GROWTH AND COLLABORATION TRENDS IN THE FIELD OF INDIAN OPTICS RESEARCH: A SCIENTOMETRIC ANALYSIS

Thesis Submitted to the Faculty of Science and Technology, Kuvempu University for the Award of the Degree of

DOCTOR OF PHILOSOPHY
IN
LIBRARY AND INFORMATION SCIENCE

Submitted by

MALLIKARJUNA KAPPI
Research Scholar

Guide

Dr. B.S. BIRADAR
Professor
Department of P.G. Studies and Research in
Library and Information Science

DEPARTMENT OF P.G. STUDIES AND RESEARCH IN LIBRARY AND INFORMATION SCIENCE, KUVEMPU UNIVERSITY, JNANA SAHYADRI, SHANKARAGHATTA-577451, SHIVAMOGGA, KARNATAKA

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2023

Dedicated to

To my parents and family
for their unwavering support and love

DECLARATION

I, **MALLIKARJUNA KAPPI,** hereby declare that the thesis entitled **"GROWTH AND COLLABORATION TRENDS IN THE FIELD OF INDIAN OPTICS RESEARCH: A SCIENTOMETRIC ANALYSIS"** which is being submitted for the award of the degree of Doctor of Philosophy in Library and Information Science is the original work carried out by me under the guidance of **Dr. B.S. BIRADAR**, Professor, Department of P.G. Studies and Research in Library and Information Science, Kuvempu University, Jnana Sahyadri, Shankaraghatta, Shivamogga.

I further declare that this work or part thereof has not been the basis for the award of any other degree/diploma or such other similar title in any institution or any other university.

Date: 07-10-2023

Place: Jnana Sahyadri

MALLIKARJUNA KAPPI

Research Scholar

Dr. B.S. BIRADAR, MA.,M.L.I.Sc.,Ph.D.
Professor
Department of Library and Information Science
Kuvempu University
Jnana Sahyadri, Shankaraghatta-577 541
Shivamogga, Karnataka, INDIA

CERTIFICATE

This is to certify that the thesis entitled **"GROWTH AND COLLABORATION TRENDS IN THE FIELD OF INDIAN OPTICS RESEARCH: A SCIENTOMETRIC ANALYSIS"** submitted to Kuvempu University for the award of the Degree of Doctor of Philosophy in Library and Information Science is a bonafide record of the research work carried out by **MALLIKARJUNA KAPPI,** in the Department of P.G. Studies and Research in Library and Information Science, Kuvempu University, under my guidance.

This is also to certify that the thesis represents his independent and original investigations without forming previous part of the material for the award of any degree, associateship, fellowship etc., of any other University or Institution.

Place: Jnana Sahyadri

Date: 07-10-2023

Dr. B.S. BIRADAR
Professor and Chairman
Dept.of Library & Information Science
Kuvempu University, Jnana Sahyadri
SHANKARAGHATTA 577 451
Shimoga Dist. Kar.

ACKNOWLEDGEMENTS

Place: Jnana Sahyadri

Date: **MALLIKARJUNA KAPPI**

LIST OF ABBREVIATIONS

A&HCI	Arts and Humanities Citation Index
AAPP	Average Author Per Paper
ACPP	Average Citation Per Paper
AcSIR	Academy of Scientific Innovative Research
AGR	Annual Growth Rate
AI	Activity Index
AICTE	All India Council for Technical Education
AIIMS	All India Institute of Medical Sciences
ARoG	Annual Ratio of Growth
BARC	Bhabha Atomic Research Center
BMC	BioMed Central
CAGR	Compound Annual Growth Rate
CAI	Co-Authorship Index
CC	Collaborative Coefficient
CI	Collaboration Index
CNKI	China National Knowledge Infrastructure
CP	Cited Papers
CPEPA	Centre with Potential for Excellence in Particular Area
CPP	Citations Per Paper
CSIR-NPL	Council of Scientific and Industrial Research-National Physical Laboratory
DC	Degree of Collaboration
DESIDOC	Defence Scientific Information & Documentation Centre
DOAJ	Directory of Open Access Journals
DOI	Digital Object Identifier
DRDO	Defence Research Development Organisation
DST	Department of Science Technology
DT	Doubling Time
FP	Funded Papers
GCS	Global Citation Score
HBNI	Homi Bhabha National Institute
HCP	Highly Cited Papers
h-index	Hirsch Index
IACS	Indian Association for the Cultivation of Science
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
IF	Impact Factor
IGCAR	Indira Gandhi Centre for Atomic Research
IISc	Indian Institute of Science
IISER	Indian Institute of Science Education and Research
IIT	Indian Institute of Technology

INSPEC	Information Service in Physics, Electrotechnology and Control
IRINS	Indian Research Information Network System
ISI	Institute for Scientific Information
ISRO	Indian Space Research Organisation
ISSI	International Society for Scientometrics and Informetrics
JCI	Journal Citation Indicator
JSTOR	Journal Storage
LIS	Library and Information Science
MAHE	Manipal Academy of Higher Education
MCC	Modifed Collaborative Coefficient
MDPI	Multidisciplinary Digital Publishing Institute
NASA	National Aeronautics and Space Administration
NCP	Non-Cited Papers
NIH	National Institutes of Health
NIRF	National Institutional Ranking Framework
NISCAIR	National Institute of Science Communication and Information Resources
NITS	National Institute of Technology System
NSF	National Science Foundation
OCC	Occurrence
PaI	Participative Index
PGIMER	Post Graduate Institute of Medical Education Research
PRL	Physical Research Laboratory
R&D	Research and Development
RGR	Relative Growth Rate
ROAI	Relative Open Access Indicator
RRCAT	Raja Ramanna Centre for Advanced Technology
RRI	Raman Research Institute
S&T	Science and Technology
SCI	Science Citation Index
SJR	SCImago Journal Rank
SSCI	Social Science Citation Index
TA	Total Authors
TC	Total Citations
TCpY	Total Citations per Year
TIET	Thapar Institute of Engineering Technology
TIFR	Tata Institute of Fundamental Research
TLS	Total Link Strengths
TP	Total Publications
TSA	Time Series Analysis
UGC	University Grants Commission
WoS	Web of Science

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CHAPTER – I

INTRODUCTION

"Who Needs a Librarian and Catloger
When you have Google and Internet?
Well, who needs a Teacher When You Have Wikipedia?
And, Who Needs a Doctor When You Have WebMD?
Just as Wikipedia Doesn't Replace the Teacher,
And WebMD Doesn't Replace the Doctor,
In the Same Way, Google Search and Internet
Doesn't Replace the Librarian and Cataloger."

