Scientometric Portrait of Dr. Ajay Kumar Sood

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Abstract

Ajay Kumar Sood's discovery on the current generation of carbon nano-tubes is now called the 'Sood Effect.' In this research article, the authors present a scientometric portrait of Dr. Ajay Kumar Sood, emphasizing his scientific achievements. A complete list of research publications from 1974 to 2021 was compiled from two sources, i.e., the Web of Science database and the latest resume of Ajay Kumar Sood. he results of the study indicate that he published only six articles as a single author and 449 in collaboration; the Collaborative Coefficient (CC) for AKS's research publications was 0.7345, and the Modified Collaborative Co-efficient (MCC) was 0.7361; Physical Review B was the most preferred journal by AKS, having an impact factor of 3.908 with 60 articles. The authors conclude that his discovery of the 'Sood Effect' made a distinctive contribution to the field of Physics.

1. INTRODUCTION

Many scientists have built or motivated others to build institutions; hence, studying their lives and scientific works would stimulate the younger generation to emulate them in their specialized fields of learning. Many studies have identified such personas and their contributions in the specific field to recognize the role model and pay homage. Research on 'eminent individual scientists' as a unit of knowledge generation has opened diverse vistas in understanding the process of Research and Development innovation communications (Kalyane and Sen, 2003). Librametry was introduced in the 1940s by Dr. S. R. Ranganathan. This technique provided the impetus for the emergence of 'bibliometrics,' 'scientometrics,' 'webometrics,' and 'altmetrics.' Scientometric is a technique that aids in evaluating the overall research performance of a researcher in a particular field and offers various approaches for assessing research contributions by individuals, Institutions, Disciplines, and Journals, which have transformed the way of research evaluation. In the current study, the authors have tried to analyze with scientometric indicators, i.e., Productivity, Authorship trend, prolific journals Collaborative Measures of Dr. Ajay Kumar Sood (hereafter referred to as AKS) from 1974 to 2021.

AKS's discovery on current generation in carbon nano-tubes is now called the 'Sood Effect.' His publications cover many topics, totalling close to four hundred and fifty. Many of his innovations have been patented. He has guided more than 30 research scholars for their Ph.D. In recognition of his scientific contributions and service to science in India, the Government of India (GOI) honoured him with "Padma Shri" in 2013. AKS is now the Principal Scientific Advisor to the Government of India.

2. REVIEW OF RELATED WORKS

As a platform for the present study, some pertinent works conducted in bibliometric studies are discussed here. In this context, Sen and Gan (1990) developed a conceptual framework for studying an individual scientist or group of individuals. They suggested five elements for a complete bio-bibliometric profile: (1) a complete list of biodata elements in chronological order, (2) complete bibliography of publications by the individual, (3) complete bibliography of material on the person (both life and work), (4) a complete list of materials cited or used by the person in his writings, (5) a complete list of references to others

from the person's writings. Kademani, Kalyane, and Vijay Kumar (1996) analyzed productivity indicators concerning the publications of Dr. Vikram Ambalal Sarabhai. Sarabhai was one of the most famous Indian scientists. The authors analyzed 160 publications spread across three domains. The study's results revealed that the Collaboration coefficient was one; the Coefficient of Productivity was 0.58.

The scientific portrait of K.S. Krishnan conducted by Kademani et al. (1996) is widely recognized. The authors examined 135 papers, which were divided into appropriate domains. 'Magnetism' was the domain where he published a maximum of 60 papers, followed by 'Spectroscopy' with 50 papers, etc. The results indicate temporal variations in productivity, and the papers he published were of such a nature that he deserves to be taken as a 'role model' for the younger generation. Citation analysis is today considered the most effective technique for measuring scientific activity and the impact of the scientific output of individual scientists, institutions, and nations. Sen and Karanjai (2003) analyzed 226 publications of renowned Indian physical chemist Biman Bagchi published between 1981 and 2002. Bagchi was highly productive, producing an average of 10 papers annually. In the beeline of authorship, Bagchi occupies the first authorship position in 69 papers. His collaborator, A. Chandra, was the first author of 30 papers, thus becoming Bagchi's closest collaborator. Three of the author's papers have received more than 200 citations, and another three have received 100–200 citations. The scientist received more than 300 citations in four years, and his citation rate per paper was 18.98.

