2020

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# Application of Lotka's Law to the research productivity in the field of Thermodynamics during 2015-2019

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**Abstract**

The study applied Lotka's law of the author's productivity in the field Thermodynamic from 2015 to 2019. The Goodness of fit test Kolmogorov – Smirnov (K-S) test was applied to the data of thermodynamics research. It is found that the applicability of Lotka's law is confirmed with 0.003 level of significance in the field of Thermodynamics. Bur Lotka's inverse square law does not fit the present data. The study found that the most productive author is 'Wang, J.' with 159 articles, and the most productive journal is 'Journal of Molecular Liquids' with 547 published articles in Thermodynamics. The study reveals that maximum countries show international collaboration trends.

**Keywords: -** Lotka's Law, Kolmogorov – Smirnov (K-S) test, Keyword analysis, Keyword plus, Domestic Collaborative Index, International Collaborative Index, Title word analysis, Lotka's Inverse Square Law.

## 1. Introduction

Bibliometrics and Scientometrics are techniques that evaluate the published research qualitatively as well as qualitatively. [1]Pritchard (1969) emphasized that the purpose of bibliometrics is to shed light on the processes of written communication and of the nature and course of development of discipline by means of counting and analysing the various facets of written communication through descriptive study and behavioural studies. Bibliometrics analyses the published Scholarly communication. The descriptive study of Bibliometrics analyses the form of transmission medium of communications, nature of information conveyed in literature, and the amount of information conveyed by various individuals, groups, organizations, and countries. In behavioural studies of bibliometrics citations received by authors are studied which help to understand most cited authors, most cited journals, linkages exist between the citing and cited work, subject distribution, and scattering of core literature of any subject. Behavioural studied also refers to 'Evaluative Bibliometrics'. One of the main areas in bibliometrics research concerns with the applications of Bibliometrics laws. The three most commonly used laws in bibliometrics are Bradford's law of scattering, Lotka's law of Scientific productivity, and Zipf's law of word occurrences. The present study deals with testing the applicability of Lotka's law of the author's scientific productivity in Thermodynamics literature published from 2001 to 2019.

'Thermodynamics' is one of the important branches of physics. It deals with heat and temperature and their relation to energy, work, radiation, and properties of matter. These studies of Thermodynamics are governed by the four laws of thermodynamics. Thermodynamics is the subject evolved in 1824 by French physicist 'Nicolas Leonard Sadi Carnot'. He applied the knowledge or principles of thermodynamics for engine efficiency. Scots-Irish physicist 'Lord Kelvin' first define thermodynamics in 1854. He started "thermodynamics is the subject of the relation of heat to forces acting between contiguous part of bodies, and the relation of heat to electrical agency." Thermodynamic initially used in Mechanical heal engines and later it is used in chemical compounds. Now thermodynamics used in 'Physical Chemistry', 'Chemical Engineering', 'Mechanical Engineering', and Meteorology'.

**2. Review of Literature: -**

[1]Kaur, Har and Gupta, B. M. (2010) examine the research output of dental science in India. Several parameters are used including the county's annual average growth rate, global publication share, international collaboration of major collaborative partners. The study reveals that India holds 14th rank among 20 productive countries in dental science with 1.66% global publications output. India had an annual averages growth rate 35.31% during the study period. In dental research largest collaborator was 'United States' with 41.38% share. The study shows 'Keerthilatha Pai' was the highest productive author. The largest participation was from 'Regional Cancer Centre, Trivandrum. The study derived the conclusion that dental science research is in a poor state of affairs in India both in terms of output as well as in quality.

[2]Kademani, B. S and et.al. (2008), analyse the growth and development of vacuum research in nuclear science and technology publications by the International NuclearInformation System (INIS) database. The study found the authorship and collaboration trend is toward multi- authored paper. 'Japan Atomic Energy Research Institute' is the highest productive institute. 'Journal of Vacuum Science and Technology' has the highest preferred journal with 857 papers. The study deals with geographical distribution of publications, productivity and domain- wise activity index, authorship and collaboration pattern and high frequency keyword appeared in research articles.

[3]Chaman, Sab M., and et.al. (2019) studied the scientific productivity of Oceanography literature. The study deals with various aspects such as the growth of papers, most prolific authors, institutions involved, relative growth rate, and doubling time. It reveals that India has produced 985 papers from 2011-2015 and received 2286 citations 'Indian Journals of Geo Marine Science' has published the highest articles with 412 (41.83% of total output). 'USA' is the most productive country with 55 articles. Relative growth rate found decreased from 0.70 to 0.19 and Doubling time increased from 1.01 to 2.81 'National Institute Oceanography, Goa' is the most productive institution with 110 publications.

[4]Arunachalam, Subbian, and Gunasekaran Subbian (2002) conducted a study on tuberculosis research in India and China. Study indicates that India and China are leading countries in the incidence of tuberculosis with 23% and 17% respectively. But the research output of India is only 5-6 % of the World research output and China had only 1% research productivity compared to World. The paper denotes the various bibliometrics indicators such as high impact journals, citation ranking, collaboration, institutional ranking, document types. The study shows that the highest preferred journal in tuberculosis is 'Tubercle and Lung Disease' with 75 papers and 224 citations.

[5]Hadagali, Gururaj S. (2019) studied Scientodermetric analysis of Materials Science research. The study shows that various parameters used such as relative growth rate (RGR), Doubling Time (Dt), Activity index (AI), Publication Efficiency Index (PET), and relative comparative advantage for publication (RCAP) are used. The study found that India had 5.61 % publications out of the total scientific publications of World with 2,87,736 publications. The annual growth rate found highest in Iran i.e. 27.00. Activity Index shows more than 1 by nine countries which indicates that the research efforts of these countries correspond to the World's average. The PET score shows that the USA (1.48), England (1.19), Australia (1.14), Germany (1.09), and France (1.07) received more than one which shows that the publications of these countries are more than research efforts taken during the study period.

[6]Ahmad, Muneer (2019) tested Lotka's law and pattern of author productivity in Artificial Intelligence. The article applied Lotka's law on authorship productivity and found applicable for the Artificial Intelligence field. K-S statistical test was applied to measure the degree of agreement between the distribution of the observed set of data against the inverse general power relationship and the theoretical value of a=2. It is found that the inverse square law of lotka follow as such. Apart from Lotka's law, the study analyses literature with some other Scientomatics indicators such as collaboration indices, RGR, and DT. The study found 0.863 average growth rate.

