

Bibliometric Analysis of Publications on Chaos Theory and Applications during 1987 - 2021

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ABSTRACT

The number of studies based on chaos theory is quite high. Therefore, it is important to analyze chaos theory's development over the years deeply. However, there is no study in the literature examining the research status of this field. The article presents the bibliometric analysis of the studies on the keywords "Chaos Theory" and "Applications" indexed in Scopus between 1987 and 2021. This study aims to quantitatively evaluate the academic output in chaos theory research, make sense of the data, reveal the state of scientific knowledge in the field, and provide scientists with a general perspective on the subject. Bibliometrix and Microsoft Excel programs were used for bibliometric analysis. Nine thousand one hundred different authors identified a total of 5088 studies. Of these studies, 60.3% were research articles, and 32.9% were conference papers. Chaos Solitons and Fractals was the most published journal, with 206 articles. Only China and the USA contributed 39.7% to the studies. Vaidyanathan, S. was the most prolific author with 72 articles. Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology was the most productive institution with 74 studies. The most cited article was the econometrics of financial markets.

KEYWORDS

Chaos Theory
Bibliometric analysis
Citation analysis
Network analysis
Scopus

INTRODUCTION

Chaos, characterized by the high sensitivity of its initial values, is significant in science. Chaos theory continues to pique people's interest because it describes nonlinear and unpredictable behavior. Chaos theory examines the dependence of motion-expressing systems (physical, economic, mathematical, biological, etc.) on initial conditions, unpredictable phase spaces of time series, and non-periodic system behavior. Scientifically, "chaos" refers to a combination that allows us to understand the cause of seemingly complex and random events.

Chaos is a branch of science aimed at understanding the movements of all kinds of events and structures that occur in the universe, from the most microstate to the most macro-state (Leutcho *et al.* 2020). Their most crucial characteristic is that chaotic systems depend on the initial condition. These systems consistently display unpredictable behavior and non-periodic traits (Thompson *et al.* 1990; Wei *et al.* 2019). Chaos studies have been observed in many

branches of science, such as biology, medicine, ecology, electronics, economics, encryption, etc. (Wang *et al.* 2016; Liu *et al.* 2009; Sun *et al.* 2020; Pandey *et al.* 2016; Rajagopal *et al.* 2019). Bibliometric analysis is a common technique for researching and analyzing vast scientific data. The latest status in a field related to the available scientific knowledge can be mapped using bibliometrics. Bibliometric analysis has gained immense popularity in recent years as the availability and accessibility of software such as Gephi, Leximancer, VOSviewer, and Bibliometrix and scientific databases such as Scopus and Web of Science have increased (Donthu *et al.* 2021; Sengupta 1992).

Bibliometric analysis is a helpful tool for mapping the literature pertinent to a specific research area (Falagas *et al.* 2006). Bibliometric analysis is employed for several purposes, including examining the performance of articles and journals, patterns of collaboration, new developments in research components, and the intellectual composition of a specific field in the body of literature (Donthu *et al.* 2021; Verma and Gustafsson 2020). While bibliometrics facilitates retrospective research, it can also aid in the quantitative and objective exploration of research points and development trends in disciplines. The results of bibliometric analysis contribute to advancement in a specific field of research in various ways. The

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bibliometric analysis assesses progress, identifies the most reliable and popular sources of scientific publication, recognizes key scientific actors such as authors and institutions, establishes the academic foundation for evaluating new developments, identifies emerging research interests, and forecasts future research success. It also assists researchers in identifying potential research topics, appropriate research institutions with which to collaborate, and potential academic collaborators (Song *et al.* 2019; Martínez *et al.* 2015; Mazlounian 2012; Geng *et al.* 2017).

This study, which covers top journals, institutions, keyword features, citation network analysis, and a review of the most significant articles, offers the potential to track historical and geographic trends at a global level using proper bibliometric analysis techniques. This work aims to reveal the state of scientific knowledge in the field by making sense of large volumes of data on “Chaos theory” and “Applications” and to present a general viewpoint to scientists on the subject.

In addition, it is aimed to evaluate the academic outputs of chaos theory research quantitatively. This study can make various contributions to the research field. First, it can provide field experts with a comprehensive overview of the research situation. Additionally, it can help researchers identify authors, institutions, journals, and countries/regions with the most significant potential. It can also increase researchers’ awareness when deciding on topic selection. Finally, it can explain how the subject has evolved over time.

MATERIAL AND METHODS

The bibliometric methodology covers the application of quantitative methods to bibliometric data. Early discussions on bibliometrics, which began in the 1950s, show that bibliometric methodology is not new (Donthu *et al.* 2021; Broadus 1987; Wallin 2005; Pritchard 1969). Scopus was preferred for the collection of bibliometric information. It has been determined that Scopus offers a more comprehensive journal profile to the user than WoS and brings faster results from more articles in citation analysis.

All publications indexed in Scopus (accessed 21.10.2022) on Chaos Theory between 1987-2021 were analyzed using bibliometric methods. “Chaos Theory” and “Applications” were used as search keywords. Documents were searched in article title, abstract, and keywords. Scopus codes used in our search are as follows; (“Chaos Theory” AND “Applications”) AND (EXCLUDE (PUBYEAR, 2023) OR EXCLUDE (PUBYEAR, 2022)).

