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REVIEW PAPER

Scientometric Analysis of Literature Output of Prof. G.N. Ramachandran in the Subjects of Biophysics and Crystallography

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ABSTRACT

The study is a bibliometric analysis of remarkable contributions of Prof. G.N. Ramachandran (popularly known as GNR), an eminent biophysicst and crystallographer. It is necessary to review the contributions made by renowned Indian scientists so as to understand the nature and magnitudes of their contributions to a particular field of study. The paper examines the contributions of GNR in the fields of biophysics and crystallography, magnitude of his collaborations, and year-wise distribution of his productivity.

Keywords: Scientometrics, Bio-scientrometrics, collaboration coefficient, GNR productivity ratio, GNR- Biophysics

1. INTRODUCTION

Research is an important aspect for the development of a nation. The research output of a nation is a yardstick to measure its socio-economic and educational status. There are a number of ways to measure the quantity and quality of the research output of the country and even the contributions of an individual. The measurement in the field of library and information science (LIS) is known as bibliometric analysis. It is interesting to note that during the last few years, bibliometric analysis has been increasingly used to evaluate the research performance of the scientists and the growth of various disciplines of science. The analysis has also been used to evaluate the research output of many leading scientists of world reputations. Before this, it is important to understand the meaning of bibliometrics. Some of the popular definitions of bibliometrics are:

Pritchard[1] coined the term 'bibliometrics' and defined it as "The application of mathematical and statistical methods to books and other media of communication". Fairthorne[2] defined bibliometric as: "The quantitative treatment of the properties of recorded discourse and behaviour pertaining to it".

The British Standard Glossary of Documentation of Terms[3] explained bibliometrics as " the study of the use of documents and patterns of publication in which mathematical and statistical methods have been applied."

This is basically similar to Pritchard's definition. Instead of the term bibliometry, the Russians, in late sixties, used the term scientometry and since than the terms like Librametrics, Bibliometrics, Informetrics, and Scientometrics have been used synonymously to study the growth of literature in a discipline, and other aspects of literature quantitatively. But scientometirc analysis is confined to quantitative aspects of science and technology disciplines. Further, scientometric could be used for identification of emerging research areas. Scientometric analysis throws light on the pattern of growth of individual to the respective science and technology subject, inter-relationship among different branches of knowledge, productivity, authorship pattern, degree of collaboration, pattern of collection building, and their use.

Sengupta[4] viewed scientometric as "Organisation, classification and quantitative evaluation of publication patterns of all macro and micro communications along with their authorship by mathematical and statistical calculus."

Broadus[5] presented a historical overview of various definitions of scientometric and proposed an alternate

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definition. According to him, "Scientometric is the quantitative study of physical published units or of bibliographic units or of surrogates of either." Besides, scientometric analysis aims to integrate the cognitive or intellectual structure of research with a view to appraise the relations among the authors, institutions, journal articles, and as a means of assisting the peer-review procedure. This study aims to apply the scientometric analysis of the literature output of Indian biophysicst and crystallography Legend Prof. GNRamachandran as a tribute to him as well as to focus on the meticulous and commendable works done by the great Indian genius when the Indian research infrastructure was at infantile stage.

2. BIOGRAPHICAL SKETCH OF PROF. RAMACHANDRAN

Prof. G.N. Ramachandran ('G' stands for Gopalasamudram, his native town, and 'N' stands for Narayana Iyer, the name of his father) was born on 8 October 1922 in a small town near Cochin, Kerala[6-7]. His father was a Professor of Mathematics at a local college. He was a meritorious student during his under and postgraduation. His academic thirst was induced by the legendary Sir C.V. Raman when he joined as a student of Physics under him (Raman) and eventually became his most distinguished student. At Indian Institute of Science (IISc), Bengaluru, he first submitted thesis entitled, 'Optics of Heterogeneous Media' for his MSc degree and later a doctoral thesis in 1947, which contained some of the earliest applications of x-ray diffraction for the study of crystal perfection. He spent two years in Cambridge, obtained a PhD degree working with W.A. Wooster and returned to Bengaluru in 1949 to began an independent career as Assistant Professor of Physics, working in the x-ray diffraction laboratory. He did not stay there long and moved to the prestigious south Indian university, University of Madras, which is also known as mother of almost all south Indian universities.