[7]Kumar, Narendra (2010), applied Lolka's law to research productivity of the Council of Scientific and Industrial Research (CSIR), India. Instead of using Lotka's law on a particular subject or discipline, it is used on the productivity of authors from CSIR which is one of the recognized and world's largest publicly funded R&D organization. The study shows that Lotka's law applied to published articles in two durations first is from 1988-1992 and the second is from 2004-2008. Kolmogorov – Smirnov K-S test is applied for the fitness of Lotka's law. But it does not fit to the two sets of CSIR data result which indicates that the

value of D-Max, i. e. 0.0333 and 0.0798 determined with Lotka's exponent a=1.682 and a=1.649 for DS-I and DS-2 respectively which are more close to the D-Max Value 0.0321 and 0.0249 determined with the Lotka's exponent a=2. Critical value determined at the 0.01 level of significance i.e. 0.0217 and 0.0130. Thus, the distribution frequency of the authorship doesn't follow the exact Lotka's Inverse law with the exponent a=2.

**3. Objective of study: -**

1. To investigate year wise and document wise publication patterns.
2. To find out, leading author's key words, keyword plus, and title keywords through keyword analysis.
3. To verify the Lotka's law in its generalized form as well as in Inverse square from in the field of Thermodynamics
4. To apply the non-parametric Kolmogorov – Smirnov (K-S) test of 'Goodness-of-fit' for conformity of the Lotka's law.
5. To find out most preferred journals in the field of Thermodynamics.

**4. Methodology and data sources: -**

The data is derived from the 'Web of Science' in the form of plain text. The keyword 'Thermodynamics' OR 'Basics of heat and temperature' are used to find out data from the Web of Science. 'Topic' is metadata category used to retrieve data. Through customize year option, the duration is selected from 2015 to 2019. Total 29919 records are analysed. Data is analysed with the help of Bibexcel, R-programming, and Microsoft Excel. The following are the indicators and Lotka's law used for data analysis.

**4.1. Lotka's law: -**

Alfred James Lotka is Chemist, Demographer, Ecologist and Mathematician. He published a paper in 1926 in the Journal 1 of the Washington Academy of Science. The study is about the frequency distribution of scientific productivity of authors observing the publication listed in 'Chemical Abstracts' for the period 1907-16. He showed that the number of authors with 'n' publications in a bibliography is described by a power law of the form 'c/$n^a$' where 'c' is a constant. The law states, "... the number (of authors) making 'n' contributions is about $1/n^2$ of those making one and the proportion of all the authors that make a single contribution is of about 60 percent...". It means that in a subject or discipline, 60% of the authors produce one publication; 15% produces two publications ($1/2^2$*60); 7% produces three publications ($1/3^2$*60), and so on. Lotka's law, when applied to large bodies of literature over a fairly long period of time, can be accurate in general but not statistically exact. The law claimed that once the number of authors writing one paper only is known than the number of authors writing two, three or more may be predicted.

Lotka's law can be represent in the following equation no I.

$$x^n * y = c$$

Where, 'x' is the number of articles published (1,2, 3…)

'y' is the number of authors with frequency 'x' number of articles

'n' is an exponent that is constant for a given set of data

'c' is a constant.

When n=2 used for a data set then the law is called Inverse square law of scientific productivity. If the special case n=2 the constant is 0.6079. The value of 'n' differs from data set to data set. In the present study linear least square (LLS) method defined by 'Pao' has been used to calculate the value of 'n'. It is calculated by the following formula (equation No. II)

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

Where, X=the logarithm value of 'x' i.e. number of publications.

Y=is the logarithm value of 'y' i.e. number of authors.

N=is the number of data pairs available for study.

The constant 'c' can be calculated by (equation No. III)

$$c = \frac{1}{\sum \frac{1}{x^n}}$$

To examine the observed frequency pattern of the author's productivity suits the expected frequency pattern. 'Peo' advised applying the non-parametric Kolmogorov – Smirnov (K-S) goodness -of- fit test. To check it, the highest deviation between the observed cumulative relative frequency and expected cumulative relation frequencies needs to be considered and then compared it with the critical value (C.V.) which can be calculated by the following equation determined by Nicholls. (equation No. IV)

$$c.v. = \frac{n}{\sqrt{\sum y}}$$

**4.2. Goodness of Fit test: -**

There are many goodness-of fit tests are available for conformity and testing the validity of data. Kolmogorov – Smirnov (K-S) test and Chi Square test are frequently applied as a goodness of fit apparatus. In the present study, K-S test is used to verify the Lotka's law.

**4.3. K-S test: -**

K-S test is carried out by calculating the theoretical and observed cumulative frequency distribution of authors the difference at each level of cumulative frequency distribution is counted. The maximum difference is observed and further, it is compared with the critical value calculated using equation no. IV. If the difference is less than the critical value, it is accepted otherwise rejected.

**4.4. Domestic Collaborative Index: -**

Collaboration can be classified as Local, Domestic, and International collaboration. In the present study, domestic and international collaboration are considered. If the affiliation of authors of an article belong to one country, then that published paper is called domestically collaborated paper. Generally, any institute starts its research publications with domestic collaboration and gradually international collaboration increases. To calculate the degree of domestic collaboration DCI (Domestic Collaborative Index) is used. It is calculated by the following formula.

$$\mathrm{DCI} = \frac{\mathrm{D}i/\mathrm{D}io}{\mathrm{D}o/\mathrm{D}oo}\ X\ 100$$

Where, Di= number of domestically co-authored paper for block 'i'

Dio = number of domestically co-authored paper for all the blocks

Do= Total number of co-authored papers

Doo= Total output

**4.5. International Collaborative Index: -**

If the affiliation of at least one author of an article belongs to a foreign country, then that published paper is called internationally collaborated paper. The degree of international collaboration is calculating by ICI (International Collaboration Index) by the following formula

$$\mathrm{ICI} = \frac{\mathrm{I}i/\mathrm{I}io}{\mathrm{I}o/\mathrm{I}oo}\ X\ 100$$

Where, Ii= number of internationally co-authored papers for block 'i'

I*io* = number of internationally co-authored paper for all the blocks

I*o* = Total number of co-authored papers for block

I*oo*= Total output

If the value of DCI or ICI is equal to 100 it means a given country's collaborative efforts correspond to the World average. If DCI or ICI >100 indicates collaboration efforts higher than World's average and if DCI or ICI<100 it means less than average collaboration.

[9]Katz and Martin (1997) discussed about the type of research collaboration. In the paper they distinguished between collaboration at different levels and show that that inter-institutional and

international collaboration need not necessarily involve inter-individual collaboration. It expressed that Co-authorship is no more than a particular indicator of collaboration. [10]Katz and Hicks (1997) explored how the impact varies with different types of collaboration. In the present study, DCI and ICI are calculated to compare country-wise collaboration efforts.