– Salman Haider

1.1. Introduction (LIS, Scientometrics, Optics)

Library and Information Science (LIS) is an interdisciplinary field that has applied several quantitative research methods over the last few decades. Scholars from various fields, including LIS, have played a role in developing these methods. Important ideas have also been contributed by scientists from other backgrounds, such as Tibor Braun (Chemistry), Vasily Nalimov (Philosophy), and S R Ranganathan (Mathematics). The development and application of measurements in information science has led to the emergence of several different metric fields, including Librametrics, Bibliometrics, Scientometrics, Informatrics, and more recently Webometrics and Altmetrics (Gingras, 2019). Although these fields are closely related, Bibliometrics, Informetrics, and Scientometrics, show significant overlap (Gorraiz et al., 2021).

As a physics branch, Optics has undergone significant growth and development, making profound contributions to various disciplines. Its focus lies in the study of light's properties, behaviour, interaction with matter, and the principles

that govern its propagation. Divided into two major branches, namely Physical Optics and Geometrical Optics, Optics encompasses a wide range of phenomena and applications.

Physical Optics primarily examines the wave nature of light, delving into phenomena such as reflection, refraction, diffraction, interference, and polarization. It investigates the microscopic behaviour of light and its interactions with materials, paving the way for ground-breaking research in fields like Spectroscopy, Quantum Optics, and Laser Physics. By understanding the fundamental properties of light, researchers have been able to unlock new applications and deepen our comprehension of its behaviour. Geometrical Optics, on the other hand, focuses on light propagation as rays, disregarding the wave nature of light. It studies light's behaviour in terms of straight-line paths and the principles governing its interaction with optical systems, including lenses, mirrors, and prisms. By analysing and predicting light propagation in these systems, Geometrical Optics enables precise imaging, focusing, and manipulation of light. This branch forms the basis for designing and constructing optical instruments in various fields, such as microscopy, telescopes, and cameras.

The impact of Optics extends beyond its two branches. In physical science, Optics has played a pivotal role in advancing our understanding of light and its properties. Significant breakthroughs have been made in reflection, refraction, diffraction, interference, and polarization, laying the groundwork for ground-breaking research in spectroscopy, quantum optics, and laser physics. Optics has also led to a revolution in the field of telecommunications. The development of fibre optics, utilizing the principles of total internal reflection, has enabled high-speed and long-distance data communication. Fibre optic cables and photonic devices have significantly improved telecommunication networks' capacity, speed, and reliability.

This advancement has transformed internet connectivity, telephony, and data transmission, shaping the modern digital era.

In medical science, Optics has facilitated remarkable advancements in diagnostic imaging and medical procedures. Techniques such as X-rays, Ultrasound, CT scans, MRI, and OCT have revolutionized medical diagnostics by providing detailed information about internal structures, tissues, and physiological processes. Optics has also played a significant role in endoscopy, enhancing visualization and precision in minimally invasive procedures. Optics has found applications in diverse multidisciplinary domains as well. It has been instrumental in developing advanced materials with unique optical properties in materials science and engineering. Optics has been integrated into designing and fabricating optoelectronic devices and sensors, contributing to energy harvesting, environmental monitoring, and data storage advancements.

Optics has been vital in astronomy for designing and constructing powerful telescopes and astronomical instruments. Thanks to Optics, scientists have observed and studied celestial objects with unprecedented detail and accuracy. Furthermore, Optics has played a role in space exploration by enabling the development of compact and lightweight imaging systems for spacecraft and rovers. The growth and development of optics have had a transformative impact on various disciplines. It has significantly contributed to physical science, telecommunications, medical science, materials science, and astronomy. With its promise for future advancements, Optics has driven progress and innovation across various scientific, technological, and societal domains.

Optics research is a critical domain in India (Kappi & Biradar, 2020a, 2020b), given the country's increasing focus on advanced technology and economic growth.

The field involves the study of light and its interaction with matter, with significant applications in areas such as telecommunications, medicine, and materials science (Goodman, 2005; Hecht, 2012; Saleh & Teich, 2019). In recent years, Indian Optics research has witnessed a substantial increase in research output, with growing numbers of publications and collaborations between different research groups and institutions (Singh, 2022). This growth and collaboration have contributed to advancing knowledge in the field and helped establish India as a prominent player in the global research landscape.

Scientometric and bibliometric tools and techniques (Handbook of Quantitative Science: The Use of Publication and Patent Statistics in Studies of S & T Systems, 2004) have been instrumental in evaluating the research output of Indian Optics researchers and tracking the development of various research areas and collaborations (Leydesdorff & Milojević, 2012). These tools provide a quantitative and qualitative assessment of research output, including publication patterns, authorship, institutions, growth rates, and sources. Scientometric analysis has become increasingly popular in recent years, providing a sound and effective method for evaluating research efficiency and excellence. Scientometric and bibliometric techniques have been precious in Indian Optics research, allowing for a better understanding of the research landscape and contributing to developing targeted policies and strategies to foster growth and collaboration in the field.