Swarna et al. (2006) analyzed 427 eponymous bibliographic records of H. J. Bhabha retrieved from the Science Citation Index (1982–2002) and their occurrence in different bibliographic circles. Fifty-nine other nouns for Bhabha have been identified and divided into 19 clusters. Most records come from the 'Bhabha scattering' cluster with 290 publications. There were 237 different keywords. Twenty-two recurring keywords were shared in at least five clusters. The authors suggest that citations should also be included when evaluating scientists based on citation counts. Sangam and Savanur (2006) investigate the publication productivity of N. Rudraiah, a leading mathematician from Bangalore, India. During his productive life of 43 years, he collaborated with 102 colleagues and students and published 271 papers spread over five different research areas during 1962-2004. The correlation

coefficient was 0.51. Major journals publishing his articles are the *Indian Journal of Pure and Applied Mathematics*, *Current Science, International Journal of Heat and Mass Transfer*, etc. The authors express that N. Rudraiah's publications and research work will inspire young mathematicians in the field of interest worldwide.

Sangam et al. (2006) have advocated the scientometric study of 337 publications of Peter Jhon Wyllie, an American geologist during 1951-2004. The study reveals that out of the total publications, 144 were single-authored, and 193 were multi-authored papers. Wyllie published 13 papers in the year 1983, which was considered as the peak productive year of Wyllie; (0.64) the highest collaboration coefficient from 1970 to 1974. During his fruitful career, Prof. Wyllie has collaborated with 75 scientists, such as Huang being the primary collaborator with 25 publications from 1973 to 2000. Out of 337 papers, a total of 241 research papers were published in 68 different communication channels; *American Mineralogy* (24) and *Journal Geology* (23) were the most preferred journals. In the author's view, citing the number of publications, authorship patterns give us the enormous interest the author has taken to reach his work to the common person's understanding of geoscience.

In 2007, Sangam et al. classified 178 publications of Prof. S. Ramaseshan into four domains and concluded that Ramaseshan's work imprinted the various fields in which he diligently promoted science in India. Undoubtedly, he helped science in the great years of the birth of modern physics in India. Keshava et al. (2010) have evaluated Prof. Kubakkaddi's scientific research output and his contribution to advancing science in India, particularly in physics. According to the findings, Kubakaddi published 85 publications between 1974 and 2008. Prof. Kubakaddi's best productivity year was in 1987 when he published nine papers, and his highest Collaborative Coefficient was 0.71 when he was 44-48 years old (1995-1999). The authors believed that the work done by Prof. Kubakadi has left a mark in the various fields in which he has diligently dealt for the promotion of science in India.

As a scientist, Prof. Anurag Kumar has collaborated with numerous eminent scientists and students and published more than 215 papers from 1982 to 2016. His significant contribution to engineering in general and Electrical and Electronics subjects in particular has been analyzed by Wodeyar et al. (2017). The

study was confined to only 215 articles; however, the authors have emphasized his contributions in various journals, and some classic papers were analyzed in line with Scientometrics. Das and Bhattacharya (2021) conducted a scientometric study on the publications of Nobel Laureate Abhijit Vinayak Banerjee from 1987 to 2019. The study was based on the data available in the Google Scholar database. There were 333 documents, of which 35.74 percent were published as journal articles. Esther Duflo was the highly collaborated author with Abhijit Banerjee with 120 documents. As per the Google Scholar database, his h-index was 87 in May 2020.

It is noticed from the Literature survey that many studies have been conducted on individual scientists, especially in the fields like Chemistry, Physics, Medicine, etc. Still, no studies have been observed on AKS and his contributions to the Physical Sciences in India and elsewhere. Considering his contributions to the development of Science and Technology and through the literature, one can understand that conducting a Scientometrics study of AKS and his scientific contributions is appropriate.

3. BRIEF BIOGRAPHY OF DR. AJAY KUMAR SOOD

AKS is a renowned Indian physicist and researcher. AKS was born in Gwalior on June 26, 1951, to Ishwar Singh Sood and Smt. Bimla Devi Sood. His schooling was at the Government School Delhi from 1957 to 1961, Ramjas Higher Secondary School, Delhi from 1962 to 1964, and Sain Das Highers Secondary School, Jalandhar from 1965 to 1967. He received his B.Sc. and M.Sc. degrees from Punjab University, Chandigarh in 1971 and 1972 respectively. He was awarded a Ph.D. from the Indian Institute of Science (IISc), Bengaluru, in 1982 under the supervision of Dr. G. Venkataraman and P.S. Narayanan. He did his postdoctoral research at the Max-Planck Institute in Stuttgart with Prof. M Cardon (1983-1985). He worked as a Scientific Officer at the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, from 1974 to 1988. He joined as an Associate Professor at the Indian Institute of Science (IISc), Bangalore 1988. During his three decades of association with IISc, he served in various capacities, including Chairman of the Department of Physical and Mathematical Sciences (1998-2008) (Sushil Kumar et al., 1992).