## 5. Analysis of Data: -

### 5.1. Documents wise analysis: -

Total 29919 documents are found published on Thermodynamics from 2015 to 2019. It is found that 16 types of documents are published. The highest documents are published in the form of research articles with 2752 records. It is 92.06% of the total published documents. 1071 are Review articles published with 3.58% contributions to the total. 603 are Proceedings papers with 2.02 % contributions. Other important forms of documents are Review Book Chapter with 73 records and Article Book Chapters are 15. All types of documents received 256884 citations.

It means 8.6 average citations per documents received during the study period. Total contributed authors to the documents are 118954. It means 0.463 documents per author and 2.16 authors per document are recorded.

**Table No.1 Document wise distribution of publications**

| Sr. No | Document Type | Records | % of 29919 |
|---|---|---|---|
| 1 | Article | 27542 | 92.06 |
| 2 | Review | 1071 | 3.58 |
| 3 | Article; Proceedings Paper | 603 | 2.02 |
| 4 | Meeting Abstract | 318 | 1.06 |
| 5 | Editorial Material | 177 | 0.59 |
| 6 | Review; Book Chapter | 73 | 0.24 |
| 7 | Correction | 57 | 0.19 |
| 8 | Letter | 28 | 0.09 |
| 9 | Article; Book Chapter | 15 | 0.05 |
| 10 | Article; Data Paper | 9 | 0.03 |
| 11 | Book Review | 7 | 0.02 |
| 12 | Reprint | 5 | 0.02 |
| 13 | Biographical-Item | 4 | 0.01 |
| 14 | News Item | 4 | 0.01 |
| 15 | Article; Retracted Publication | 3 | 0.01 |
| 16 | Retraction | 3 | 0.01 |
| **Total** | | **29919** | **100.00** |

### 5.2. Year-wise analysis of publications: -

The table No. 2 expressed the highest documents are published in 2019 with 6486 records but as these documents published duration is only one year for citation, they received only 11161 citations which are 4.34% of the total. The lowest number of documents are published in 2015 with 5500 records. But these documents received 88135 citations which are 34.31% of total citations in 5 years duration. The table shows that there is continuous glide in publications.

**Table No. 2 Year wise distribution of publications**

| Sr. No | Year | No. of Records | % of 29919 | Citation | % of 256884 |
|---|---|---|---|---|---|
| 1 | 2015 | 5500 | 18.38 | 88138 | 34.31 |
| 2 | 2016 | 5746 | 19.21 | 70801 | 27.56 |
| 3 | 2017 | 6015 | 20.10 | 55008 | 21.41 |
| 4 | 2018 | 6172 | 20.63 | 31776 | 12.37 |
| 5 | 2019 | 6486 | 21.68 | 11161 | 4.34 |
| **Total** | | **29919** | **100.00** | **256884** | **100.00** |

**5.3. Contributed authors ranking: -**

As per table No.3 represents the most productive author in the field of Thermodynamics is 'Wang J.' with 159 articles. The second and third highly productive authors are 'Liu Y' and 'Li J' with 142 and 117 published articles respectively. The table also represents the highest citations received by 'Wang J' with 1577 citations. But the highest average total citations per paper received by 'Hendi S.H.' with 22.68 TCPP and highest average citations per year is received by 'Wand J' with 815.40 TCPY. The table represents the first 50 highly contributed authors with 31 ranks.

**Table No. 3 Ranking of the contributed authors in 'Thermodynamics' with citation details**

| Sr.No. | Author | NP | TC | TCPP | TCPY | Rank |
|---|---|---|---|---|---|---|
| 1 | Wang J | 159 | 1577 | 9.92 | 315.40 | 1 |
| 2 | Liu Y | 142 | 1125 | 7.92 | 225.00 | 2 |
| 3 | Li J | 117 | 1063 | 9.09 | 212.60 | 3 |
| 4 | Zhang Y | 116 | 964 | 8.31 | 192.80 | 4 |
| 5 | Wang Y | 116 | 1505 | 12.97 | 301.00 | 4 |
| 6 | Li Y | 108 | 808 | 7.48 | 161.60 | 5 |
| 7 | Zhang L | 91 | 861 | 9.46 | 172.20 | 6 |
| 8 | Wang L | 90 | 659 | 7.32 | 131.80 | 7 |
| 9 | Zhang J | 89 | 1126 | 12.65 | 225.20 | 8 |
| 10 | Li H | 89 | 970 | 10.90 | 194.00 | 8 |
| 11 | Zhang X | 80 | 655 | 8.19 | 131.00 | 9 |
| 12 | Wang H | 79 | 994 | 12.58 | 198.80 | 10 |
| 13 | Yang Y | 75 | 878 | 11.71 | 175.60 | 11 |
| 14 | Zhang YH | 73 | 385 | 5.27 | 77.00 | 12 |
| 15 | Chen LG | 68 | 999 | 14.69 | 199.80 | 13 |
| 16 | Navrotsky A | 68 | 436 | 6.41 | 87.20 | 13 |
| 17 | Chen J | 66 | 1045 | 15.83 | 209.00 | 14 |
| 18 | Zhang H | 64 | 410 | 6.41 | 82.00 | 15 |
| 19 | Zhang Q | 63 | 510 | 8.10 | 102.00 | 16 |
| 20 | Yang L | 61 | 447 | 7.33 | 89.40 | 17 |
| 21 | Liu J | 60 | 614 | 10.23 | 122.80 | 18 |
| 22 | Wang X | 60 | 680 | 11.33 | 136.00 | 18 |
| 23 | Chen L | 59 | 403 | 6.83 | 80.60 | 19 |
| 24 | Wang Q | 58 | 565 | 9.74 | 113.00 | 20 |
| 25 | Li X | 57 | 1154 | 20.25 | 230.80 | 21 |
| 26 | Chakraborty S | 55 | 576 | 10.47 | 115.20 | 22 |
| 27 | Li L | 53 | 304 | 5.74 | 60.80 | 23 |
| 28 | Hendi SH | 53 | 1202 | 22.68 | 240.40 | 23 |
| 29 | Kumar A | 53 | 807 | 15.23 | 161.40 | 23 |
| 30 | Liu H | 52 | 531 | 10.21 | 106.20 | 24 |
| 31 | Liu W | 52 | 542 | 10.42 | 108.40 | 24 |
| 32 | Wang C | 52 | 393 | 7.56 | 78.60 | 24 |
| 33 | Wang F | 52 | 467 | 8.98 | 93.40 | 24 |
| 34 | Wang K | 52 | 546 | 10.50 | 109.20 | 24 |
| 35 | Liu F | 50 | 357 | 7.14 | 71.40 | 25 |
| 36 | Martinez F | 50 | 449 | 8.98 | 89.80 | 25 |
| 37 | Qi Y | 50 | 439 | 8.78 | 87.80 | 25 |
| 38 | Zhang C | 50 | 543 | 10.86 | 108.60 | 25 |
| 39 | Li W | 49 | 364 | 7.43 | 72.80 | 26 |
| 40 | Chen Y | 48 | 435 | 9.06 | 87.00 | 27 |
| 41 | Zhang F | 48 | 401 | 8.35 | 80.20 | 27 |
| 42 | Liu Q | 47 | 658 | 14.00 | 131.60 | 28 |
| 43 | Shakeel F | 47 | 539 | 11.47 | 107.80 | 28 |
| 44 | Roy S | 46 | 313 | 6.80 | 62.60 | 29 |
| 45 | Wang Z | 46 | 337 | 7.33 | 67.40 | 29 |
| 46 | Li Q | 45 | 439 | 9.76 | 87.80 | 30 |
| 47 | Liu C | 45 | 332 | 7.38 | 66.40 | 30 |
| 48 | Chen X | 44 | 190 | 4.32 | 38.00 | 31 |
| 49 | Li B | 44 | 664 | 15.09 | 132.80 | 31 |
| 50 | Wang S | 44 | 285 | 6.48 | 57.00 | 31 |