The effectiveness of research can only be achieved through a proper communication system. A historian, economist, sociologist, librarian, etc, can view communication in science. In this way, science and scientific communication are so intertwined that one influences the other in producing information. Scientists and sociologists believe that scientific research conducted by academic and research

organizations are the driving force behind advanced technology and economic growth. Scientific research significantly contributes to developing a country's economy, so research efficiency is a measure of research excellence in that country. Interestingly, in the last few years, scientometrics/bibliometric tools and techniques have been and are increasingly being used to evaluate the research output of scientists and the development of various scientific disciplines.

Optics research has gained considerable importance in India, driven by the country's emphasis on advanced technology and economic growth (Akram & Illiyan, 2023; Bhattacharya et al., 2017). This field involves the study of light and its interaction with matter, yielding various applications in binding domains such as telecommunications, medicine, and materials science (Kennedy et al., 2014; Saleh & Teich, 2019; Tuchin, 2016). In recent years, Indian Optics research has experienced a substantial surge in research output, as evidenced by the exponential rise in publications and collaborations among different research groups and institutions. These collaborative endeavours have propelled the advancement of knowledge in the field and positioned India as a notable contender in the global research landscape. The growing trend of Indian Optics research has established it as a vital research domain, promising to enhance scientific and technological breakthroughs and impact the nation's socioeconomic growth. India has a long history of research in Optics, with renowned institutions such as the Indian Institute of Technology (IIT) and the Indian Institute of Science (IISc) at the forefront of research in this field. The country has witnessed a significant increase in the number of research papers being published by Indian institutions and researchers, as per the Web of Science database. Between 1992 and 2021, India ranked 13th globally in terms of the number of research papers

published in the field of Optics. This upward trend in research activity in optics in India indicates the growing significance of this field in the country.

This study aims to examine the growth and collaboration trends in the field of Indian Optics research over the last three decades. It seeks to understand the emergence of research areas, research groups, and collaborations and to reflect the cognitive and intellectual structure of research in the field. The study employs scientometric and bibliometric techniques to evaluate research output, assess the impact of research publications, and identify key players and contributors in the field. The findings of this study provide valuable insights into the state of Indian Optics research, highlighting areas of strength and opportunities for growth and collaboration. Ultimately, this study aims to contribute to the development of targeted policies and strategies to enhance the impact and reach of Indian Optics research, supporting the country's broader goals of economic growth and technological advancement.

1.2. Proposed Research

The proposed research topic of "Growth and collaboration trends in the field of Indian Optics" aims to examine the recent trends in research output and collaborations within the Indian Optics research community. This study focuses on understanding the drivers of growth in this field and the factors contributing to the increasing number of research publications and collaborations among different research groups and institutions. Through this research, researcher aims to understand better the advancement of knowledge in the field of Indian Optics and its impact on the global research landscape. By presenting a detailed examination of these trends, the study aspires to contribute valuable insights that could further fuel the progress

and development of Indian Optics, ultimately enhancing its position in the global scientific community.

1.3. Need and Significance of the Study

The study on growth and collaboration trends in the field of Indian Optics is of utmost importance in informing policies, strategies, and funding decisions, given Optics Research critical role in various areas, including telecommunications, medicine, and materials science. As India continues to focus on advanced technology and economic growth, understanding the current trends and growth patterns in this field is essential. This study provides valuable insights into the current state of Optics research in India, contributing to the growth and advancement of the area. By analysing the trends and patterns in Indian Optics research output, collaborations, and publications, this study identifies the potential research partnerships, knowledge-sharing opportunities, and research gaps. Additionally, the analysis establishes India's position as a prominent player in the global research landscape by showcasing the country's contributions and collaborations in this critical research domain. The study's results also inform future research directions and collaborations, ultimately contributing to the advancement of knowledge and innovation in the field. Therefore, the need and significance of the study on growth and collaboration trends in the field of Indian Optics cannot be overstated.

1.4. Research Title

The research title, **"Growth and Collaboration Trends in the Field of Indian Optics Research: A Scientometric Analysis,"** aims to study the current state of optics research in India and identify the growth and collaboration trends in the field. With India's increasing focus on advanced technology and economic development, Optics research has emerged as a critical domain with significant

applications in telecommunications, medicine, and materials science. The study analyses the research output in the field of Indian optics, including the number of publications and collaborations between different research groups and institutions, to identify the current trends and growth patterns. This research's findings contribute to advancing knowledge in the field and help establish India as a prominent player in the global optics research landscape.

1.5. Literature Survey

A literature review is essential to any research paper, including a thesis, providing a foundation for identifying knowledge gaps and offering insights into current research trends. This study conducts a comprehensive exploration of the growth and collaboration trends in the field of Indian Optics research, utilising relevant studies from multiple reputable sources. Specifically, studies published in prominent publishers, including Emerald, Sage, Elsevier, and bibliometrics/ scientometrics journals, are analysed. Additionally, the studies indexed in esteemed databases such as Web of Science (*Web of Science Core Collection*, 2022), Scopus (*Scopus Preview*, 2022), PubMed (*PubMed*, 2022), arXiv (*Https://Arxiv.Org/*, 2022), Optics InfoBase (*Optica Publishing Group*, 2022), and Google Scholar (*Google Scholar*, 2022) are included to capture a wide range of perspectives and opinions. The approach taken in this review aims to provide a thorough evaluation of the current state of Indian Optics research. Analysing and synthesising a diverse range of studies, gaps in the literature are identified, and potential areas for future research are highlighted. Various sources ensure that this review is based on a solid foundation of high-quality research, enabling it to contribute meaningfully to the academic discourse surrounding Indian Optics research.