AKS served as the President of the Indian Academy of Sciences (IASc), Bengaluru, from 2010 to 2012; in 2015, he was elected as a fellow of the Royal Society (FRS) London. He was the President of the Indian National Science Academy, New Delhi, and Secretary-General of TWAS (2013-2018). AKS is an elected Fellow of all three National Science Academies in India and the World Academy of Sciences (TWAS).

Awards and Honours

AKS has been honoured with many prestigious awards, which include

1. S.S. Bhatnagar Award (1990)
2. The World Academy of Science (TWAS) prize (2000)
3. G.D. Birla Science Award (2000)
4. Materials Research Society (India) Medal (2000)
5. Millennium Gold Medal of Indian Science Congress (2000)
6. Bhabha Medal of INSA (Indian National Science Academy) (2002)
7. M.N. Saha Birth Centenary Award of the Indian Science Congress (2003-2004)
8. Sir C.V. Raman Award (2003)
9. Goyal Prize (2003)
10. National Award in Nanoscience and Nanotechnology, DST (Department of Science and Technology) (2006)
11. Bhatnagar Fellowship of CSIR (Council of Scientific and Industrial Research) (2007)
12. G.M. Modi Award (2012)
13. Padma Shri, Govt. of India (2013)
14. R D Birla Award for Excellence in Physics by IPA (Indian Physics Association) (2014)
15. Life Time Achievement Award by Optical Society of India (2016)
16. Distinguished Alumnus Award of IISc (Indian Institute of Science) (2016)
17. MRSI (Materials Research Society of India) Distinguished Material Scientist of the Year (2016).

Dr. Ajay Kumar Sood at the national level

AKS was a member of

1. Scientific Advisory Council to the Prime Minister of India (2009-2014)
2. Member, Science and Engineering Research Board (SERB) (2012-2014)
3. Nano Mission Council of DST, Chairman, Nano Science Advisory Group of DST

4. Board of Governors of the Academy of Scientific and Innovative Research (AcSIR)
5. Governing Body and the Society of the CSIR (2013-2016), and
6. Prof. Sood was the Chairman of the Council Raman Research Institute (2016-2022)

4. OBJECTIVES OF THE STUDY

The main objective of the study is to provide the Scientometric portrait of Dr. Ajay Kumar Sood. The Specific objectives of the study are to:

1. study the year-wise distribution of publications of Ajay Kumar Sood;
2. find the author's productivity and authorship pattern;
3. identify the publication patterns according to age;
4. Analyse and compare AKS's Degree of Collaboration (DC), Collaborative Coefficient, and Modified Collaborative Co-efficient.
5. find out the collaborators of AKS;
6. Identify the core journals preferred by AKS;

5. SIGNIFICANCE OF THE STUDY

Several scientometric studies appeared in the literature of individual scientists or researchers. However, this study is unique for the Indian scientific community for discovering the phenomenon named the 'Sood Effect' and many other scientific innovations after his name. The study identifies the impact of his research on the scientific community and as a teacher-cum-leader in training generations. This type of scientific portrait study has shown that the publication list of successful scientists can be scientifically analyzed and shed light on the history of science, scientific development, interaction among the research peers, and the quality of scientific leadership in disseminating research results. The present study on AKS and his publications will help us to know the pattern of publications, collaborative studies, and his role in advancing science and technology in India and elsewhere.

6. METHODOLOGY

Scientific publications provide the best basis for measuring research output. This study intends to measure the research productivity of AKS. A complete list of research publications from 1974 to 2021 was compiled from two sources, i.e., the Web of Science database and the latest resume of AKS. There were 455 publications. Many scientific indicators were used to analyze the data to meet the study's objectives statistically.

7. SCOPE AND LIMITATIONS OF THE STUDY

The present study aims to trace and present the scientific research output of AKS, limited to published research data for 47 years, i.e., from 1974 to 2021. 497 publications appeared during the study period, including articles, conference papers, books/book chapters, editorials, etc., but the study was limited to only 455 journal articles.