**5.4. Country wise distribution of domestic and international collaboration: -**

The study used Domestic Collaborative Index (DCI) indicator to measure the domestics degree of collaboration and International Collaborative Index (ICI) for measuring the degree of international collaboration. As per data, it is found that the highest domestic collaboration found by 'China' with 131.73 DCI score and lowest found by 'Swizerland' with 42.28 DCI score. As per DCI indicator output tells that if DCI value is more than 100 it means collaborative efforts taken by the country in research correspond to the world's average. From the data it is clear that in domestic collaboration 'China' (131.73), 'USA'

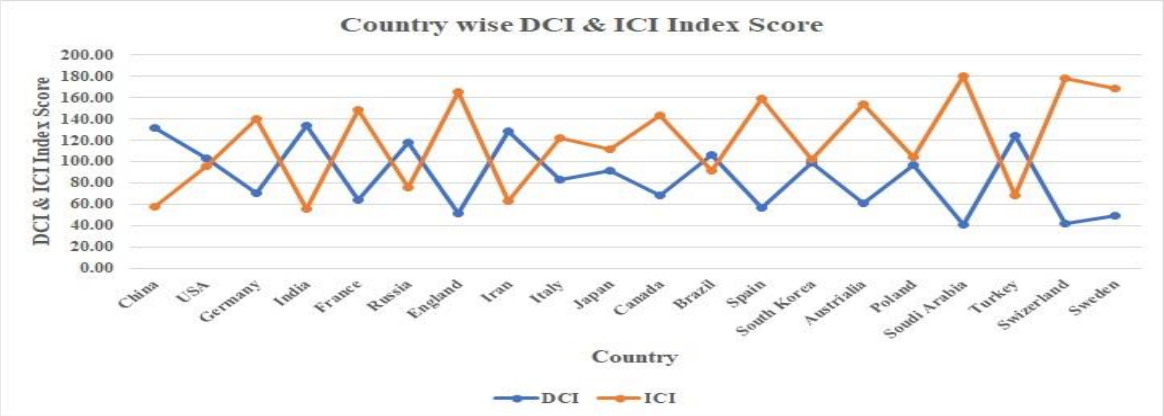
(103.30), 'India' (1333.39), 'Russia' (118.20) 'Iran' (127.92), 'Brazil' (100. 09) and Turkey (123.89) corresponds their collaborative efforts to world's average in the field of Thermodynamics.

As data conveys the information that the highest international collaboration efforts found by 'Soudi Arabia' with 180.42 ICI score and lowest by 'India' with 55.03 ICI score. The data in table No. 4 denotes that 'Germany' (140.10), 'France' (148.45), 'England' (165.75), 'Italy' (123.59), 'Japan' (111.83), 'Canada' (143.38), 'Spain' (158.59), 'South Korea' (102.02), 'Australia' (153.37), 'Poland' (104.63), 'Soudi Arabia' (180.42), 'Switzerland' (177.74) and 'Sweden' (168.56) are the countries whose international collaborative index is more than 100. It means collaborative efforts taken by these countries corresponding to the world average in international collaboration in field of Thermodynamics. The table expressed the highest contributed 20 countries out of which 13 countries show international collaboration trends. It means in the field of Thermodynamics international collaboration trend is available during the study period.

**Table No. 4 Country wise distribution of Domestic and International Collaboration**

| Sr. No. | Country | Paper in Domestic Collabration | DCI | Paper in International Collabration | ICI | Total Paper |
|---|---|---|---|---|---|---|
| 1 | China | 5322 | 131.73 | 1718 | 57.27 | 7040 |
| 2 | USA | 3740 | 103.30 | 2569 | 95.56 | 6309 |
| 3 | Germany | 970 | 70.22 | 1437 | 140.10 | 2407 |
| 4 | India | 1714 | 133.39 | 525 | 55.03 | 2239 |
| 5 | France | 539 | 64.02 | 928 | 148.45 | 1467 |
| 6 | Russia | 989 | 118.20 | 469 | 75.49 | 1458 |
| 7 | England | 400 | 51.18 | 962 | 165.75 | 1362 |
| 8 | Iran | 983 | 127.92 | 356 | 62.39 | 1339 |
| 9 | Italy | 629 | 83.22 | 688 | 122.59 | 1317 |
| 10 | Japan | 591 | 91.22 | 538 | 111.83 | 1129 |
| 11 | Canada | 361 | 67.79 | 567 | 143.38 | 928 |
| 12 | Brazil | 551 | 106.09 | 354 | 91.80 | 905 |
| 13 | Spain | 284 | 56.49 | 592 | 158.59 | 876 |
| 14 | South Korea | 368 | 98.50 | 283 | 102.02 | 651 |
| 15 | Austrialia | 211 | 60.37 | 398 | 153.37 | 609 |
| 16 | Poland | 307 | 96.56 | 247 | 104.63 | 554 |
| 17 | Soudi Arabia | 123 | 40.29 | 409 | 180.42 | 532 |
| 18 | Turkey | 369 | 123.89 | 150 | 67.83 | 519 |
| 19 | Swizerland | 115 | 42.28 | 359 | 177.74 | 474 |
| 20 | Sweden | 131 | 49.09 | 334 | 168.56 | 465 |
| | **Total** | **18697** | | **13883** | | **32580** |