1.5.1. *Research Gap*

The field of Indian Optics research has experienced significant growth and collaboration in recent years. However, there needs to be more research regarding the specific trends and factors that have contributed to this growth and collaboration. To address this gap, further research is required in order to explore the various factors that have influenced the development of the field, including government policies, funding sources, academic and industry partnerships, and technological advancements. Additionally, there is a need for research examining the impact of this growth and collaboration on advancing knowledge in the field and its practical applications. By filling this research gap, a better understanding can be gained of the current state and future prospects of Indian Optics research, which can inform the development of policies and strategies to promote further and enhance the growth and collaboration of the field.

1.6. Research Design and Methodology

The research design and methodology for studying the growth and collaboration trends in the field of Indian Optics involves a comprehensive review of the literature on the subject. This review aims to identify and analyse relevant research publications, collaborations, and institutional collaborations in the field of Indian Optics. The data is collected through a systematic search of academic databases, i.e., Web of Science core collection, using specific keywords related to the research topic. The search includes research papers, conference proceedings, and other relevant literature published in the last 30 years (1992-2021). After identifying the relevant publications, the study analyses the growth trends and collaborations in the field of Indian Optics through bibliometric analysis, including co-authorship, citation analysis, and institutional affiliations.
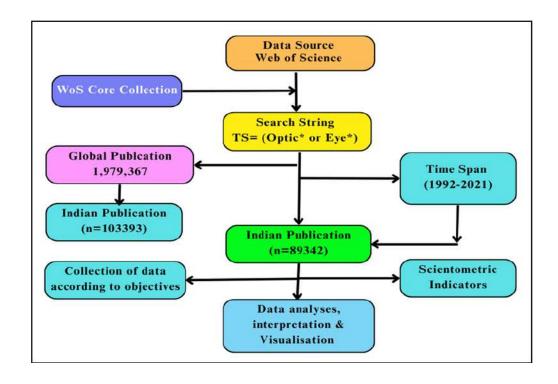
Figure 1.1: Research Design Flowchart

Further, VOSviewer (van Eck & Waltman, 2010) and Biblioshiny (Aria & Cuccurullo, 2017) software tools are utilized to analyse and visualize the research output of Indian Optics. VOSviewer is a software tool that is used for bibliometric visualization and mapping, while Biblioshiny is a web-based application that is used for bibliometric analysis. Using VOSviewer allows us to create maps and visualizations of the co-authorship and co-citation relationships between authors and publications in the field of Indian Optics. This helps to identify the most influential authors, institutions, and countries in the field, as well as the key research themes and topics. On the other hand, Biblioshiny is used to generate descriptive statistics and to perform network analysis, clustering, and trend analysis on the bibliographic data. These software tools are critical in enabling us to effectively analyse and interpret the large volume of bibliographic data on Indian Optics, providing insights into the growth and collaboration trends in the field. The study also identifies the factors

contributing to the development and collaboration trends in Indian Optics research, including funding sources, research infrastructure, and policy support. This study aims to provide a comprehensive overview of the growth and collaboration trends in the field of Indian Optics and identify potential areas for future research and collaboration as shown in Figure 1.1.

1.7. Objectives of the Study

The following are the main objectives of the study.

1. To compare the growth and collaboration trends of Indian Optics research with other countries in the global research landscape.

2. To analyse the growth of Indian Optics research in terms of research output, publications, and citations during 1992-2021.

3. To identify the main areas of research in Indian Optics and their trends.

4. To explore the collaboration patterns among Indian Optics researchers and research groups and identifies potential areas for future collaboration.

5. To analyse the growth and collaboration trends in Indian Optics research over the past decade using bibliometric tools such as VOSviewer and Biblioshiny.

6. To identify the highly cited papers in the field of Indian Optics and analyse their impact on the research landscape.

7. To identify the top research groups and institutions in Indian Optics and analyse their contribution to the field.

8. To explore the significant keywords in Indian Optics researchers and identify potential areas for future collaboration.

9. To provide insights into potential future directions of Indian Optics research based on the current trends and findings.

The study provides valuable insights into the current state of Indian Optics research, its growth and collaboration patterns, and its impact on the global research landscape. The findings of this study help researchers, institutions, and policymakers in India to identify potential areas for collaboration and investment, and to develop strategies for enhancing the quality and impact of Indian Optics research.

1.8. Data Analysis and Interpretation

Data analysis and interpretation are essential for gaining insights into research progress in a critical domain such as Optics, which has become increasingly important in India due to its focus on advanced technology and economic growth. The study of light and its interaction with matter has significant applications in areas such as telecommunications, medicine, and materials science, making it a subject of great interest to researchers worldwide. In recent years, Indian Optics research has witnessed a significant increase in research output, with a growing number of publications and collaborations between different research groups and institutions. Therefore, analysing and interpreting the growth and collaboration trends in Indian Optics research provides valuable insights into the advancement of knowledge in this field and help establish India's position as a prominent player in the global research landscape. This study aims to analyse data on research output, collaborations, and other relevant factors to interpret the growth and collaboration trends in Indian Optics research comprehensively and gain a deep understanding of the current state and future prospects of this critical research domain in India.

1.9. Scope and Limitations

Optics research has emerged as a critical domain in India, driven by the country's increasing focus on advanced technology and economic growth. This study has garnered considerable attention from researchers and policymakers nationally and internationally. The primary objective of this study is to investigate the trends and patterns in research output and collaboration in Indian Optics, utilizing the Web of Science core collection database as the primary source of information. The Web of Science database is a widely used and trusted resource in the academic community, which indexes and abstracts a vast collection of high-quality scientific literature, including journals, conference proceedings, books, and patents. It provides researchers with a comprehensive tool for exploring trends and patterns in research output, making it an ideal source of information for our investigation.