8. RESULTS AND DISCUSSION

As observed from the data, AKS had 497 publications, including 455 journal articles (91.55%), 19 conference proceedings (3.82%), eight editorials (1.61%), five book/book chapters (1.01%), four review articles (0.80%), and 3(0.60%) letters and notes respectively. The results show that over 95% of the publications are journal articles and conference proceedings. As the Scope and Limitations section mentioned, the study was limited to journal articles. The subsequent sections provide an analysis of 455 journal articles using different indicators.

Authorship Pattern

The authorship model reflects the collaboration between authors and determines single- and multi-authored publications. The collaboration in research is growing and varies from discipline to discipline, from one country to another, and sometimes within the discipline. These are studied in authorship patterns. There are several parameters devised and applied in scientometric studies. The first general and common characteristic of authorship studied is the number of single-author two, three, and multi-authored papers. So, this study also analyzes the data on single, two, three, and multi-authored papers. The study also measures the Degree of Collaboration and the Collaboration Coefficient.

Table 1: Authorship Pattern

APL	Year	Single and Multi-Authored Papers								MT	TP	AA
		1	2	3	4	5	6	7	8+			
1	1974		1	1						2	2	23
2	1976			1						1	1	25
3	1979		1	1						2	2	28
4	1980		2							2	2	29
5	1981		2		3					5	5	30
6	1983		2							2	2	32
7	1984		2	1	3		1			7	7	33
8	1985		1	4	5					10	10	34
9	1986		1	1						2	2	35
10	1987	1	1	1	2					4	5	36
11	1988			1	4	2	2	1		10	10	37
12	1989	1		1	3				2	6	7	38
13	1990			1	3				2	6	6	39
14	1991	1	1	1						2	3	40
15	1992			2	4	1	1	1		9	9	41
16	1993			1		2				3	3	42
17	1994		1	4	4	2	2		1	14	14	43
18	1995	1	6		3	1				10	11	44
19	1996	1	3	1	2	1			1	8	9	45
20	1997		1	1	2	1	1			6	6	46
21	1998		1	5	2			1		9	9	47
22	1999			2	1	1				4	4	48
23	2000			2	3	3			1	9	9	49
24	2001		1	2	3		1	1	2	10	10	50
25	2002		2	2	5	3	1			13	13	51
26	2003		1	2	4		1			8	8	52
27	2004	1	1	2	5	1			1	10	11	53
28	2005		1	8		6			1	16	16	54
29	2006		3	1	5	3	2	1	1	16	16	55
30	2007			4	8	3	4		2	21	21	56
31	2008		3	5	2	2	2	2	1	17	17	57
32	2009		1	3	6	3	4		1	18	18	58
33	2010		2	2	7	3	3	2	1	20	20	59
34	2011		3	4	2	4	2	1	2	18	18	60
35	2012		1		4	9	3	1	4	22	22	61
36	2013			1	6	2	4		1	14	14	62
37	2014		1		8	6	1			16	16	63
38	2015				5	1	2	1	2	11	11	64
39	2016			2	4	7	3	1	2	19	19	65
40	2017				4	4			1	9	9	66
41	2018			2	2	1	1	2	2	10	10	67
42	2019		1		6	2				9	9	68
43	2020		1	1	3	4	6	2	5	22	22	69
44	2021			1	5	2	3	2	4	17	17	70
		6	48	73	135	80	55	18	40	449	455	

(APL = Age of Productive Life; MT= Total of Multi Authored Papers; TP - Total Publications; AA - Biological Age of the Author)

As shown in Table - 1, AKS had published 455 articles with an average of 9 to 10 articles per year. The data indicate that AKS prefers publishing his works in collaboration rather than solo-authored publications. He published only six articles as a single author and 449 in collaboration. Among the multi-authored papers, AKS had 48 two-authored articles, 73 three-authored, 135 four-authored, and 80 five-authored articles. The articles with three, four, and five authors accounted for 288 of the 455 articles.

AKS had no publications during 1975, 1977, 1978, and 1982. The reason might be that it is a formative stage of his scientific career and sometimes the discoveries take longer. His peak productivity was in 2012 (age 61) and 2020 (age 69), with an output of 22 publications each, followed by 21 papers in 2009 (age 58), 20 papers in 2010 (age 59), and 19 papers in 2016 (age 65), these years are more productive. Thus,

his 58th to 69th years are the most effective. These formative years saw the publication of 104 newspapers.