With this search method, all articles published between 1987-2021 containing the words “Chaos Theory” and “Applications” in the title, abstract, and keywords of the studies were found in the Scopus database. Microsoft Excel and Bibliometrix (Aria and Cucurullo 2017) were used for bibliometric network visualizations.

BIBLIOMETRIC ANALYSIS OF PUBLICATIONS ON CHAOS THEORY AND APPLICATIONS

Literature Distribution

From 1987 to 2021, 5088 publications of different types appeared: articles (3068, 60.3%), conference papers (1674, 32.9%), reviews (117, 2.3%), book chapters (78, 1.5%), conference reviews (77, 1.5%), book (52, 1%) and others (15, 0.29%). As shown in Figure 1, articles on Chaos Theory; “Engineering” (2815, 33%), “Computer Science” (2291, 21%), “Mathematics” (1625, 19%), “Physics and Astronomy” (1355, 16%), “Materials Science” (499, 6%) and “Multidisciplinary and others” (453, 5%). Since a study can be matched into different categories, the total number of studies is more than 5088.

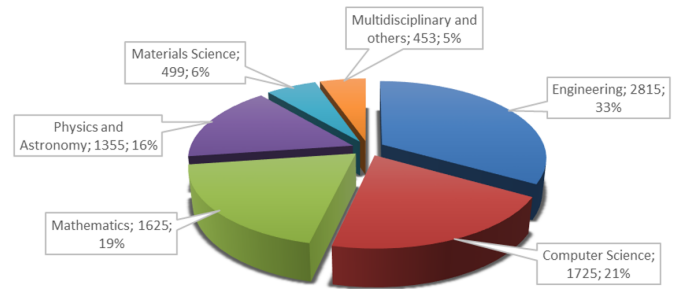


Figure 1 The distribution of subject areas

Development of Publications

Figure 2 shows the annual scientific production graphic. Despite some fluctuations, the number of publications generally increased until 2004. It is seen that the number of studies decreased from 2004 to 2008. Although there was a slight increase in the number of publications in the following years, it generally remained stable.

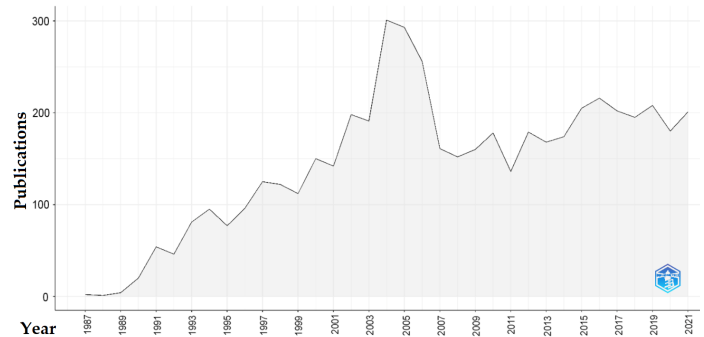


Figure 2 Annual scientific production

Active Authors

A total of 5088 publications were produced by 9100 authors. Of these, 3068 authors published articles, and 1674 authors published conference papers. The top five authors producing the highest number of publications were Vaidyanathan S. (72, 1.4%), Zhang Y. (54, 1%), Wang X. (48, 0.94%), Chen G. (39, 0.76%) and Wang Y. (36, 0.7%). These authors were significant research pioneers in “Chaos Theory” and “Applications” related fields. Table 1 shows the top 25 authors with the highest h_index for “Chaos Theory” and “Applications”.

Figure 3 shows the collaboration network of the top 25 authors. The larger the circle, the greater the cooperation. Clusters are separated by colors. The strength of collaboration between authors is expressed in the thickness of the lines.

■ Table 1 Top 25 authors with h_index (TC: Total Citation, NP: Number of Publication, PY_start: Start of Publication Year).

No	Author	h_index	g_index	m_index	TC	NP	PY_start
1	VAIDYANATHAN S.	26	55 Sec.	2.6	3048	72	2013
2	CHEN G.	19	39	0.633	2890	39	1993
3	WANG X.	16	28	0.667	834	48	1999
4	LIAO X.	15	16	0.75	1197	16	2003
5	ZHANG Y.	14	34	0.56	1207	54	1998
6	AIHARA K.	13	19	0.406	753	19	1991
7	WANG L.	13	32	0.52	1379	32	1998
8	LEUNG H.	11	20	0.344	636	20	1991
9	LI C.	11	21	0.55	960	21	2003
10	LIU L.	11	16	0.524	709	16	2002
11	PEHLIVAN I.	11	14	0.917	952	14	2011
12	SAVI MA.	11	16	0.579	313	16	2004
13	ROVATTI R.	10	15	0.385	742	15	1997
14	SETTI G.	10	17	0.385	748	17	1997
15	WANG Y.	10	16	0.4	278	36	1998
16	BANERJEE S.	9	11	0.375	610	11	1999
17	JAFARI S.	9	9	0.6	413	9	2008
18	KURTHS J.	9	10	0.31	1274	10	1994
19	LIU X.	9	20	0.45	559	20	2003
20	PHAM VT.	9	14	1.125	700	14	2015
21	ZHANG X.	9	13	0.391	207	29	2000
22	AKGUL A.	8	9	1.143	569	9	2016
23	CHEN Z.	8	15	0.333	397	15	1999
24	LI H.	8	13	0.364	196	19	2001
25	LIU J.	8	14	0.308	212	20	1997