However, it is essential to acknowledge that our study has some limitations. Firstly, the scope of the study is limited to publications indexed in the Web of Science database, which may not capture all research output in the field of Indian Optics. Secondly, the study confines to a specific time frame of 30 years (1992-2021), and our findings may not represent long-term trends in the field. Moreover, the analysis of collaboration patterns is limited to co-authorship analysis based on the available data. Despite these limitations, this study provides valuable insight into the growth and collaboration trends in Indian Optics research over the past three decades. Findings contribute to a better understanding of the development of the field and its role in advancing knowledge and innovation in India. The Web of Science database served as an indispensable resource for the study, providing a comprehensive and reliable source of information on trends and patterns in research output and collaboration in Indian Optics.

1.10. Organization of the Chapters

Chapter – I: Introduction provides an overview of the study and its objectives. It begins with an introduction to the conceptual frameworks and background on Library and Information Science, Optics, and Scientometrics. The research problem, definition of concepts, and objectives are presented. The methodology used is briefly outlined, and the scope and limitations are discussed. Lastly, an overview of the organization of the thesis is presented.

Chapter – II: Scientometrics: An Overview provides an overview of the concept and development of Scientometrics and its trends and issues.

Chapter – III: Review of Literature highlights the importance of literature review in research and presents the findings of various studies. The reviews and findings are grouped into seven sub-groups: growth of literature and growth models, Scientometric analysis of different disciplines, authorship, and collaboration work in different disciplines, ranking of journals and institutions, studies on scientometrics studies employed visualization techniques and future developments: alternative metrics.

Chapter – IV: Data Analysis and Interpretation presents the relative growth rate, doubling time, growth models, science indicators for productivity like activity index, priority index, correlation study, the ranking of journals and scientific institutes in India. It visualizes the results of keywords, co-authorship, network of institutions by applying mapping tools.

Chapter – V: Findings, Suggestions, Suggestions for Future Study and Conclusion. In this chapter, the summary of the research findings is presented, including the growth and collaboration trends in Indian Optics research, the main areas of research and their trends, collaboration patterns among Indian Optics

researchers, impact of Indian Optics research on society, industry, and economy, highly cited papers in the field, top research groups and institutions, and significant keywords. Suggestions for future research directions are provided, and the chapter concludes with an overall reflection on the topic.

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CHAPTER – II

SCIENTOMETRICS: AN OVERVIEW

2.1. Introduction

The evaluation of scientific work began in late 1960s as an important factor in rational political decision-making in scientific research. There is a strong desire for a systematic approach to evaluating scientific work from the competitive financial pressures of various research streams. Other perceptions supporting the objective approach are the advent of well-designed systems for the work/type of scientific research, with science playing a major role in the economy and society, and scientific research seeking increased financial support from the government (Edge, 1995). Thus, from the 1960s onwards, scientific research - real data collected in scientific work and regularly reviewed - began to play an important role in shaping scientific predictions.

Scientometrics is mainly associated with the creation of S&T indicators that accurately measure various aspects of latent variables of "scientific activity" (such as productivity, and quality). Indicators derived directly from empirically measurable variables (viz publications, citations, patents) are used to indirectly assess the status or dynamics of the associated latent change(Ivancheva, 2008; Van Raan, 1997).

2.2. Origin, Meaning and Definition

The term "scientometrics" is used for the "measurement of informatics process". The term informatics is used in several places to refer to the "documentation/information processing function". There is no difference between Western bibliometrics and Eastern Europe scientometrics. Scientometrics was introduced by Vasily Nalimov, and the word is derived from the Russian word 'Naukometriya' in 1969, which means the application of numerical methods in the history of science, and studies of the numerical aspects of science. This term got its

name from the publication of the journal "Scientometrics" by T. Braun in 1977, published in Hungary and now in Amsterdam, Netherlands. Scientometrics refers to the process of information communication in science, as well as the socio-cultural facets, and seems to be almost entirely linked to science in its field.

Derek John de Solla Price (1922-1983) (Price, 1963) is the father of scientometrics. Earlier he was a scientist, historian of science, and information scientist and worked as a professor of mathematics at Raffles College (the University of Singapore in 1948). He formulated a theory on the expansion of scientific growth, an idea that came to him when he noticed the growth of the philosophical transactions of the Royal Society during 1665 – 1850. Moreover, the contribution of Garfield (Garfield & Joshwa, 1977) to scientometrics is very important; His contributions have evolved through the SCI (Science Citation Index). Merton also had his views on scientometrics, based on the Matthew effect (Neelameghan, 1969).

In the field of scientometrics research, other terms related to scientometrics are also used, viz, bibliometrics(Pritchard, 1969) and informetrics (Nacke, 1979). All these together are known as the "3-metrics" in the disciplines of library and information science. However, the terms do not have limitations in applied research, as the terms are often used interchangeably (Siluo & Qingli, 2020).

2.3. Relationship between the '3-Metrics'

Scientometrics, bibliometrics, and informetrics are all sub-disciplines of library and information science that focus on quantitative analysis of scientific and scholarly communication, these 3-metrics have evolved to share many of the objectives and have many methods and tools in common (Qiu et al., 2017). Metrics refer to "the components involved in the study of different curricula as evidenced in the production of their literature" and are often published simultaneously or used by authors, such as the Second International Conference on Bibliometrics,

Scientometrics, and Informetrics (now called "ISSI"). However, the words are different from their warning attitudes; Specifically, bibliometrics belongs to the library and science, scientometrics belongs to the science of science, and infometrics belongs to information science. Scientometrics and infometrics have been provided for nearly 50 and 40 years respectively; however, they have varied concepts that could be accepted by society; Various descriptions of bibliometrics are also available (Hood & Wilson, 2001; Sengupta, 1992; Siluo & Qingli, 2020). These three fields share some similarities, but there are also differences that set them apart from each other. The relationship between scientometrics, bibliometrics, and informetrics is complex, and it is important to understand how these fields are interconnected to gain a more comprehensive understanding of scientific literature and its impact on society.