Authorship Status

For any researcher, authorship status varies from paper to paper. In some papers, an individual may be the first author, second, third, fourth, and so on. AKS's authorship status is shown in Table 3. AKS was the first author of 38 papers and the second of 93 papers. AKS stands third and fourth and has published 82 papers. He was the fifth author out of 75 papers, sixth out of 40 papers, seventh out of 15 papers, and eighth out of 30 papers. Collaborators, who are the first authors, where AKS was the second author, are listed in Table 4. The authorship status among the core collaborators is documented in Table 2.

Table 2: Position of the Author

No. of Authors	Position of Author								Total
	1st aut	2nd aut	3rd aut	4th aut	5th aut	6th aut	7th aut	8th aut	
Single Authored	6	-	-	-	-	-	-	-	6
2-authored	8	40	-	-	-	-	-	-	48
3-authored	10	23	40	-	-	-	-	-	73
4-authored	9	21	33	72	-	-	-	-	135
5-authored	2	3	6	7	62	-	-	-	80
6-authored	1	4	1	3	10	35	-	-	54
7-authored	2	1	1	-	2	2	11	-	19
8 and above authored	-	1	1	-	1	2	5	30	40
Total	38	93	82	82	75	39	16	30	455

Table 3: Collaborators of AKS

Collaborating Paper	Name of Collaborator with No. of papers	Total
2-authored	Sanyal Subrata (6), Bandyopadhyay Ranjini (4), Sayantan Majumdar (4), Dattagupta S (3), Anushree Roy (2), Roy A(2), Debendranath Sahoo (3), Ganapathy R (3), Manas Khan (3), Ajay Singh Negi (1), Anindya Das (1), Bera Pradeep K (1), Chandrabhas N (1), Deb S.K (1), Kar Srabani (1), Polla D.L (1), Rema Krishnaswamy (1), Sengupta S (1), Sharma A.C (1)	40
3-authored	Kanakaraju S (3), Contreras G (2), Ghosh Shankar (2), Rojo A.G (2), Arora P (1), Bulbul Chakraborty (1), Chakrabarti J (1), Chandan K. Mishra (1), Das Chinmay (1), Ganapathy R (1), Guisheng Pan (1), Bansal, M.L. (1), Navneet Singh (1), Seikh M.M (1), Shreyas Gokhale (1), T.A.Al-Dhahir (1), Tata B.V.R. (1), Vernon N. Goetz (1)	23
4-authored	G. Contreras (1), K. Aoki (1), G. A. Kourouklis (1),W Kauschke (1), R Kesavamoorthy (1), C S Sundar (1), B.N. Meera (1), Subrata Sanyal (1),V. S. D. Muthu (1), Rajeev Gupta (1), R K Yadav (1), R. Arvind Singh (1), P.V.Teredesai (1), Rajeev Gupta (1), Janhavi P. Joshi (1), S. Ghosh (1), Manas Khan (1), S.Mruthinti (1), Manas Khan (1), C. N. R. Rao (1), C.S. Sundar (1)	21
5-authored	P. V. Santos (1), Pallavi V Teredesai (1), Anindya Dasa (1)	3
6-authored	N Chandrabhas (1), P. V. Teredesai (1), Manas Khan (1), Anindya Das (1)	4
7-authored	Jin Wang (1)	1
8 and autho	N Chandrabhas (1)	1

Measures of Collaboration

To Measure the authorship career, the following indicators were used: Degree of Collaboration (DC) given by Subramanyam in 1983 and Collaborative Co-efficient (CC) by Ajiferuke in 1988.

I. Degree of Collaboration

$$DC = \frac{Nm}{Nm + Ns}$$

Where DC= Degree of Collaboration
NM= Number of Multi-Authored Publications
Ns= Number of Single Authored Publications

II. Collaborative Coefficient

$$CC(CC) = 1 - \frac{\sum_{j-1}^{k} \binom{1}{j} fj}{N}$$

Where F1 Represents Single Authored Publications
F2 Represents Multi-Authored Publications
N Is the Total Number of Publications

Collaboration Rate

The collaboration rate is the ratio between collaborative papers and the total number of articles published in a particular year or for a specific period. AKS had only six single-authored papers, published in 1987, 1989, 1991, 1995, 1996, and 2004 respectively. He had 449 multi-authored papers, and the overall collaboration rate was 0.99. The lowest collaboration rate was found in 1991 (0.67) and 1987 (0.80). AKS had a 1.00 collaboration rate throughout his career, except for a few years. He has always supported the younger generation; as a result, most of his publications are collaborative works. The Collaborative Coefficient (CC) for AKS's research publications was 0.7345, and Modified Collaborative Co-efficient (MCC) was 0.7361.