**Graph No. 1 Country wise distribution of Domestic and International collaboration**




**5.5. Keyword analysis: -**

Keyword means most frequently used words to express the content of topics. Authors generally express the key concepts in different parts of the paper. Titles of the paper always expressed in a meaningful way that clears the topic of research and methodology used in the paper. It expresses clear content of paper with less words. Through title analysis, one can get the most important words or concepts of that field. Similarly, authors always provide keywords in the papers in the keyword section. These also expressed main concepts and related theoretical concepts. It also expressed the statistical application and

methodological related topics. So, with the help of keyword analysis, one can easily gather the most important words in a particular field. Another important word analysis is keyword plus. These are the words or phrases that frequently appear in the titles of an article's references. It means these words are index from cited articles. From 1991 onwards Web of Science is providing keyword plus facility. This type of keywords also represents the main concepts of a particular field.

In the present study, title words, keywords and keywords plus have been listed and ranked as per the frequency. Table No. 5 expressed Author keywords, keywords plus and Title worlds. As per the table first five most occurred author keywords are 'thermodynamics' (7919), 'kinetic' (1929), 'water' (1753), 'adsorption' (1622), and 'model' (1526). As per keyword plus list first five keywords plus are 'thermodynamics' (4767), 'adsorption' (1655), 'kinetics' (1563), 'solubility' (436) 'entropy' (393). As per the table, five most frequently occurred title words are 'thermodynamics' (7763), 'adsorption'(2041), 'study'(1731), 'kinetics'(1614) and 'aqueous'(1593). The table gives the first 50 frequently occurred words each from authors keywords, keyword plus, and title words.

**Table No. 5 Keyword analysis from Authors keywords, Keywords plus, Title words**

| Sr. No. | Author Keyword | Frequency | Keyword Plus | Frequency | Title Words | Frequency |
|---|---|---|---|---|---|---|
| 1 | thermodynamics | 7919 | thermodynamics | 4767 | thermodynamics | 7763 |
| 2 | kinetics | 1929 | adsorption | 1655 | adsorption | 2041 |
| 3 | water | 1753 | kinetics | 1563 | study | 1731 |
| 4 | adsorption | 1622 | solubility | 436 | kinetics | 1614 |
| 5 | model | 1526 | entropy | 393 | aqueous | 1593 |
| 6 | equilibrium | 1490 | isotherm | 295 | model | 1420 |
| 7 | removal | 1480 | isotherms | 272 | analysis | 1397 |
| 8 | aqueous solution | 1262 | density functional theory | 218 | removal | 1360 |
| 9 | temperature | 1152 | exergy | 208 | properties | 1310 |
| 10 | behavior | 1124 | black holes | 179 | phase | 1292 |
| 11 | systems | 1099 | methylene blue | 178 | solution | 1199 |
| 12 | dynamics | 1052 | molecular dynamics | 177 | water | 1120 |
| 13 | stability | 990 | modeling | 172 | energy | 1082 |
| 14 | energy | 974 | entropy generation | 166 | heat | 1053 |
| 15 | aqueous solutions | 962 | activated carbon | 165 | quantum | 1023 |
| 16 | sorption | 941 | dft | 164 | system | 995 |
| 17 | performance | 860 | quantum thermodynamics | 161 | entropy | 954 |
| 18 | activated carbon | 803 | non equilibrium thermodynamics | 160 | black | 948 |
| 19 | mechanism | 803 | biosorption | 153 | solutions | 905 |
| 20 | system | 715 | equilibrium | 145 | molecular | 901 |
| 21 | entropy | 692 | phase diagram | 142 | systems | 899 |
| 22 | nanoparticles | 684 | calorimetry | 141 | carbon | 888 |
| 23 | waste water | 677 | thermodynamic | 139 | thermal | 869 |
| 24 | optimization | 586 | isothermal titration calorimetry | 137 | studies | 863 |
| 25 | simulation | 578 | phase transition | 137 | modeling | 859 |
| 26 | binding | 543 | thermodynamic properties | 136 | based | 848 |
| 27 | design | 526 | hydrogen storage | 134 | equilibrium | 817 |
| 28 | acid | 512 | optimization | 132 | theory | 795 |
| 29 | molecular dynamics | 507 | finite time thermodynamics | 129 | temperature | 775 |
| 30 | transition | 498 | microstructure | 129 | dynamics | 770 |
| 31 | mixtures | 480 | adsorption kinetics | 128 | acid | 752 |
| 32 | methylene blue | 473 | enthalpy | 119 | effects | 743 |
| 33 | biosorption | 468 | diffusion | 118 | surface | 711 |
| 34 | ions | 454 | adsorption isotherm | 116 | structure | 699 |
| 35 | adsorbent | 446 | kinetic | 115 | synthesis | 695 |
| 36 | growth | 445 | nanoparticles | 115 | kinetic | 693 |
| 37 | separation | 440 | second law of thermodynamics | 115 | hydrogen | 679 |
| 38 | solubility | 415 | sorption | 113 | formation | 654 |
| 39 | diffusion | 407 | energy | 109 | mechanism | 635 |
| 40 | surface | 405 | physical chemistry | 104 | gas | 623 |
| 41 | crystal structure | 402 | calphad | 103 | approach | 609 |
| 42 | transport | 399 | heat transfer | 103 | binding | 568 |
| 43 | prediction | 393 | temperature | 102 | experimental | 568 |
| 44 | microstructure | 380 | heat capacity | 101 | performance | 546 |
| 45 | evolution | 375 | stability | 100 | liquid | 540 |
| 46 | chemistry | 351 | black hole thermodynamics | 99 | investigation | 538 |
| 47 | phase | 350 | thermodynamic parameters | 98 | solubility | 538 |
| 48 | density functional theory | 345 | efficiency | 97 | behavior | 526 |
| 49 | oxidation | 340 | ads cft correspondence | 95 | application | 521 |
| 50 | efficiency | 332 | water | 95 | process | 508 |

**5.6 Ranking of preferred journals by contributed authors: -**

The table No. 6 represents the first 60 most contributed journals in the field of thermodynamics. The listed journals are arranged by descending order of the contributions. The first ranked journal is 'Journal of Molecular Liquids' with 547 contributed articles. The second and third rank journals are 'Physical Review E.' and 'Desalination and Water Treatment' with 507 and 451 contributed articles in thermodynamics during the study period. The highest citations received by the preferred journal is 'Journal of Molecular Liquids' with 6233 citations. 'Chemical Engineering Journal' is received highest average citations per article with 37.79 ACPP and 'Journal of Molecular Liquids' received highest average citations per year with 1246.60 ACPY. The table also represents the h-index calculated in 2019 and it shows that 'Journal of Molecular Liquids' received 38 h-index which is highest among all preferred journals during the study period. 'Abstracts of Papers of the American Chemical Society' published 229 articles and obtained rank 16 in preferred journals list but it has not received any citation during the study period.