Madras University beckoned him Professorship and the responsibility to head the Department of Physics. When Ramachandran moved to Madras, he was just 30. At Madras, he flourished under the benign and supportive influence of an enlightened Vice-Chancellor, A. Lakshmanaswamy Mudaliar. In 1954 and 1955, the triple helix structure and Ramachandran plot and collagen structure were published in two papers in *Nature*, introducing the coil concept, a fundamental advance in the understanding of polypeptide structures. This was undoubtedly Ramachandran's finest contribution to structural biology. Ramachandran later introduced Biophysics and crystallography in the University of Madras. Ramachandran, along with his colleagues, published series of research articles, both in reputed national and international journals. One such article laid the foundation for the conformational analysis of polypeptide chains. This seminal paper circumspectly titled 'Stereochemistry of polypeptide chain configurations' was published in the *Journal of Molecular Biology* in 1963, and introduced the famous two-dimensional map, which was called Ramachandran Map. This map was fundamental research output and is still used by students of biochemistry and biophysics.

During the period of 1960 and 1970, he published a number of articles, which addressed key issues in the structural chemistry of proteins and peptides; chain reversals, *cis*-peptide bonds, hydrogen bonding, non-planar amide distortions, and novel helices in poly-peptides with alternating L and D-residues. Many of his research works were on polypeptide stereochemistry. He also published a book titled, 'Fourier Methods in Crystallography' on x-ray crystallography and Fourier methods. Ramachandran's paper titled, 'A new method for the structure analysis of non-centrosymmetric crystals' promoted the use of anomalous scattering for solving the crystallographic phase problem. In 1971, Ramachandran, together with Lakshminarayanan, published a key paper on three-dimensional image reconstruction, which later had important applications in computer-assisted tomography. Ramachandran was the editor of *Current Science* from 1950 to 1957. In this reputed journal, he published several excellent papers, notably his work on the x-ray topographs of diamond and anomalous dispersion. In 1990, to show tribute to GNR, *Current Science* highlighted his contributions to polypeptide stereochemistry in a special issue. For his outstanding contributions, Prof. Ramachandran was awarded *Ewald Prize* of the International Union of Crystallography.

Professor Ramachandran organised two notable International Conferences on Molecular Biology and Biophysics in 1963 and 1968, which were attended by some of the most famous names like Linus Pauling, Severo Ochoa, Maurice Wilkins, Stanford Moore, David Phillips, Ephraim Katchalski, Harold Scheraga, Paul Flory, Elkan Blout, and John Schellman. following the footsteps of his mentor C.V. Raman. Following the footsteps of his mentor C.V. Raman, he did all his research work in India only. Prof. Ramachandran set up the Molecular Biophysics Unit at IISc in 1971. During 1971 and 1979, Ramachandran fashioned a new department, which has now grown into a major centre of Structural Biology. He was an extraordinarily gifted individual, but he spent his last years in trouble. A stroke and the steady onset of Parkinson disease greatly reduced his movements and activities. Since August 1999, he was under nursing care in a hospital in Chennai until his death due to cardiac arrest in early April 2001.

3. OBJECTIVES OF THE STUDY

- To examine the contributions of Prof. G.N. Ramachandran in the field of biophysics and crystallography.
- To measure and compare the growth rate of his research contributions.
- To analyse the authorship patterns of his research contributions.
- To examine the extent of collaborative research he made with other eminent scientists.
- To study the year-wise distribution of his research productivity during his active research life.

4. LIMITATIONS

This study is confined to the list of publications provided in his *curriculum vitae* on the Internet under the name of Prof. G.N. Ramachandran. It is hoped that we have focused his entire research output.