2.3.1. *Bibliometrics*

Bibliometric is a term derived from the Greek words "***biblion***", which means book, and "***metron***", which means measure or quantify. It is the study of the quantitative aspects of recorded knowledge. Bibliometric analysis is a quantitative method for analysing and measuring the creation, distribution, and use of scientific information. It is used to track trends in research, identify emerging research areas, and assess the impact of research. The term "bibliometrics" originated by Pritchard in 1969 (Pritchard, 1969) defined as "Bibliometrics means the application of mathematics and statistical method to books and other communication media", although it had been used previously in a different context in 1934. Today, Gorraiz defines bibliometrics as the application of mathematical and statistical methods to understand the processes of written communication. The concept of bibliometrics itself has a long history, primarily used as bibliographical statistics to examine publications on current topics. These early studies were primarily focused on evaluating content on specific subjects. Consequently, the original use of

bibliometrics was more prevalent in library science. First bibliometric analysis was conducted by Cole and Eales, who utilized this information to assess the significance of publication outlets, which aligns with the core idea of journal rankings and impact factors. Additionally, librarians Gross and Gross aimed to assist libraries in making decisions regarding journal procurement. Their analysis revealed uneven distribution of citations among different journals, laying the foundation for Bradford's law, which was developed in 1934. According to Bradford's law, a small number of core journals contained a significant portion of key academic publications (Ball, 2017).

2.3.2. *Scientometrics*

Scientific research is a process of generating information and is fundamentally driven by communication. The dynamics of scientific communication constitute a highly intricate system (P Vinkler, 1996; Péter Vinkler, 2010). Scientometrics, derived from the Greek words "*scientia*" meaning "knowledge" and "*metron*" meaning "measure," is a quantitative research field that analyses scientific literature and research output. It serves the purpose of tracking research trends, identifying emerging areas of research, and assessing the impact of scientific research.

The term "scientometrics" was coined by Vassily V. Nalimov in 1969, this term has grown in popularity and is used to describe the study of science: growth, structure, interrelationships, and productivity. Later, modern scientometrics was based on the work of Derek J. de Solla Price in 1969, a British physicist and information scientist, who developed bibliometric methods such as the h-index and g-index to measure the impact of individual researchers (Price, 1963). Braun et al. (1987) define scientometrics as the analysis of quantitative aspects of generating, disseminating, and utilizing scientific information to enhance our understanding of the mechanisms of scientific research activities (Péter Vinkler, 2001). The goal of scientometrics is to

unveil the characteristics of scientometric phenomena and processes in scientific research, aiming for more efficient scientific management. In recent years, scientometrics has gained increasing importance as the volume of scientific literature continues to grow, making scientometric methods indispensable for tracking and comprehending the state of scientific research. Moreover, scientometrics informs policy decisions regarding research funding and allocation (Kappi & Biradar, 2022).

2.3.3. *Informetrics*

The term "*informetrics*" was first introduced by Nacke in 1979, originating from the German term "*informetrie*." Informetrics encompasses the quantitative measurement of information phenomena and the application of mathematical methods to various areas, including information science, bibliometrics, and aspects of information retrieval theory (Hood & Wilson, 2001).

Tague-Sutclifle (Tague-Sutcliffe, 1992) defined "informetrics as the study of quantitative aspects of information in any form, extending beyond records or bibliographies to encompass all social groups, not just scientists". As a subfield of information science, informetrics focuses on the quantitative analysis of information and communication processes. It examines patterns in the creation, dissemination, and utilization of information, involving the analysis of publication and citation data. The primary objective is to comprehend the mechanisms underlying information generation and evaluate its impact on society. Informetrics is closely related to bibliometrics, but it distinguishes itself by investigating information and communication processes across various channels, including scholarly journals, books, and social media, as well as examining the societal influence of scientific research on public policy.

2.4. Relationship between Bibliometrics, Scientometrics and Informetrics

Bibliometrics, scientometrics, and informetrics are closely related fields that share common elements while also having distinct focuses within the broader domain of quantitative analysis in library and information science.

Bibliometrics primarily deals with the measurement and analysis of patterns and trends in bibliographic records, such as publications, citations, and authorship. It aims to provide quantitative insights into scholarly communication and information dissemination within specific disciplines or domains. Bibliometrics often focuses on assessing the impact and influence of scholarly publications, as well as the productivity and scientific collaboration patterns of researchers.

Scientometrics, on the other hand, extends the scope of bibliometrics by encompassing the quantitative analysis of the entire scientific research landscape. It examines the production, dissemination, and impact of scientific knowledge across disciplines, using bibliometric methods to study research output, citations, collaboration networks, and other related factors. Scientometrics aims to understand the dynamics of scientific research and its impact on various aspects, such as the advancement of knowledge, innovation, and societal progress.

Informetrics is a broader field that encompasses both bibliometrics and scientometrics, while also considering quantitative aspects of information beyond scholarly literature. It focuses on the analysis of information creation, dissemination, and utilization across various contexts and social groups. Informetrics aims to understand the quantitative aspects of information behaviour and its impact on society, including decision-making, policy development, and knowledge management. Bibliometrics, scientometrics, and informetrics are interconnected fields within information science. Bibliometrics focuses on the quantitative analysis of

bibliographic records, scientometrics expands this analysis to the broader scientific research landscape, and informetrics encompasses quantitative study of information and communication processes in various contexts beyond scholarly literature.

Overall, bibliometrics, scientometrics and informetrics are all valuable tools for understanding the landscape of scientific research. By using these fields together, researchers gain a deeper understanding of how science is evolving and how it is used to solve the world's most pressing problems as shown in the table 2.1.