Table 4: Degree of Collaboration

Year	MT	TP	Degree of Collaboration
1974	2	2	1.00
1976	1	1	1.00
1979	2	2	1.00
1980	2	2	1.00
1981	5	5	1.00
1983	2	2	1.00
1984	7	7	1.00
1985	10	10	1.00
1986	2	2	1.00
1987	4	5	0.80
1988	10	10	1.00
1989	6	7	0.86
1990	6	6	1.00
1991	2	3	0.67
1992	9	9	1.00
1993	3	3	1.00
1994	14	14	1.00
1995	10	11	0.91
1996	8	9	0.89
1997	6	6	1.00
1998	9	9	1.00
1999	4	4	1.00
2000	9	9	1.00
2001	10	10	1.00
2002	13	13	1.00
2003	8	8	1.00
2004	10	11	0.91
2005	16	16	1.00
2006	16	16	1.00
2007	21	21	1.00
2008	17	17	1.00
2009	18	18	1.00
2010	20	20	1.00
2011	18	18	1.00
2012	22	22	1.00
2013	14	14	1.00
2014	16	16	1.00
2015	11	11	1.00
2016	19	19	1.00
2017	9	9	1.00
2018	10	10	1.00
2019	9	9	1.00
2020	22	22	1.00
2021	17	17	1.00
	449	**455**	0.99

Table 5: Collaboration Coefficient

Year	Single and Multi-Authored Papers								TP	CC	MCC
	1	2	3	4	5	6	7	8+			
1974	0	1	1	0	0	0	0	0	2	0.9982	1.0004
1976	0	0	1	0	0	0	0	0	1	0.9993	1.0015
1979	0	1	1	0	0	0	0	0	2	0.9982	1.0004
1980	0	2	0	0	0	0	0	0	2	0.9978	1.0000
1981	0	2	0	3	0	0	0	0	5	0.9962	0.9983
1983	0	2	0	0	0	0	0	0	2	0.9978	1.0000
1984	0	2	1	3	0	1	0	0	7	0.9951	0.9972
1985	0	1	4	5	0	0	0	0	10	0.9932	0.9954
1986	0	1	1	0	0	0	0	0	2	0.9982	1.0004
1987	1	1	1	2	0	0	0	0	5	0.9949	0.9971
1988	0	0	1	4	2	2	1	0	10	0.9951	0.9973
1989	1	0	1	3	0	0	0	2	7	0.9949	0.9971
1990	0	0	1	3	0	0	0	2	6	0.9971	0.9993
1991	1	1	1	0	0	0	0	0	3	0.9960	0.9982
1992	0	0	2	4	1	1	1	0	9	0.9952	0.9974
1993	0	0	0	1	2	0	0	0	3	0.9986	1.0008
1994	0	1	4	4	2	2	0	1	14	0.9919	0.9941
1995	1	6	0	3	1	0	0	0	11	0.9891	0.9913
1996	1	3	1	2	1	0	0	1	9	0.9920	0.9941
1997	0	1	1	2	1	1	0	0	6	0.9963	0.9985
1998	0	1	5	2	0	0	1	0	9	0.9938	0.9960
1999	0	0	2	1	1	0	0	0	4	0.9975	0.9997
2000	0	0	2	3	3	0	0	1	9	0.9953	0.9975
2001	0	1	2	3	0	1	1	2	10	0.9946	0.9967
2002	0	2	2	5	3	1	0	0	13	0.9919	0.9941
2003	0	1	2	4	0	1	0	0	8	0.9949	0.9971
2004	1	1	2	5	1	0	0	1	11	0.9918	0.9940
2005	0	1	8	0	6	0	0	1	16	0.9901	0.9923
2006	0	3	1	5	3	2	1	1	16	0.9906	0.9928
2007	0	0	4	8	3	4	0	2	21	0.9893	0.9915
2008	0	3	5	2	2	2	2	1	17	0.9894	0.9916
2009	0	1	3	6	3	4	0	1	18	0.9903	0.9925
2010	0	2	2	7	3	4	1	1	20	0.9891	0.9913
2011	0	3	4	2	4	2	1	2	18	0.9893	0.9915
2012	0	1		4	9	3	1	4	22	0.9902	0.9924
2013	0	0	1	6	2	4	0	1	14	0.9934	0.9955
2014	0	1	0	8	6	1	0	0	16	0.9915	0.9937
2015	0	0	0	5	1	2	1	2	11	0.9952	0.9974
2016	0	0	2	4	7	3	1	2	19	0.9913	0.9935
2017	0	0	0	0	4	4	0	1	9	0.9965	0.9987
2018	0	0	2	2	1	1	2	2	10	0.9955	0.9976
2019	0	1	0	6	2	0	0	0	9	0.9947	0.9969
2020	0	1	1	3	4	6	2	5	22	0.9906	0.9927
2021	0	0	1	5	2	3	2	4	17	0.9928	0.9950
	6	**48**	**73**	**135**	**80**	**55**	**18**	**40**	**455**	**0.7345**	**0.7361**