5. REVIEW OF RELATED LITERATURE

Though there are countless number of articles available on scientometrics, a review of closely related literature is presented. Kalyane and Devarai[8] studied the works of C.S. Venkata Ram, which revealed solo research authorship pattern.

Kalyane and Samanta[9] have done a scientometrics study of articles published by K. Ramaiah, an agricultural scientist from India, which throws light on history of science, scientific development, interaction within a research group and organisation of reseaerch systems. While some contributions are based on solo research, many represent multiple authorship.

Another study by Kalyane and Sen[10] reflects the contributions by Nobel laureate Pierre-Gilles de Gennes published during 1956-1995, which reveals that scattering of publications did not follow Bradford's Law, but assumptions formed about author's productivity were to be more or less correct. The honours and awards received by scientists tend to attract more collaborators and increase the productivity of the awarded scientists.

Kulkarni[11] analysed the works of M.V. Bhole, a pioneer on Yoga, who contributed 147 articles during 1965-1995. The study revealed that about 60 per cent of his contributions were based on collaborative research and did not confined to one type of research.

A similar study was conducted by Vijay Kumar, Kalyane, and Kademani[12] on the publications of Ahmed Hassan Zewail, Nobel laureate in Chemistry, who had collaborated with one or two colleagues and published 246 papers during 1976-1994.

6. METHODOLOGY

6.1 Data Collection

The information was mainly collected from the *curriculum vitae* of Prof. Ramachandran, which included the list of his publications from web resources and the data available in the University of Madras. Besides, information in his biographical details appeared in the peer-reviewed journals like *Current Science* and *Nature,* was also considered.

6.2 Data Analysis

For analysis, Fox Pro database software was used to classify and quantify the extracted data from web resources. In addition to the frequency distribution and percentage analyses, the following statistical tools and bibliometric indicators were employed during analysis and interpretation of data. For analysis of data, the following methods given by Lancaster[6], Leydesdroff[7], Kalyane[8] Sen and Gan[13], were used:

- Authorship pattern.
- Collaboration coefficient.
- Fifty percentile age.
- Productivity coefficient.
- Core collaborators.
- Productivity life.

7. DATA ANALYSIS AND INTERPRETATION

7.1 Contributions of Prof. Ramachandran

From the available resources it was found that Prof. Ramachandran published 304 publications during his life time. Among these publications, the journal articles constituted more than 60 per cent (184) followed by mathematical philosophy reports (77) that constituted 25 per cent of his publications. Remaining were book articles (21), conference and symposium articles (9), one book, seven edited books, and five monographs and reviews. Thus, altogether he contributed 214 articles in the field of biophysics and crystallography.

7.2 Authorship Pattern of the Articles

Based on his 214 published articles, further evaluations were made to know the percentage of articles he published in individual capacity and in

collaboration. It was found that 35.51 per cent (76 articles) were contributed in his individual capacity, 108 articles (50.46 per cent) with one joint author, and 21(9.81 per cent) with three joint authors. Thus, nearly 64.49 per cent of his contributions were of collaborative nature. Besides, four per cent of his articles were with four and more authors. This analysis reveals that collaborative research predominated Prof. Ramachandran contributions (Table 1). The ratio of collaboration is 1:1.51, which indicates that the collaborative output is dominant over his individual output.

7.3 Collaboration Coefficient

To analyse the pattern of co-authorship, the contributions of GNR, among Indian and foreign authors were divided into single, two, and more than two authors for each country. The patterns of co-authorship among Indian and foreign authors have been examined using Collaborative Coefficient (CC) suggested by Ajiferuke. Accordingly, the CC has been calculated as:

$$CC = 1 - [\Sigma(1/j)Fj/N]$$

where

Fj = the number of authored papers; N = total number of research published; and j = the greatest number of authors per paper. The CC for Prof. Ramachandran is 0.48, which is less than 0.50. The dearth of collaboration is comparatively less with foreign authors and more with Indian authors.

7.4 Year-wise Frequency of Publications

The year-wise distribution of Prof. Ramachandran contribution is shown in Table 2. He made contributions throughout his life, except in 1977, 1983-85, 1987, and 1989.