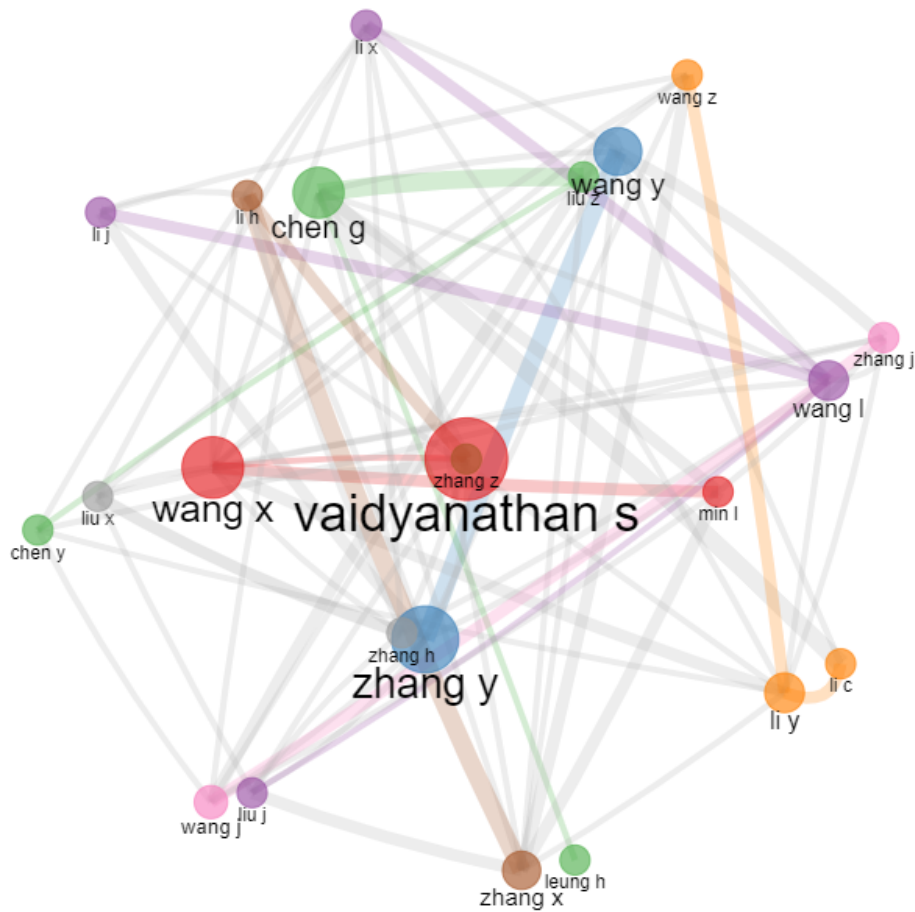


Figure 3 Authors collaboration network

Active Institutions

The top 7 organizations that contributed the most to the literature were: Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology (74, 1.4%), City University of Hong Kong (57, 1.1%), Zhejiang University (45, 0.88%), Ministry of Education China (42, 0.82%), and Shanghai Jiao Tong University (41, 0.8%). Figure 4 shows the number of publications published by institutions over the 1987-2021 period, with an increasing trend with slight fluctuations.

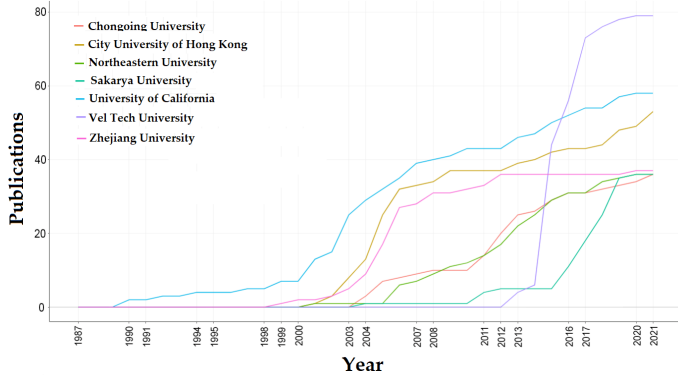


Figure 4 Affiliation production over time

Figure 5 shows the cooperation network of the top 25 institutions. The larger the circle, the greater the cooperation. Clusters are separated by colors. The strength of collaboration between institutions is expressed in the thickness of the lines.