Relative Growth Rate (RGR) and Doubling Time (Dt.) of Publications

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The Relative Growth Rate (RGR) is the increase in the number of articles per unit of time. It is also called the Exponential Growth Rate or the continuous Growth Rate. The growth of publications of an individual or institution could be measured by calculating the RGR. The following equation widely calculates the RGR over a specific time interval.

$$RGR = \frac{\log_{e2} W - \log_{e1} W}{2T - 1T}$$

Where,

RGR = Relative Growth Rate of publications over a specific period
Loge1 W = Log of the preceding number of publication
Loge2 W = Log of the following number of publication
2T-1T = the unit difference of period between the initial and final year

Doubling Time (Dt.)

Doubling time (Dt.) is the time that takes for a population to double in size/value. Doubling time could measure the growth pattern of any field, for instance, population growth, inflation, resource extraction, consumption of goods, and several other things that are inclined to grow over time. Samuel C. Bradford assumes that there will be a direct similarity between the relative growth rate and the doubling time if a subject's number of articles/pages doubles during a given period. The difference between the logarithms of numbers at the beginning and end of the period must be the logarithms of number 2. If a natural logarithm is used, this difference has a value of 0.693. The doubling time measures the relative growth rate. It refers to the ratio between the value of natural logarithms of 2, i.e., Loge 2 =0.693, and RGR. Thus, the corresponding doubling time for each specific period of interval and both articles and pages can be calculated by the formula –

Doubling time (Dt.) = 0.693/RGR

Table 5 shows AKS's research productivity. The study indicates that the value of the Relative Growth Rate (RGR) of publications was high in the year 2004 (0.77), followed by 2002 (0.70). The RGR declined from 0.77 in 2004 to 0.03 in 2020. At the same time, the value of Doubling Time (Dt.) amplified from 0.89 in 2004 to 99.67 in 2019. It is evident from the analysis that the articles published by AKS have

grown over time. The study indicates that the RGR value of publications was highest in 1981 (0.54), followed by 1979 (0.51), and 1976 and 1984 recorded 0.41, respectively. The Doubling Time value (Dt.) has been enhanced from 0.00 in 1974 to 31.22 in 2019. It is clear from the analysis that the articles published by AKS have grown over time.