**Table No. 6 Ranking of most productive Journals in the field of Thermodynamics**

| Sr. No. | Sources | Articles | Rank | Total Citation | ACPP | ACPY | h-index |
|---|---|---|---|---|---|---|---|
| 1 | Journal of Molecular Liquids | 547 | 1 | 6233 | 11.39 | 1246.60 | 38 |
| 2 | Physical Review E | 507 | 2 | 3656 | 7.21 | 731.20 | 26 |
| 3 | Desalination and Water Treatment | 451 | 3 | 2025 | 4.49 | 405.00 | 18 |
| 4 | Physical Review D | 428 | 4 | 4894 | 11.43 | 978.80 | 32 |
| 5 | Entropy | 391 | 5 | 1724 | 4.41 | 344.80 | 17 |
| 6 | Journal of Chemical Physics | 380 | 6 | 2671 | 7.03 | 534.20 | 22 |
| 7 | Physical Chemistry Chemical Physics | 348 | 7 | 2752 | 7.91 | 550.40 | 22 |
| 8 | Journal of Physical Chemistry B | 321 | 8 | 2626 | 8.18 | 525.20 | 22 |
| 9 | Journal of Chemical Thermodynamics | 300 | 9 | 2051 | 6.84 | 410.20 | 21 |
| 10 | Journal of Physical Chemistry C | 296 | 10 | 2580 | 8.72 | 516.00 | 24 |
| 11 | RSC Advances | 290 | 11 | 3103 | 10.70 | 620.60 | 25 |
| 12 | Physical Review B | 255 | 12 | 2309 | 9.05 | 461.80 | 21 |
| 13 | International Journal of Hydrogen Energy | 254 | 13 | 2265 | 8.92 | 453.00 | 22 |
| 14 | Journal of Alloys and Compounds | 237 | 14 | 2191 | 9.24 | 438.20 | 22 |
| 15 | Scientific Reports | 237 | 14 | 2049 | 8.65 | 409.80 | 22 |
| 16 | Journal of Chemical and Engineering Data | 236 | 15 | 1263 | 5.35 | 252.60 | 15 |
| 17 | Abstracts of Papers of The American Chemical Society | 229 | 16 | 0 | 0.00 | 0.00 | 0 |
| 18 | Physical Review Letters | 220 | 17 | 4885 | 22.20 | 977.00 | 39 |
| 19 | European Physical Journal C | 219 | 18 | 2024 | 9.24 | 404.80 | 23 |
| 20 | Fluid Phase Equilibria | 210 | 19 | 1223 | 5.82 | 244.60 | 16 |
| 21 | Journal of High Energy Physics | 207 | 20 | 2903 | 14.02 | 580.60 | 28 |
| 22 | Energy | 169 | 21 | 2023 | 11.97 | 404.60 | 25 |
| 23 | New Journal of Physics | 165 | 22 | 2251 | 13.64 | 450.20 | 25 |
| 24 | Russian Journal of Physical Chemistry A | 158 | 23 | 204 | 1.29 | 40.80 | 6 |
| 25 | Physical Review A | 156 | 24 | 1208 | 7.74 | 241.60 | 16 |
| 26 | Physica A-Statistical Mechanics and Its Applications | 152 | 25 | 872 | 5.74 | 174.40 | 15 |
| 27 | Langmuir | 151 | 26 | 1300 | 8.61 | 260.00 | 18 |
| 28 | Applied Thermal Engineering | 150 | 27 | 1682 | 11.21 | 336.40 | 22 |
| 29 | Journal of The American Chemical Society | 144 | 28 | 3688 | 25.61 | 737.60 | 32 |
| 30 | Journal of Thermal Analysis and Calorimetry | 142 | 29 | 556 | 3.92 | 111.20 | 11 |
| 31 | Energy Conversion and Management | 139 | 30 | 2417 | 17.39 | 483.40 | 29 |
| 32 | Acta Materialia | 137 | 31 | 2966 | 21.65 | 593.20 | 21 |
| 33 | Industrial & Engineering Chemistry Research | 134 | 32 | 814 | 6.07 | 162.80 | 15 |
| 34 | Physics Letters B | 133 | 33 | 1417 | 10.65 | 283.40 | 22 |
| 35 | Journal of Environmental Chemical Engineering | 119 | 34 | 1721 | 14.46 | 344.20 | 23 |
| 36 | Nature Communications | 113 | 35 | 3200 | 28.32 | 640.00 | 30 |
| 37 | Chemical Engineering Journal | 109 | 36 | 4119 | 37.79 | 823.80 | 36 |
| 38 | Proceedings of The National Academy of Sciences of The United States of America | 109 | 36 | 2438 | 22.37 | 487.60 | 27 |
| 39 | International Journal of Biological Macromolecules | 106 | 37 | 1012 | 9.55 | 202.40 | 18 |
| 40 | Classical and Quantum Gravity | 105 | 38 | 785 | 7.48 | 157.00 | 12 |
| 41 | International Journal of Modern Physics D | 104 | 39 | 563 | 5.41 | 112.60 | 12 |
| 42 | General Relativity and Gravitation | 103 | 40 | 615 | 5.97 | 123.00 | 13 |
| 43 | Biophysical Journal | 101 | 41 | 417 | 4.13 | 83.40 | 12 |
| 44 | Journal of Chemical Education | 101 | 41 | 243 | 2.41 | 48.60 | 7 |
| 45 | Applied Surface Science | 99 | 42 | 1512 | 15.27 | 302.40 | 23 |
| 46 | Journal of Statistical Mechanics-Theory and Experiment | 99 | 42 | 558 | 5.64 | 111.60 | 12 |
| 47 | Macromolecules | 99 | 42 | 1112 | 11.23 | 222.40 | 20 |
| 48 | International Journal of Heat and Mass Transfer | 97 | 43 | 1064 | 10.97 | 212.80 | 19 |
| 49 | Soft Matter | 97 | 43 | 867 | 8.94 | 173.40 | 17 |
| 50 | Calphad-Computer Coupling of Phase Diagrams and Thermochemistry | 95 | 44 | 822 | 8.65 | 164.40 | 12 |
| 51 | Journal of Physical Chemistry A | 94 | 45 | 722 | 7.68 | 144.40 | 13 |
| 52 | Chemistry-A European Journal | 93 | 46 | 778 | 8.37 | 155.60 | 15 |
| 53 | Metallurgical and Materials Transactions B-Process Metallurgy and Materials Processing Science | 89 | 47 | 541 | 6.08 | 108.20 | 13 |
| 54 | Journal of Colloid and Interface Science | 87 | 48 | 1743 | 20.03 | 348.60 | 24 |
| 55 | Computational Materials Science | 86 | 49 | 543 | 6.31 | 108.60 | 12 |
| 56 | Journal of Chemical Theory and Computation | 86 | 49 | 1267 | 14.73 | 253.40 | 17 |
| 57 | EPL | 85 | 50 | 729 | 8.58 | 145.80 | 14 |
| 58 | Journal of Physics A-Mathematical and Theoretical | 83 | 51 | 774 | 9.33 | 154.80 | 11 |
| 59 | Journal of Solution Chemistry | 83 | 51 | 281 | 3.39 | 56.20 | 8 |
| 60 | Advances in High Energy Physics | 82 | 52 | 359 | 4.38 | 71.80 | 9 |

