 3996 (11.3%); 505 (9.1%) of articles were by seven authored 3535 (10%); 360 (6.5%) of articles were by eight authored 2880 (8.1%); 287 (5.2%) of articles were by nine authored 2583 (7.3%); 708 (12.8%) of articles were by ten and above authored 74 (0.21%) contribution.

Author Productivity and the Application of Lotka's Law in Cytokine Publications

Table 5 reveals that the statistical analysis of scientific literature began almost 50 years before the term "bibliometrics" was coined. Lotka's law concluded that: "the number (of authors) making n contributions is about $1/n^2$ of those making one; and the proportion of all contributors, that makes a single contribution, is about 60%." This result can be considered as a rule of thumb even today, 75 years after its publication.

It states that the number of authors making n contributions is about $1/n^2$ of those making one, and the proportion of all contributions that make a single contribution is in the range of 60 percent. This means that out of all authors in a given field, 60 percent will have just one publication ($1/3^2$ times 60), and so on. For the present study, Lotka's inverse power law model that states the function describing the pattern of productivity of authors publishing in a specified subject field in a fixed time period has been applied and it is mathematically represented as:

$$x^n y = c \quad (1) \quad \text{Lotka Equation}$$

Author's productivity analysis in the co-author network for cytokines publications from 1998 to 2022 shows that out of 35518 authors, 74 (0.21%) of authors contributed only one article, 1138 (3.2%) of authors contributed every two articles. The first step in the testing of Lotka's law is to determine the value of n (Table 5).

$$n = \frac{N \sum XY - \sum X \sum Y}{N \sum X^2 - (\sum X)^2} \quad (1)$$

$$62 * 42.97 - 89.07 * 47.624$$

=

$$62 * 140.513 - 89.07 * 89.07$$

$$n = -2.0270$$

Using the value of n , the value of c is estimated using the equation of $C = 1 / \sum 1/x^n = 0.6154$.

Kolmogorov-Smirnov (K-S) One Sample Goodness of Fit Test

This test was conducted to determine whether Lotka's law predicts author contribution from the sample data. It is observed from the difference in the table analysis that the maximum difference in the cumulative distributions, D_{max} , is 0.0096. The critical value is calculated by using the equation suggested by Black (Black TR, 2003).

$$\text{Critical value} = 1.22 / \sqrt{n+1} ; = 1.22 / \sqrt{2.0270+1} ; = 1.22 / \sqrt{3.027} ; \quad CV=0.7012$$

The values of n and C were calculated to be 2.0270 and 0.6154 (61.54%), respectively. The K-S test was concluded at a 0.10 percentage level of significance. The D_{max} value is 0.0096 and the resulting CV is 0.7012. Since the CV value is greater the D_{max} , hence Lotka's law is applicable to co-author networks for cytokine publications.

Author Productivity and the Application of Lotka's Law in Cytokine Publications

Lotka's Law is used to describe the frequency distribution of scientific productivity among authors in a given domain. It states that the number of authors producing n publications is inversely proportional to n^2 . Below is the analysis and application of Lotka's Law to cytokine publications using the provided data.

- Consistency with Lotka's Law: The observed data is consistent with Lotka's Law, validating the inverse relationship between the number of authors and their productivity.
- Significance of Exponent n : The derived exponent ($n=1.6250$) suggests a slightly steeper productivity decline compared to the classical $n=2$.
- Practical Implication: In cytokine research, few authors dominate the field, contributing significantly to advancements, while most contribute fewer articles.

Discussion And Finding

Some notable outcomes from the research process are shown below for this study: In the field of cytokines, 5,533 research publications by 35,518 researchers with 115,300 total citations (TC) were published in the Web of Science database between 1998 and 2022. The highest number of research papers on Cytokines were published in 2021, with total publications of 681 (12.31%). Kumar Anjani from Umea University, Sweden, is identifying the most prolific author. The overall degree of collaboration (DC) value across the sample period of 1998 to 2022 is 0.98, indicating a high level of collaboration among researchers in the field of Cytokines. Publication trends of the number of publications increased significantly after 2007, with notable peaks in 2021, 2022, 2020, and 2016, suggesting a substantial increase in research output over the years. Researchers from 117 countries collaborated with Indian scientists on Cytokine research, with the USA, UK, Saudi Arabia, Germany, and Australia being the top collaborating countries, indicating extensive international collaboration. The top twenty researchers, including Kumar Anjani, Kumar Sathish, Sharma Anjay, and Singh Shailza, made significant contributions to cytokine research, with varying numbers of publications, h-index, and total global citation scores (TGCS). The relative growth rate (R(P)) collaborative index (CI) values varied over the years, with a declining trend after peaking in 2018. The doubling time (Dt(P)) gradually increased from 1998 to 2022, indicating changes in the publication growth rate over time. Authorship trends of the majority of articles were authored by multiple researchers, with varying degrees of authorship ranging from single-authored to ten or more authors, suggesting collaborative research efforts.

Conclusion

This research concludes that in the years between 1998 and 2022, a total of 5533 published articles were downloaded from the Web of Science database. The year with the most publications was 2021. The mean relative growth rate of the sample duration is 0.11 and doubling time is 7.12 years. According to the data, the United States of America, the United Kingdom, Saudi Arabia and Germany are the leading countries of collaborated with India in the field of cytokine research. The highly contributed author is Umea University of Sweden, with the highest h-index and contribution. In the authorship pattern, less than 2% of articles were written by single-authors and the highest numbers of articles were produced by four authors, in controversy, six authored teams are the highest. Collaborative efforts were noted in the majority of the publications with multiple authors, indicating the range of contributions to the field of cytokine research. The degree of collaboration value is 99.79, i.e., almost nearly 100 percent of articles were published by team collaborated pattern. This result clearly indicated the collaborative work is

dominant and succeeds in this field. The K_S test shows the result that Lotka's law is applicable in Cytokine publications. Hence, it's concluded that Lotka's law is essentially predicts the distribution of co-authors to cytokine publications. The significance of cytokines is based on their ability to control immune cell development and function, which in turn affects inflammatory and immunological responses. Although there were variations in the relative growth rate, the general pattern indicated rising publishing rates over time, even with some changes. This study provides valuable insights into the global landscape of cytokine research, highlighting collaborative efforts, key contributors, and emerging trends, which can inform future studies in the field.

Availability of Data and Materials

CSV files from the Web of Science, as well as analytical tools HistCite and MS Excel.

Conflict of Interest

The authors declare that they have no conflict of interest. This study is purely descriptive, analyzing cytokine-related publications retrieved from the Web of Science database from 1998 to 2022. Data collection and analysis were conducted using various software tools, including HistCite and MS Excel. The study examined patterns in authorship, research productivity, and collaboration without any financial or personal biases.

Author's Contribution

The authors contributed to this study as follows: The design and methodology of the study were spearheaded by the author. The first author conducted data retrieval from the Web of Science database and performed initial data processing on 28th November, 2022. Data extraction and preliminary analysis using HistCite and MS Excel were also carried out by the author. The analysis of the Local Citation Score (LCS) and Global Citation Score (GCS) was performed by the author. The author also identified year-wise authorship patterns, co-authorship structures, growth trends, and analyzed document types, authors, countries, sources, institutions, co-authorship ratios, degrees of collaboration, collaborative indices, and collaborative efficiencies. The manuscript was drafted by the author and underwent significant input and revisions from the corresponding author

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