7.5 Productive Life

Prof. Ramachandran published 214 research papers in the Journals (124); books (21), and in conferences and seminars (9) during the 48 years of his productive life. The productivity age, chronological age, and publication details are given in Table 3. His productivity age began in 1942 at his chronological age of 20 years. He has published highest number of research papers (13) during 1963 and 12 research papers each in 1965 and 1966 at the productivity age of 22, 24, and 25 years and chronological age of 41, 43, and 44, respectively. It can be seen that his productive interest continued even after his superannuating. At the productivity age of 22 and chorological age of 41, he attained 50 percentile age.

The productivity coefficient has been calculated using the formula

$$P_c = \frac{\text{Chronological age of last publication}}{\text{Chronological age of fifty percentage}}$$

The productive coefficient of Prof. Ramachandran is 1.0:1.7.

7.6 Peak Productivity Age

The contributions of Prof. Ramachandran are grouped into five blocked years and each block year comprises 10 years of chronological age as well as productivity age (Table 4). It shows that the peak productivity age of Prof. GNR lies between 21-30 and 40-49 in chronological age.

7.7 Average Yearly Contribution

During the productive age, Prof. Ramachandran's average yearly contribution has been calculated using the formula

$$Ay_c = \frac{\text{Total contribution}}{\text{Total productivity age}}$$

Ay_c of Prof. Ramachandran is 4.458. The result shows that on an average he contributed 4 to 5 papers in a year during 1942 to 1990.

Table 1. Collaboration ratio of Prof. G.N. Ramachandran Contributions

Description	First productive year	Last productive year	Authored by G.N.R. alone	With two authors	With three authors	With > four authors	Total	Multiple-authored papers
Total authorship	1942	1990	76	108	21	9	214	138
Percentage authorship			35.51	50.46	9.81	4.22	100	
Number of authors			76	20	37	24	141	91
Authorship per paper			1	5.4	0.56	0.38	1.51	1.51

Table 2. Year-wise distributions of G.N.R. publications

Year	No. of articles published	Percentage
1942	1	0.5
1943	6	2.8
1944	6	2.8
1945	3	1.4
1946	6	2.8
1947	9	4.2
1948	2	0.9
1949	3	1.4
1950	3	1.4
1951	10	4.7
1952	7	3.3
1953	2	0.9
1954	4	1.9
1955	7	3.3
1956	4	1.9
1957	5	2.3
1958	1	0.5
1959	2	0.9
1960	7	3.3
1961	6	2.8
1962	8	3.7
1963	13	6.1
1964	2	0.9
1965	12	5.6
1966	12	5.6
1967	7	3.3
1968	10	4.7
1969	4	1.9
1970	10	4.7
1971	8	3.7
1972	5	2.3
1973	7	3.3
1974	2	0.9
1975	4	1.9
1976	3	1.4
1978	2	0.9
1979	1	0.5
1980	2	0.9
1981	2	0.9
1982	2	0.9
1986	2	0.9
1988	1	0.5
1989	0	0.0
1990	1	0.5
Total	**214**	**100**

7.8 Authorship Collaboration Pattern

Prof. Ramachandran contributed 138 articles in collaboration with various scientists (Table 5). Table 5 shows that he collaborated with Prof. R. Srinivasan for 13 papers and with R. Chandrasekhar, A.V. Lakshmi Narayanan, and V. Sasisekaran for 11 papers each. He also collaborated with foreign scientists, namely, J.T. Edsall; P.J. Flory; J.C. Kendrew; A.M. Liquori; W.A. Wooster, etc. Prof. Ramachandran made 304 contributions during 1942-1990. Out of 304 publications, the journal articles constitute 61 per cent (184 articles) followed by mathematical philosophy reports (25 per cent).