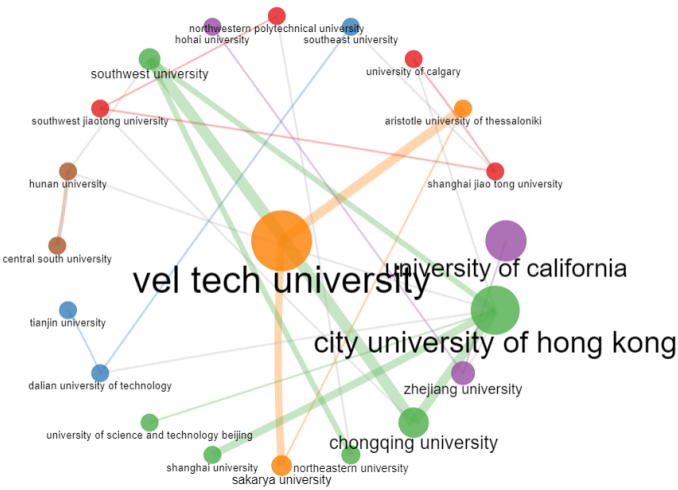


Figure 5 Institutions collaboration network

Active Journals

In total, 5088 articles were published in 659 journals. Table 2 shows the top 25 journals with the highest *h_index* on "Chaos Theory" and "Applications". Chaos, Solitons, and Fractals by chart IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, Nonlinear Dynamics, Physical Review E - Statistical, Nonlinear, and Soft Matter Physics, International Journal of Bifurcation and Chaos are the most productive journals. More than 22% of 5088 articles are from these 25 sources.

The citation visualization map between these journals is given in Figure 6. Figure 6 shows the common citation network of the top 25 journals. The larger the circle, the greater the number of citations. Clusters are separated by colors. The strength of collaboration between magazines is expressed in the thickness of the lines.

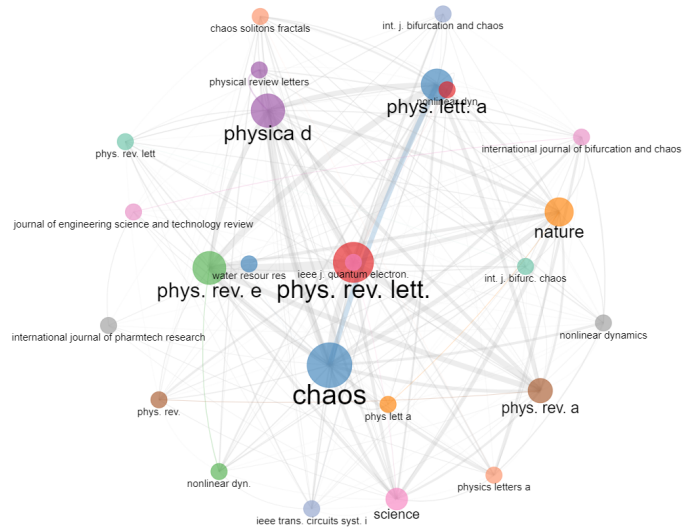


Figure 6 Sources co-citation network

In Figure 7, there is a graph of the increase in the number of publications according to the topics that are the research subject for the first six journals in terms of the number of publications between 1987-2021.

Active Countries

The analyses showed that the articles covered 91 different countries (or regions). The publication numbers of the first 25 countries are shown in Figure 8. a, and the collaboration network is shown in Figure 8. b. As for the number of publications, China ranked first with 1415 (27.8%) studies. The USA was in second place with 852 (16.7%) studies. India and Japan ranked third and fourth with 287 (5.6%) studies. The United Kingdom was ranked 5th with 276 (5.4%).

The geographical distribution of country collaboration for the overall study period is shown in Figure 9. Figure 10 shows the growth trends of publications for the six most productive countries from 1987 to 2021. Compared to the other five countries, the upward trend in the number of publications in China increased more rapidly after 2003. It is observed that the number of publications originating in the USA has decreased in the growth trend since 2006. It is seen that the number of publications in India has been on increasing trend since 2013. The growth trends of the number of publications in Japan, Italy, and the United Kingdom seem to have had a low rate of increase in the last fifteen years.

■ Table 2 Top 25 journals with h_index (TC: Total Citation, NP: Number of Publication, PY_start: Start of Publication Year).

No	Journals	h_index	g_index	m_index	TC	NP	PY_start
1	Chaos, Solitons and Fractals	46	84	1.484	8133	206	1992
2	IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications	35	58	1.129	5574	58	1992
3	Nonlinear Dynamics	34	54	1.172	3261	92	1994
4	Physical Review E - Statistical, Nonlinear, and Soft Matter Physics	27	42	1.227	1928	67	2001
5	International Journal of Bifurcation and Chaos	24	42	1.333	2164	107	2005
6	Physical Review Letters	20	24	0.769	2187	24	1997
7	Physica D: Nonlinear Phenomena	19	46	0.704	2392	46	1996
8	Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics	18	27	0.692	1911	27	1997
9	Communications in Nonlinear Science and Numerical Simulation	17	29	0.895	1352	29	2004
10	International Journal of Chemtech Research	17	19	2.125	942	19	2015
11	Journal of Sound and Vibration	17	25	0.515	776	25	1990
12	IEEE Access	16	30	2.286	926	39	2016
13	International Journal of Bifurcation and Chaos in Applied Sciences and Engineering	16	42	0.762	1844	50	2002
14	Physica A: Statistical Mechanics and Its Applications	16	33	0.593	1145	44	1996
15	Optik	13	20	1.083	704	20	2011
16	Physics Letters, Section A: General, Atomic, and Solid State Physics	13	28	0.481	791	29	1996
17	IEEE Journal of Quantum Electronics	12	16	0.414	1238	16	1994
18	Multimedia Tools and Applications	12	23	1.5	564	23	2015
19	Neurocomputing	12	16	0.444	819	16	1996
20	IEEE Transactions on Circuits and Systems I: Regular Papers	11	14	0.579	628	14	2004
21	Neural Networks	11	14	0.344	460	14	1991
22	Proceedings - IEEE International Symposium on Circuits and Systems	11	18	0.344	446	60	1991
23	Signal Processing	11	14	0.379	1524	14	1994
24	Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	10	13	0.357	302	64	1995
25	Nonlinear Dynamics, Psychology, and Life Sciences	10	18	0.556	327	23	2005