**5.7 Application of Lotka's law: -**

**5.7.1 To determine the value of 'n', 'c' and c.v.: -**

Lotka's law is about the frequency distribution of authors' productivity in the given subject. In the present study, an attempt is made to study the applicability of Lotka's law in the field of thermodynamics. To apply Lotka's law following table is created from the data extracted from the Web of Science.

| Sr. No. | No. of Publication (x) | No. of Authors (y) | X (Log x) | Y (log y) | X*Y | X^2 | x^n | 1/x^n |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 14021 | 0.000 | 9.548 | 0.000 | 0.000 | 1.000 | 1.000 |
| 2 | 2 | 2079 | 0.693 | 7.640 | 5.295 | 0.480 | 9.383 | 0.107 |
| 3 | 3 | 697 | 1.099 | 6.547 | 7.192 | 1.207 | 34.762 | 0.029 |
| 4 | 4 | 293 | 1.386 | 5.680 | 7.874 | 1.922 | 88.035 | 0.011 |
| 5 | 5 | 116 | 1.609 | 4.754 | 7.651 | 2.590 | 180.998 | 0.006 |
| 6 | 6 | 76 | 1.792 | 4.331 | 7.760 | 3.210 | 326.158 | 0.003 |
| 7 | 7 | 38 | 1.946 | 3.638 | 7.078 | 3.787 | 536.620 | 0.002 |
| 8 | 8 | 20 | 2.079 | 2.996 | 6.229 | 4.324 | 826.001 | 0.001 |
| 9 | 9 | 20 | 2.197 | 2.996 | 6.582 | 4.828 | 1208.379 | 0.001 |
| 10 | 10 | 16 | 2.303 | 2.773 | 6.384 | 5.302 | 1698.244 | 0.001 |
| 11 | 11 | 7 | 2.398 | 1.946 | 4.666 | 5.750 | 2310.460 | 0.000 |
| 12 | 12 | 8 | 2.485 | 2.079 | 5.167 | 6.175 | 3060.240 | 0.000 |
| 13 | 13 | 1 | 2.565 | 0.000 | 0.000 | 6.579 | 3963.118 | 0.000 |
| 14 | 14 | 4 | 2.639 | 1.386 | 3.659 | 6.965 | 5034.931 | 0.000 |
| 15 | 15 | 3 | 2.708 | 1.099 | 2.975 | 7.334 | 6291.798 | 0.000 |
| 16 | 16 | 3 | 2.773 | 1.099 | 3.046 | 7.687 | 7750.104 | 0.000 |
| 17 | 17 | 4 | 2.833 | 1.386 | 3.928 | 8.027 | 9426.490 | 0.000 |
| 18 | 18 | 3 | 2.890 | 1.099 | 3.175 | 8.354 | 11337.837 | 0.000 |
| 19 | 19 | 1 | 2.944 | 0.000 | 0.000 | 8.670 | 13501.255 | 0.000 |
| 20 | 20 | 1 | 2.996 | 0.000 | 0.000 | 8.974 | 15934.076 | 0.000 |
| 21 | 21 | 1 | 3.045 | 0.000 | 0.000 | 9.269 | 18653.843 | 0.000 |
| **Total** | | **17412** | **45.380** | **60.995** | **88.663** | **111.434** | **102173.731** | **1.162** |

In the above table 'x' denotes that the number of single-author publications and 'y' denotes the number of authors having a single publication. Study attempt to find out whether these authors' productivity fits in Lotka's law or not. The first step in applying Lotka's law is to find out the value of 'n', 'c', and critical value (c.v.) from the data of the present study.

The value of 'n' can be calculated using the following formula

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

$$n = \frac{(21 * 88.663) - (45.380 * 60.995)}{(21 * 111.434) - (45.380)^2}$$

$$n = \frac{-906.03}{280.7544}$$

$$n = -3.23$$

Therefore $n$ =-3.23.

'c' will be calculated with following formula

$c = \frac{1}{\sum \frac{1}{x^n}}$ …… (from the above table the value of $\sum \frac{1}{x^n}$ =1.1617)

$$c = \frac{1}{1.1617}$$

$$c = 0.86$$

Critical value can be calculated with

$$c.v. = \frac{n}{\sqrt{\sum y}}$$

$$c.v. = \frac{3.23}{\sqrt{17412}}$$

$$c.v. = 0.0245$$

From the above mathematical calculation n=3.23, c=0.86, c.v.=0.0245.