8. MAJOR FINDINGS

8.1 Authorship Pattern

- About 35.51 per cent of the total contributions were solo research. In other words, collaborative research is dominated in the contribution of our protagonist.
- Authorship collaboration ratio, 1.00:1.51, indicates that collaboration is higher than the individual publications that too mostly with Indian authors.
- The collaboration coefficient, 0.48, is < 0.50. The dearth of collaboration is less with foreign authors.
- Authorship productivity coefficient is 1.0:1.7.
- Productivity age of G.N.R. started at 22 when his chronological age was 41 years.
- Peek productivity period of G.N.R. was 40-49 of his chronological age and 21-30 of his productivity age.
- Prof. G.N.R.'s popular collaborative author was Prof. R. Srinivasan (13 research papers).

8.2 Year-wise Contributions

- The publication trend of Prof. Ramachandran is more or less linear in nature.
- Highest number (13) research papers were published during 1963; 12 research papers were published in 1965 and 1966.
- On an average, Prof. Ramachandran contributed nearly 4 to 5 papers in a year during 1942-1990.
- Peek productivity of Prof. Ramachandran was during 1962-1971.

Table 3. Year-wise distribution of productivity of Prof. G.N. Ramachandran

Year	Total publications	Cumulative	Productivity age	Age of G.N.R.
1942	1	1	1	20
1943	6	7	2	21
1944	6	13	3	22
1945	3	16	4	23
1946	6	22	5	24
1947	9	31	6	25
1948	2	33	7	26
1949	3	36	8	27
1950	3	39	9	28
1951	10	49	10	29
1952	7	56	11	30
1953	2	58	12	31
1954	4	62	13	32
1955	7	69	14	33
1956	4	73	15	34
1957	5	78	16	35
1958	1	79	17	36
1959	2	81	18	37
1960	7	88	19	38
1961	6	94	20	39
1962	8	102	21	40
1963	13	115	22	41
1964	2	117	23	42
1965	12	129	24	43
1966	12	141	25	44
1967	7	148	26	45
1968	10	158	27	46
1969	4	162	28	47
1970	10	172	29	48
1971	8	180	30	49
1972	5	185	31	50
1973	7	192	32	51
1974	2	194	33	52
1975	4	198	34	53
1976	3	201	35	54
1978	2	203	37	56
1979	1	204	38	57
1980	2	206	39	58
1981	2	208	40	59
1982	2	210	41	60
1986	2	212	45	64
1988	1	213	47	66
1990	1	214	49	68
Total	**214**			

Table 4. Contributions of Prof. Ramachandran in block years

Productive age	Chronological age	Year	No. of contributions	Percentage
1-10	20-29	1942-1951	39	18.22
11-20	30-39	1952-1961	55	25.71
21-30	40-49	1962-1971	86	40.18
31-40	50-59	1972-1981	28	13.08
41-48	60-68	1981-1990	6	2.81
			214	100

Table 5. Contribution of Prof. Ramachandran with other authors

Name of authors who have done collaborative publications with G.N.R.	Single author	Two authors	Three authors	Four authors	Five authors	Six authors	Total
G.N. Ramachandran	108	21	2	2	1	4	138
Srinivasan, R.	4	6	2	1	-	-	13
Chandrasekhar, R.	3	8	-	-	-	-	11
Lakshmi Narayanan, A.V.	-	9	1	1	-	-	11
Sasisekaran, V.	-	9	1	1	-	-	11
Ramakrishnan, C.	1	3	4	1	-	-	9
Bamsal, M	1	5	-	-	-	-	6
Kartha, G.	2	4	-	-	-	-	6
Kollaskar, A.S.	-	3	3	-	-	-	6
Parthasarathy, S.	4	1	-	-	-	-	5
Venkatachalam, C.M.	-	4	1	-	-	-	5
Wooster, W.A.	-	5	-	-	-	-	5
Balasubramamia, R	1	2	1	-	-	-	4
Chidambaram, R.	1	-	3	-	-	-	4
Chandrasekaran, V.	-	4	-	-	-	-	4
Edsall	3	-	-	-	-	-	3
Flory	-	3	-	-	-	-	3
Kendrew, J.C.	-	-	3	-	-	-	3
Liquori, A.M	-	-	-	3	-	-	3
Nemethy, G.	-	-	-	-	3	-	3
Parthasarathy, R.	1	2	-	-	-	-	3
Raman, S.	1	2	-	-	-	-	3
Ramaseshan, S.	1	2	-	-	-	-	3
Sarathy, K.P.	1	2	-	-	-	-	3
Santhanam, M.S.	-	2	1	-	-	-	3
Venketesan, K.	-	-	1	-	1	1	3
Ambaby	-	2	-	-	-	-	2
Chandrasekaran, K.S.	-	1	1	-	-	-	2
Leelavathi	-	1	1	-	-	-	2
Lang, A	-	-	2	-	-	-	2
Mazumdar	-	1	1	-	-	-	2
Radhakrishnan, A.	-	2	-	-	-	-	2
Sharma, R.	-	1	1	-	-	-	2
Tegori, G.	-	-	-	2	-	-	2
Amrithalingam	1	-	-	-	-	-	1
Bhatanagar, R.S.	-	-	1	-	-	-	1
Dowj	1	-	-	-	-	-	1
Doyle, B.B.	-	1	-	-	-	-	1