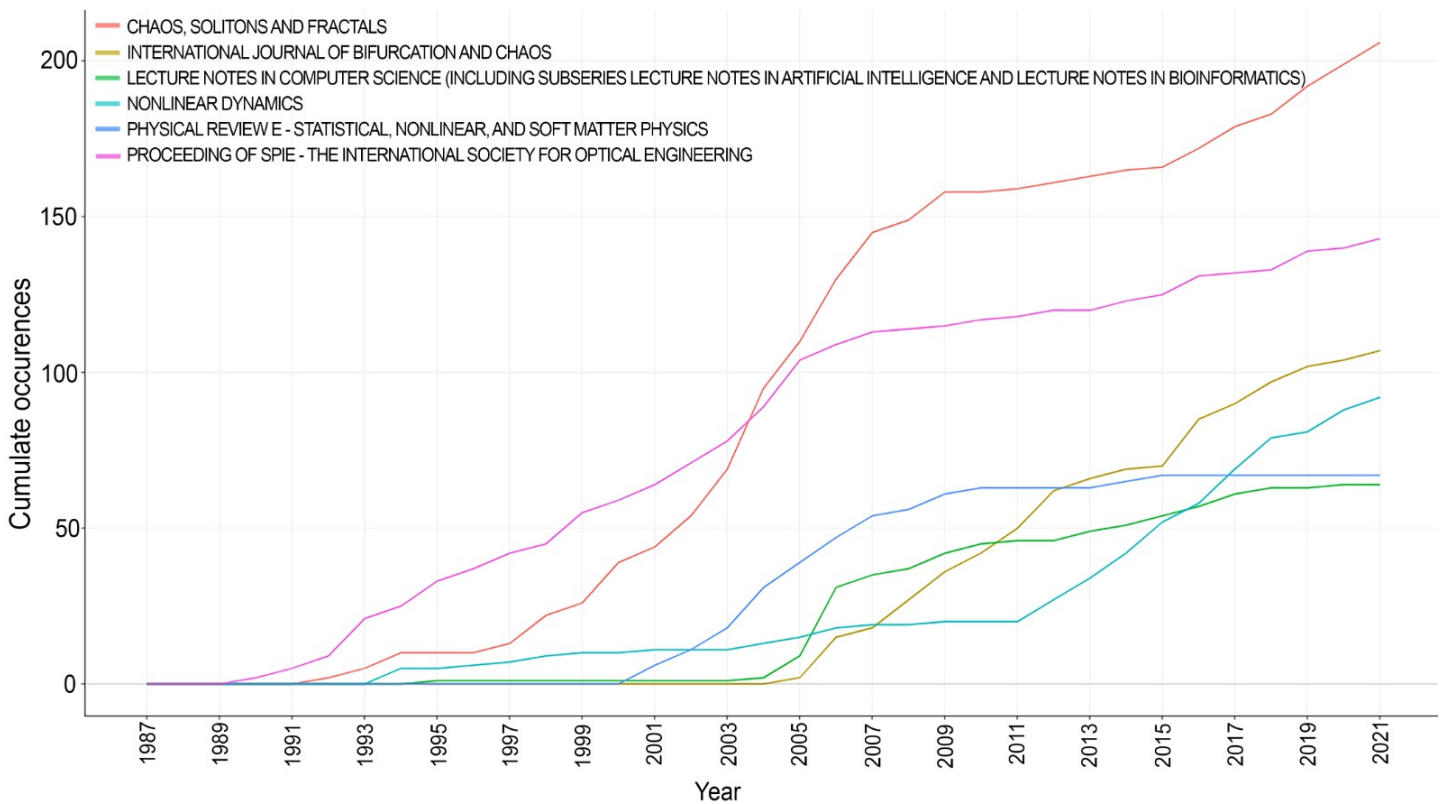


Figure 7 Top 6 journals with the highest number of articles

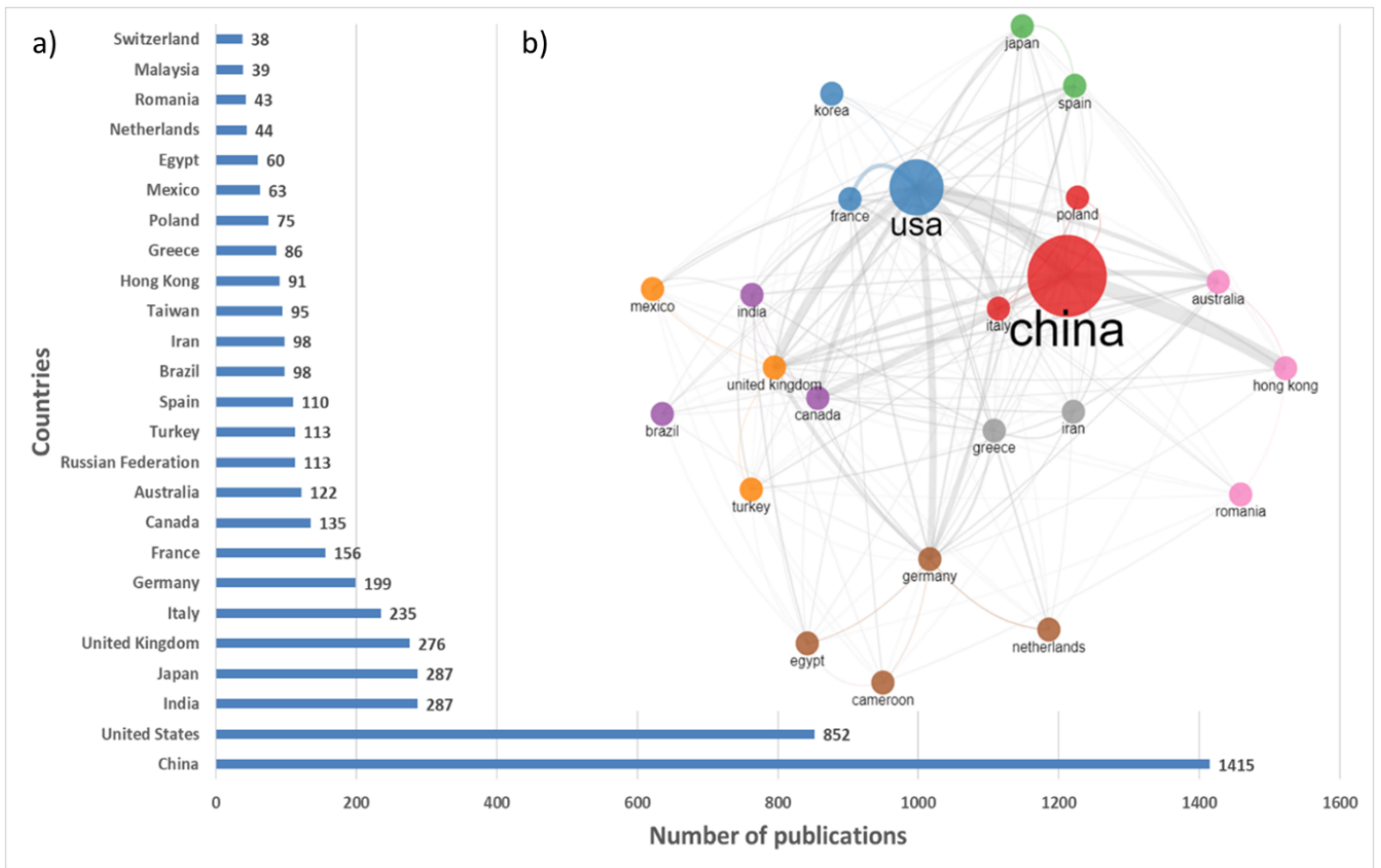


Figure 8 a) Bar chart showing the 25 most productive countries in the world. b) Network visualization map for international collaboration of countries on "Chaos Theory" and "Applications". Footnote: As the size of the circle increases, the number of publications also increases. Clusters are separated by colors. The thickness of the lines expresses the strength of cooperation between countries.