Table 2.1: Relationship between Bibliometrics, Scientometrics and Informetrics

Field	Focus	Methods
Bibliometrics	The quantitative analysis of scientific literature	Number of publications, citations, and authors
Scientometrics	The quantitative analysis of scientific research	Bibliometrics, informetrics, and other methods
Informetrics	The quantitative analysis of information in general	Number of documents, citations, and users

Figure 2.1 shows the field of webometrics entirely encompassed by bibliometrics, because web documents, whether text or multimedia, are recorded information stored on web servers. This recording may be temporary only, just as not all paper documents are properly archived. Webometrics is partially covered by scientometrics, as many scholarly activities, today are web-based, while other such activities are even beyond bibliometrics, i.e., nonrecorded, such as person-to-person conversations. Also, webometrics is fully integrated into the field of cybermetrics.

Further, the cybermetrics exceeds the limits of bibliometrics, because some events are not recorded in space but instead are communicated, such as inside a chat room. Cybermetric studies of such works still fall into the category of informetrics as studies of the numerical aspects of information "in any form" and "in any social group" as put into practice by (Tague-Sutcliffe, 1992). Of course, the inclusion of webometrics expands the domain of bibliometrics. Because webometrics inevitably

contributes to further methodological progress in web-based approaches. Although ideas rooted in bibliometrics, scientometrics, and informetrics contributed to the emergence of webometrics, ideas from webometrics may now contribute to the development of these surrounding areas.
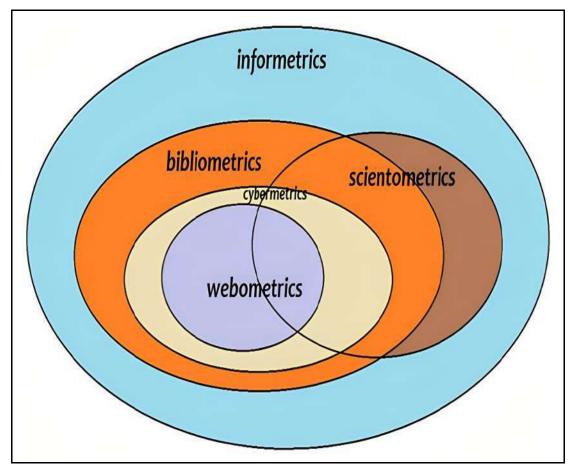
Figure 2.1: Relationship between informetrics, bibliometrics, and scientometrics

2.5. Citation Analysis

Citation analysis is a quantitative technique used to identify significant and influential literature in a specific field based on how frequently a publication is cited by other works. It plays an increasingly important role in scientific research, allowing for the evaluation of scientific journals, researchers, research organizations, academic institutions, and countries based on their publication and citation counts (Aksnes et al., 2019; Wikipedia, 2022). By analysing citations, researchers determined the expected quality and impact of an article, author, or institution. This method serves as

a common approach in bibliometrics, aiding in establishing connections between authors and their work. Through the statistical analysis of references within scientific communications, citation analysis enables the identification of core references and serves as a valuable tool for identifying significant sources of information (Chaman Sab, M., et al., 2016; Chikate & Patil, 2008).

On the other hand, Interpreters of citation analysis argue that these issues are relatively small. Bibliographic data of highest citations counted in journal articles and books are helpful such as prolific authors, prolific institutions, and the finding publications, furnishing background for reading, and informing readers of future works. The citations also validate privileges, give credit to related work, and provide clues to poorly circulated poorly indexed, or uncited work. According to Michael Koenig (Koenig, 2003) of the Palmer School of Library and Information Science at Long Island University in the United States, citations provide - despite their complexity - "the characteristics of what is called differences in productivity, importance, quality, value, impact, effectiveness or impact of scientists and their academic research outputs".

The Institute for Scientific Information (ISI) database - which includes the Arts and Humanities Citation Index (A&HCI), Science Citation Index (SCI), and Social Science Citation Index (SSCI) - has been used for decades as a starting point and as often as the only tool for interpretation of citation analysis. Since they were first published in the 1960s and 1970s, these databases have grown exponentially in size and impact, and today contain 171 million records from more than 12,000 of the world's most reputed and high-impact journals. SCI, released in 1964, became rapidly evolving among scholars and librarians and is now one of the largest multidisciplinary databases in the world owned by Clarivate.

Even though conversation hitherto has proposed counting citations only for individual articles or journals, of course, various levels of accumulation are conceivable. The units of study can be individual papers or books, sources, authors, research associations, scholarly divisions, universities, states, and even telescopes. If citations are supposed to be indicators of importance, such analyses are used to decide the most prolific scholars, journals, organizations, etc. in a particular discipline and domain analysis in which the results of the citation analysis are to be understood.

2.6. Application of Citation Analysis

- **Literature of studies:** Citations in a specific subject area should be studied to explain the citation pattern.

- **Form of Literature Studies:** Citation analysis is used to calculate the distribution of reported results in certain types of literature such as government publications, theses, or the literature exchange of regional cultural societies.

- **User studies:** The citation analysis technique was used to solve the needs of the library users, which are very useful for the development of the collections and the design of the library services.

- **Historical studies:** (Linda C Smith, 1981) has argued that historical research using citation analysis is based on a literary model of the scientific process. Citations are used to specify the order of events, the relationships between them, and their relevant importance.

- **Communication Pattern:** Citations also indicate the patterns of scientific communication. These studies also define the types of researchers involved in the field of study, such as one or more researchers, etc.

- **Evaluative Bibliometrics:** In these studies, citation analysis is defined as the assessment and explication of citation counts by research results, organizations, and nations (Linda C Smith, 1981).

- ➢ **Information Retrieval:** It is being explored that the use of the citation relationship is having a greater impact on information retrieval, where citations have been used to improve more traditional literature search approaches.

- ➢ **Collection Development:** Mainly, citation analysis is applied to developing journal collections in a library, and it helps in selecting the journal titles to acquire.