### 5.7.2 Kolmogorov – Smirnov (K-S) Test (n=3.23 c= 0.86 and n=2 and c= 0.6.79)

| Publication (x) | Author (y) | Observed=yx/Σxy | Value=Σ(yx/Σyx) | Expected Freq | Value of Freq/Cum | Diff(D) | Expected Freq | Value of Freq/Cum | Diff(D) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 14021 | 0.805 | 0.805 | 0.861 | 0.861 | -0.055 | 0.608 | 0.608 | 0.197 |
| 2 | 2079 | 0.119 | 0.925 | 0.092 | 0.952 | 0.028 | 0.152 | 0.760 | -0.033 |
| 3 | 697 | 0.040 | 0.965 | 0.025 | 0.977 | 0.015 | 0.068 | 0.827 | -0.028 |
| 4 | 293 | 0.017 | 0.982 | 0.010 | 0.987 | 0.007 | 0.038 | 0.865 | -0.021 |
| 5 | 116 | 0.007 | 0.988 | 0.005 | 0.991 | 0.002 | 0.024 | 0.890 | -0.018 |
| 6 | 76 | 0.004 | 0.993 | 0.003 | 0.994 | 0.002 | 0.017 | 0.907 | -0.013 |
| 7 | 38 | 0.002 | 0.995 | 0.002 | 0.996 | 0.001 | 0.012 | 0.919 | -0.010 |
| 8 | 20 | 0.001 | 0.996 | 0.001 | 0.997 | 0.000 | 0.009 | 0.929 | -0.008 |
| 9 | 20 | 0.001 | 0.997 | 0.001 | 0.997 | 0.000 | 0.008 | 0.936 | -0.006 |
| 10 | 16 | 0.001 | 0.998 | 0.001 | 0.998 | 0.000 | 0.006 | 0.942 | -0.005 |
| 11 | 7 | 0.000 | 0.998 | 0.000 | 0.998 | 0.000 | 0.005 | 0.947 | -0.005 |
| 12 | 8 | 0.000 | 0.999 | 0.000 | 0.999 | 0.000 | 0.004 | 0.951 | -0.004 |
| 13 | 1 | 0.000 | 0.999 | 0.000 | 0.999 | 0.000 | 0.004 | 0.955 | -0.004 |
| 14 | 4 | 0.000 | 0.999 | 0.000 | 0.999 | 0.000 | 0.003 | 0.958 | -0.003 |
| 15 | 3 | 0.000 | 0.999 | 0.000 | 0.999 | 0.000 | 0.003 | 0.961 | -0.003 |
| 16 | 3 | 0.000 | 0.999 | 0.000 | 0.999 | 0.000 | 0.002 | 0.963 | -0.002 |
| 17 | 4 | 0.000 | 1.000 | 0.000 | 0.999 | 0.000 | 0.002 | 0.965 | -0.002 |
| 18 | 3 | 0.000 | 1.000 | 0.000 | 0.999 | 0.000 | 0.002 | 0.967 | -0.002 |
| 19 | 1 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | 0.002 | 0.969 | -0.002 |
| 20 | 1 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | 0.002 | 0.970 | -0.001 |
| 21 | 1 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | 0.001 | 0.972 | -0.001 |
| | **17412** | **1.000** | **20.635** | **Present Study** | | **0.028** | **Lotka's Study** | | **0.197** |

The K-S goodness-of-fit test is used to test the fitness of Lotka's law. As per the table represents that this test applies to data and tested on the observed frequency of authors in comparison with the expected frequency of the author's productivity. It is observed that the maximum deviation between cumulative of observed and expected distributions was found $D_{max}$=0.028 in the present study where n=3.23 and c=0.06. It is found that the maximum deviation between cumulative of observed and expected distributions of authors' productivity as per Lotka's law was $D_{max}$=0.197 where n=2, c=0.6079. In the first case $D_{max}$=0.028 which is more than the critical value observed i.e. 0.0245. The difference between the two is 0.0035. so, it can be affirmed that the K-S test reveals that present data set confirms the applicability of Lotka's law in the field of thermodynamics with 0.003 level of significance. In the second case with Lotka's inverse square law, the $D_{max}$ value is 0.197 which is more than critical value i.e. 0.0245, But the difference between the two is 0.172 which is more than level of significance 0.01. So Lotka's inverse square law will not confirm the present data.

## 6.Finding and Conclusion: -

The study reveals the following findings in the field of Thermodynamics

1. Documents analysis shows that the highest documents are published in the form of articles with 2752 records which are 92.06% of the total contribution.
2. The average citations per document are 8.6. and total authors contributed are 118954 which means 0.463 document per author and 2.16 authors per document.
3. The Year-wise analysis shows the highest documents are published in 2019 with 6486 records and highest citations received in 2015 with 88135 citations which are 34.31% to the total citations.
4. The most productive author in Thermodynamic is 'Wang, J' with 159 articles, and the same author received the highest citations with 1577.
5. 'Hendi, S.H.' received the highest average total citations per paper with 22.68 TCPP.
6. Out of the highest 20 contributed countries, 13 countries show international collaboration trends in the subject of Thermodynamics.

7. It is found that the most productive preferred journal is the 'Journal of Molecular Liquids' with 547 contributed articles and the highest citations received in study duration with 6233 citations. The same journal received 38 h-index score which is highest in all journals.
8. Lotka's law of author's productivity in the field Thermodynamic confirms for the present data with 0.003 level of significance. But Lotka's inverse square law does not confirm to the present data of Thermodynamics.

**7. References: -**


1. Pritchard, Alan (1969), Statistical Bibliography or Bibliometrics, *Journal of Documentation*, 24(4), 348-349.
2. Kaur, Har, and Gupta, B. M. (2010), 'Mapping of Dental Science research in India a Scientometric analysis of India's research output, 1999-2008', *Scientometrics*, Vol. 85, pp. 361 - 376.
3. Kademani, B.S, Sugar, Anil, and Kumar Vijai (2008), "Scientometric Mapping of vacuum research in Nuclear Science & Technology: A Global perspective.
4. Chaman Sab M, Dharani Kumar, and Biradar, B.C. (2019), "Scientific productivity of Oceanography literature: A Scientometric Analysis", *Fish & Ocean OPJ*; 5(2).555657 DOI:10. 19080/OFOAJ. 2017. 05. 555657
5. Arunchalam, Subbian, and Gunasekaram, Subbian (2002), "Tuberculosis research in India and China: From bibliometrics to research policy", *Current Science*, Vol. 82 (8) pp. 933-947.
6. Hadagali , Gururaj S., Hiremath, Rudramuni S., Gourikeremath, Gouri N. and Bulla Shivanand D. (2019), "Scientometric Analysis of Material Science research", *Library Philosophy and Practice (e-journal)* .2771.
7. Ahmad, Muneer, Batcha, M. Sadik, and Jahina, S. Roslein (2019), "Testing Lotka's law and pattern of author productivity in the scholarly publication of Artificial Intelligence", *Library Philosophy and Practice (e-journals)*.
8. Kumar, Nerendra, (2010), "Applicability to Lotka's law to research productivity of council of Scientific and Industrial Research (CSIR), India", *Annals of Library and Information Studies*, Vol.57, pp.1-5.
9. Katz, J. S., and Martin, B.R. (1997), What is research collaboration? *Research Policy*, 26.1
10. Katz,J.S., and Hicks, Diana (1997), How much is a collaboration worth? A Calibrated bibliometric Model, *Scientometrics*, 40, 541-554.