Table 6: Relative Growth Rate and Doubling Time

Year	No of Papers	Cumulative No. of Papers	log W1	log W2	RGR	Doubling Time
1974	2	2	0.00	0.69	0.00	0.00
1975	-	2	0.69	0.69	0.00	0.00
1976	1	3	0.69	1.10	0.41	1.71
1977	-	3	1.10	1.10	0.00	0.00
1978	-	3	1.10	1.10	0.00	0.00
1979	2	5	1.10	1.61	0.51	1.36
1980	2	7	1.61	1.95	0.34	2.06
1981	5	12	1.95	2.48	0.54	1.29
1982	-	12	2.48	2.48	0.00	0.00
1983	2	14	2.48	2.64	0.15	4.50
1984	7	21	2.64	3.04	0.41	1.71
1985	10	31	3.04	3.43	0.39	1.78
1986	2	33	3.43	3.50	0.06	11.08
1987	5	38	3.50	3.64	0.14	4.91
1988	10	48	3.64	3.87	0.23	2.97
1989	7	55	3.87	4.01	0.14	5.09
1990	6	61	4.01	4.11	0.10	6.69
1991	3	64	4.11	4.16	0.05	14.43
1992	9	73	4.16	4.29	0.13	5.27
1993	3	76	4.29	4.33	0.04	17.21
1994	14	90	4.33	4.50	0.17	4.10
1995	11	101	4.50	4.62	0.12	6.01
1996	9	110	4.62	4.70	0.09	8.12
1997	6	116	4.70	4.75	0.05	13.05
1998	9	125	4.75	4.83	0.07	9.27
1999	4	129	4.83	4.86	0.03	22.00
2000	9	138	4.86	4.93	0.07	10.28
2001	10	148	4.93	5.00	0.07	9.91
2002	13	161	5.00	5.08	0.08	8.23
2003	8	169	5.08	5.13	0.05	14.29
2004	11	180	5.13	5.19	0.06	10.99
2005	16	196	5.19	5.28	0.09	8.14
2006	16	212	5.28	5.36	0.08	8.83
2007	21	233	5.36	5.45	0.09	7.34
2008	17	250	5.45	5.52	0.07	9.84
2009	18	268	5.52	5.59	0.07	9.97
2010	20	288	5.59	5.66	0.07	9.63
2011	18	306	5.66	5.72	0.06	11.43
2012	22	328	5.72	5.79	0.07	9.98
2013	14	342	5.79	5.83	0.04	16.58
2014	16	358	5.83	5.88	0.05	15.16
2015	11	369	5.88	5.91	0.03	22.90
2016	19	388	5.91	5.96	0.05	13.80
2017	9	397	5.96	5.98	0.02	30.22
2018	10	407	5.98	6.01	0.02	27.86

2019	9	416	6.01	6.03	0.02	31.68
2020	22	438	6.03	6.08	0.05	13.45
2021	17	455	6.08	6.12	0.04	18.20

Table 7: Channels of Communication

Rank	Title	No. of Papers	Cumulative No. of Papers	FPY-LPY	Impact Factor
1	Physical Review B - Condensed Matter and Materials Physics	60	60	1985-2021	3.908
2	Solid State Communications	24	84	1984-2021	1.804
3	Physical Review E	22	106	1993-2020	2.707
4	Physical Review Letters	23	129	1985-2020	9.185
5	Pramana	22	151	1979-2012	1.688
6	Journal of Physics-Condensed Matter	17	168	1994-2020	2.745
7	Europhysics Letters	16	184	1988-2017	1.958
8	Applied Physics Letters	13	197	1989-2016	3.971
9	Chemical Physics Letters	13	210	1992-2010	2.328
10	Journal of Applied Physics	13	223	1980-2014	2.877

Channels of Communication

The research communication medium is essential in conveying information to the scientific community or the public. Journals are the primary information source frequently searched by users to get updated information published in their domain areas. AKS has considered journal articles as the main channels of communication documents for his publications. He has a distribution of 455 publications in 120 journals. The top ten journal-wise scattering of AKS's publications is provided in Table 5. Top-ranked journals with many publications are *Physical Review B* (60), *Solid State Communications* (24), *Physical Review E* (22), *Physical Review Letters* (23), *Pramana* (22), *Journal of Physics-Condensed Matter* (17), *Europhysics Letters* (16), *Applied Physics Letters* (13), *Chemical Physics Letters* (13) and *Journal of Applied Physics* (13). In a multidisciplinary journal, *Physical Review Letters* has a very high impact factor, and he has published 23 articles.

9. CONCLUSION AND SUGGESTIONS

AKS, a physicist, is known for pioneering graphene and nanotechnology research. He has published more than 455 scientific papers and holds seven patents. From the study, it is inferred that AKS's publication productivity has constant growth with an average of 9 to 10 publications per year throughout his productive period; Journal Articles were the most common document type in publications. AKS has always supported the younger generation; as a result, most of his works are published collaboratively, which can be observed in the authorship pattern discussed in this study. *Physical Review B* was the most preferred journal by AKS, having an impact factor of 3.908 with 60 articles.

The analysis also highlights his contributions to Science and Technology in India and elsewhere. His discovery of the 'Sood Effect' made a distinctive contribution to Physics. It influences many researchers to study its application in many disciplines. AKS is undoubtedly a role model to the younger generation. Further, it is suggested that a citation analysis of his publications may be undertaken to assess the impact of his research.

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