Name of authors who have done collaborative contributions with G.N.R.	Single author	Two authors	Three authors	Four authors	Five authors	Six authors	Total
Hirsch, P.B.	1	-	-	-	-	-	1
Jensen, L.H.	-	1	-	-	-	-	1
Krishnan, G.	1	-	-	-	-	-	1
Krishnamoorthy, E.V.	-	1	-	-	-	-	1
Kopple, K.K.	-	-	1	-	-	-	1
Krimm, S	-	-	1	-	-	-	1
Lonappam, M.A.	-	1	-	-	-	-	1
Mohanakrishnan, P.	-	-	1	-	-	-	1
Narayan	-	-	1	-	-		1
Nanir, P.M.	-	-	-	1	-	-	1
Pandiya, U.V.	-	1	-	-	-	-	1
Plout	-	1	-	-	-		1
Phat, H.B.	-	1	-	-	-	-	1
Ramachandran, G.	-	1	-	-	-	-	1
Ramani, R.	-	1	-	-	-	-	1
Raghavan, V.K.	-	-	-	-	1	-	1
Shamala, N.	-	1	-	-	-	-	1
Subraminan, E.	-	-	1	-	-	-	1
Sabesan, M.N.	-	-	1	-	-	-	1
Thathachaory	1	-	-	-	-	-	1
Tagara, S.G.	-	-	1	-	-	-	1
Vedam	1	-	-	-	-	-	1
Vambu	-	1	-	-	-	-	1
TOTAL	**138**	**115**	**37**	**12**	**6**	**5**	**314**

9. DIRECTIONS FOR FURTHER RESEARCH

The present study of research productivity of Prof. Ramachandran. offers avenues for further research in the following areas:

- It will be interesting to examine the extent and pattern of collaborative research by other renowned scientists in other domains.
- It will also be interesting to compare the findings of this study with experts of other branches of science.
- It will be significant to study the citation pattern of Prof. Ramachandran's research contributions.
- It is also possible to examine intensively the nature and patterns of research collaboration with a view to ascertain the impact of factors such as location of the authors, their affiliations, specialisations, experience, age, etc.

10. CONCLUSION

A legendary researcher, Prof. Ramachandran was also interested in classical Indian and Western music, besides philosophical systems of India and the west. During his brilliant and illustrious academic career, the number of awards, medals and citations conferred on him are numerous to be listed. As a man who breathed science, and in terms of his lasting contributions to structural biology, Ramachandran belonged to the same intellectual class as Srinivasa Ramanujan in mathematics, and Subrahmanya Chandrasekhar in astrophysics.

Ramachandran's death was a grievous loss not only to his family members but also to the Indian and international scientific community. His scientific contributions will remain as monumental as his superb intellect. The authors dedicate this paper to the memories of Prof. Ramachandran, the protagonist of Indian science research.

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