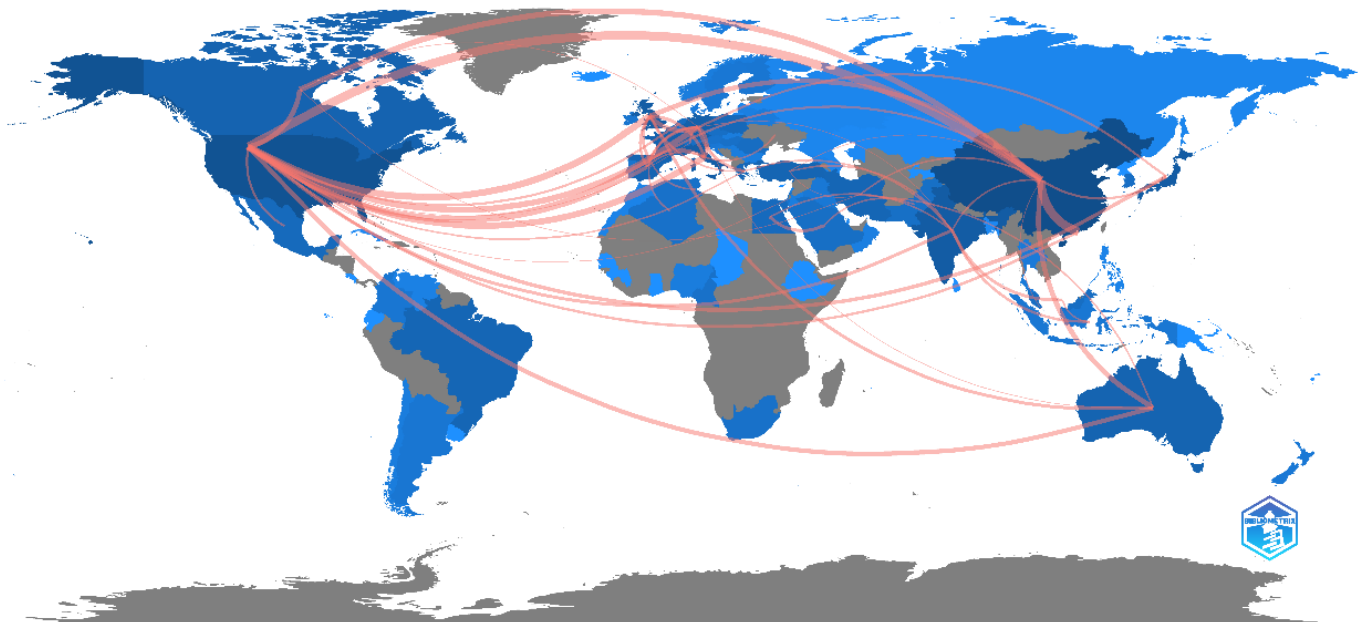


Figure 9 Country collaboration map.

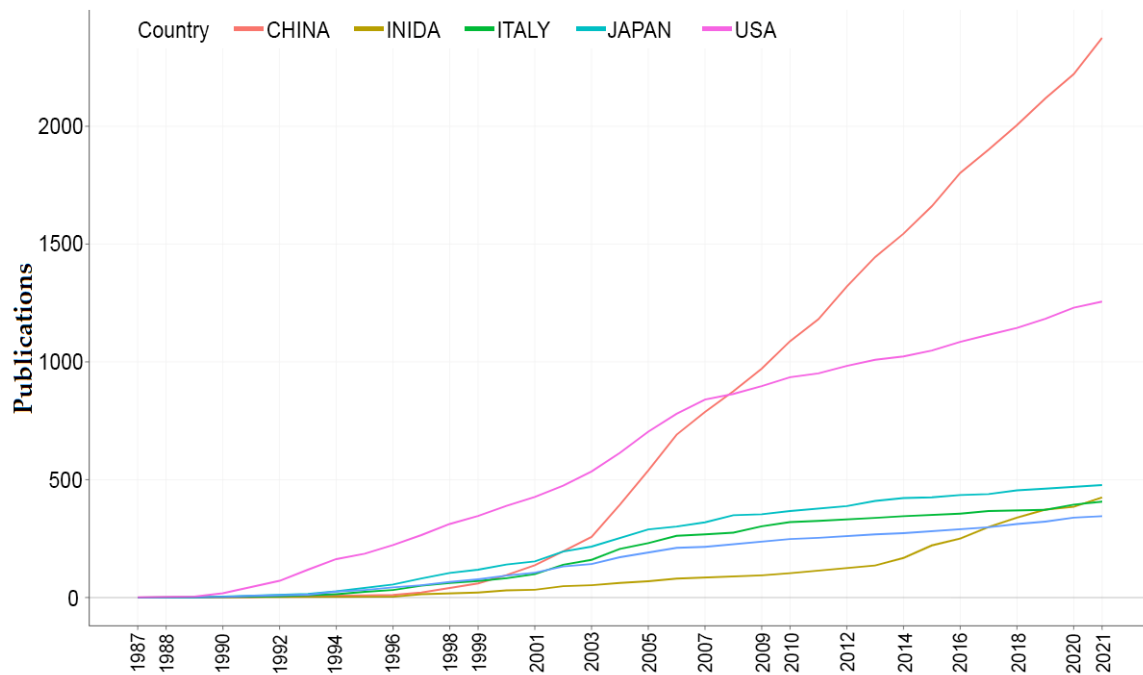


Figure 10 Country production over time

Citations

Citations are shown in Table 1 according to authors, Table 2 according to journals, and Table 3 according to publications. Figure 11 shows the co-citation network of the top 25 authors. As the size of the circle increases, the number of citations also increases. Clusters are separated by colors. The amount of citations between authors is expressed in line thickness.

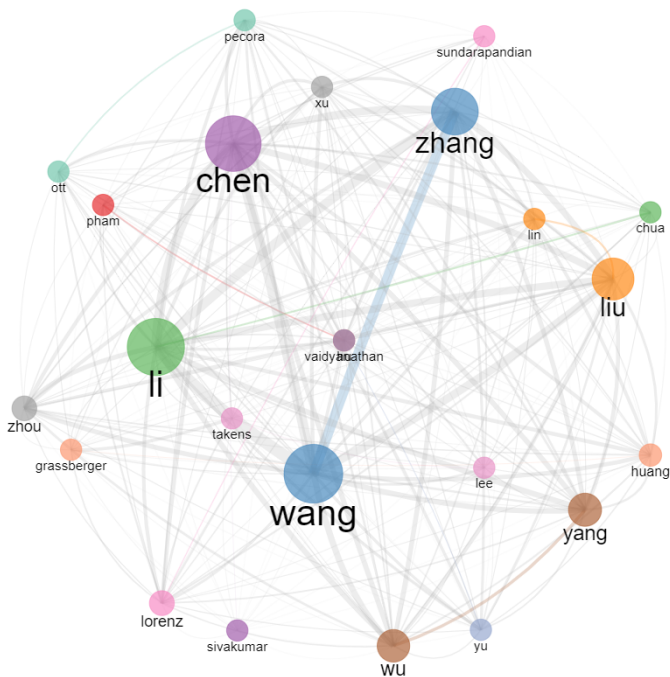


Figure 11 Author co-citation network

Price's Law

Price's Law is the most commonly used indicator when the aim is to analyze productivity in a specific discipline or a given country; it reflects an essential fact of scientific production, which is its exponential growth. According to Price's Law, the total number of citations for the first authors, obtained by taking the square root of the number of authors in our study, should be half the total number of citations. The total number of citations is 21783. When the square root of the number of 25 authors is taken, the number of citations of the first five authors with the highest number of scientific publications was found to be 9738. To assess whether the growth of scientific production in citations follows Price's Law of exponential growth, we made a linear adjustment of the data obtained, according to the equation $y = 80.096x - 169.93$, and another adjustment to an exponential curve, according to the equation $y = 196.94e^{0.0947x}$ (Fig. 12).

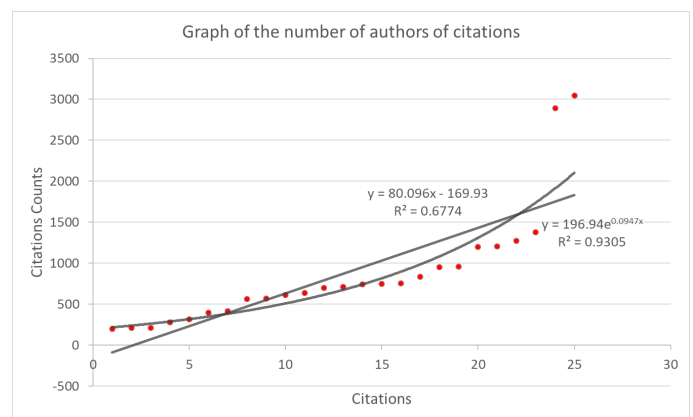


Figure 12 Price's Law

Wang X., Liao X. and Zhang Y. Journals with the highest h -index on the subject: Chaos, Solitons and Fractals, IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, Nonlinear Dynamics, Physical Review E - Statistical, Nonlinear, and Soft Matter Physics and International Journal of Bifurcation and Chaos. Institutions with the highest h -index on the subject: Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, City University of Hong Kong, Zhejiang University, Ministry of Education China, and Shanghai Jiao Tong University.

When evaluating international cooperation, it is commonly assumed that regional geographical location has an impact on cooperation. When the number of publications in a particular country is evaluated, it is seen that countries with large populations or high economic power, such as China, the USA, India, Japan, and the United Kingdom, publish the most studies on chaos theory. This is in line with the literature showing that academic productivity has a significant relationship with economic power (Demir 2019; Yildirim and Demir 2019; Doğan and Kayır 2020).

From the Price's Law and curve-fitting analyses, we can conclude that the analyzed database is compatible with a more exponential fit than a linear one and that the Price law assumptions are met. López-Muñoz et al. used Price's Law as a bibliometric indicator of production in their studies (López-Muñoz et al. 2016, 2014). The Price Law was calculated in my study, and similar results were obtained in these studies. The most cited article (Campbell et al. 1998) was published in *Macroeconomic Dynamics* with the title "The econometrics of financial markets" (Campbell et al. 1998). The next most cited article (Jaeger and Haas 2004) was published in the journal *Science* with the title "Harnessing nonlinearity: Predicting chaotic systems and saving energy in wireless communication" (Jaeger and Haas 2004). The next most cited article (Sudret 2008) is "Global sensitivity analysis using polynomial chaos expansions" (Sudret 2008).

The most frequently used keywords in the articles were chaos theory, chaotic systems, Lyapunov methods, synchronization, bifurcation (mathematics), dynamical systems, differential equations, random processes, numerical methods, and Lyapunov exponent. The limitations of the study, although the Scopus database is advantageous compared to other databases in terms of the number of publications, not all publications were included in the study.

CONCLUSION

This study presents a holistic review of articles on chaos theory and its applications from 1987-2021. According to the findings, there has been a decrease in the annual number of studies produced after 2003. It was seen that the author with the highest h -index on the subject was Vaidyanathan S., the journal with the highest h -index was Chaos, Solitons, and Fractals, and the institution with the highest h -index was Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology. The most cited article (Campbell et al. 1998) was published in *Macroeconomic Dynamics* with the title "The econometrics of financial markets." The most productive countries in publications on the subject are developed or overpopulated countries. It can assist researchers in developing or underdeveloped countries in conducting more research on this topic by planning multinational studies rather than regional studies.

Conflicts of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Availability of data and material

Not applicable.

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