2.7. Scientometric Laws

Three basic laws are commonly used and discussed in scientometrics:

1. **Lotka's law of scientific output – 1926** (authors publishing in a certain discipline);

2. **Bradford's law of scatter – 1934** (scattering of articles);

3. **Zip's law of word occurrence – 1935, 1949** (ranking of keywords frequency).

These three classical laws of scientometrics are the key laws and are practically used as the tool to measure the scientific subject arena in different prospects and these laws are the pillar of the scientometric or bibliometric studies.

2.7.1. *Lotka's law of scientific output – 1926*

'Lotka's Law of scientific productivity' is the law of bibliometrics which is used to map the productivity pattern of authors in a subject. In 1926, Alfred J. Lotka published a classic paper on his study about the frequency distribution of scientific productivity of authors observing the publications listed in Chemical Abstracts for the period 1907-16. Law provided a formula for measuring/predicting the productivity of scientific researchers. In his study, he found that "… the number of 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 about 60%".

$$p(n) = \frac{k}{n^2}$$

Where,

p = Number of authors producing n papers;

k = Constant characteristic of the respective subject domain.

The application of Lotka's Law of scientific productivity means the number of authors making 2 publications is *½*2 = ¼ = 0.25* of those making 1 publication; those making 3 publications: *1/3*3 = 1/9 =0.11* of those making 1 publication. In other words, for every 100 authors contributing one article. 25 authors contributed 2 articles, 11 authors contributed 3 articles, and 6 authors contributed 4 articles, and so on as per table 2.2.

Table 2.2: Ranking of authors (According to Lotka's law)

No. of authors	No. of publications
100	1
25	2
11	3
6	4

2.7.2. *Bradford's Law of Scattering – 1934*

Bradford's Law of Scattering denotes the numerical link between the journals and the articles published in those journals. Samuel Clement Bradford, Chemist, and Librarian at the Landon Science Museum conducted a quantitative analysis of two Geophysical journals, "Current Bibliography of Applied Geophysics" (1992-1931) and "Quarterly Bibliography of Lubrication" (1931-1933). He questioned the journals that containing the up the references of the domains, reducing productivity and dividing them into three closely equivalent areas or sets; the firstly highly productive zone (nuclear zone), the second moderately productive zone, and the third low productivity zone. In calculating the number of titles in each of the three areas, Bradford found consistency. Following the findings, Bradford decided that the journal titles followed a familiar pattern in successive zones. Bradford's verbal formulation

stated that if scientific journals were structured to reduce the productivity of publications on a specific topic, they could be distributed across the discipline's publication core with greater precision. Multiple groups (zones) with the same papers of the nucleus, in which the number of journals in the nucleus and the following zones is as high as 1: n: n2 (n=multiplier) (Bradford, 1934, 1948). In other words, the first nucleus zone has the highest number of articles and a small number of most productive journals, say n1, the second zone has a greater number of articles and a large number of moderately productive journals, say n2, and the third zone has a smaller number of articles and a large number of journals, say n3.

Bradford's law of scattering is mathematically described as:

$$= 1: n: n^2$$

Bradford's law was later described as a linear relation by Brookes(Brookes, 1969) and expressed as:

$$F(x) = a + b \log x$$

Where, F(x) = Cumulative number of references the first 'x' most prolific journals

a, b = Constant

Later, the verbal formulation was generalized in Vickery's interpretation, illustrating that it was used to equalize performance zones. The following simple Bradford distribution function was applied by Leimkuhler (Leimkuhler, 1980) and it is known by his name. The mathematical expression is as follows:

$$R(r) = a \log(1 + br)$$

Where, R(r)= cumulative number of articles in journals ranked '*1*' through '*r*';

a, b = parameters

Likewise, Brooke's (Brookes, 1969) derivation for journals output is expressed as:

$$R(r) = a \log \left(\frac{b}{r}\right)$$

Furthermore, Wilkinson (Wilkinson, 1972) noted that the formulas provided by Leimkuhler and Brookes do not describe the same phenomenon. Various other mathematicians have provided different models, but Brookes' and Bradford's laws have nevertheless gained more acceptance than others.

2.7.3. *Zipf's Law of Word Occurrence – 1935, 1949*

Zipf's law is a statistical distribution of a given set of data, the frequency (f) of a given word is inversely relative to its rank (r). Named after American linguist George Kingsley Zipf (1935, 1949) (Zipf, 1935, 1949) the law first focused on this phenomenon, with natural language words occurring two to three times more often than the more common second ones. This frequency is given as $f(r) \cong 0.1/r$. Thus, the most common word (level 1) in English, that is 'the', appears about one-tenth of the time in the text; the second most common word (level 2), that is 'of', occurs about one-twentieth of the time; and so on. Often the following words are followed by the less frequent words. Words in position n are displayed 1/n times as the most common words. Another way to check this is that the word r appears 1/r times more commonly than the word commonly used, so word rank 2 is half of the word rank 1, and word rank 3 is 1/3 of the frequency, the word 4 is 1/4 as often, and so on. Except for about rank 1,000 levels, the law is completely broken.

Zipf analysed the words and ranked them in descending order, multiplying the numerical value of each rank (r) by its frequency (f) to arrive at a product (c). Zipf's law says that "when words in the text of a natural language of considerable length are listed in descending order of frequency, the position of each word in the list is inversely proportional to the frequency of occurrence of the word".

The mathematical equation of Zipf's law is;

$$rf = c$$

Where,

r = Word rank;

f = Word frequency;

c = Constant

Table 2.3: Ranking of words occurrence (according to Zipf's law)

Rank (r)	Frequency (f)	Product (c)
1	500	500
2	250	500
3	167	501
4	125	500
5	100	500
6	83	498
7	71	497
8	62	496
9	55	495
10	50	500

Zipf's law is derived from the general principle of "minimum effort," where words that are easy to use or require minimal cognitive load are frequently employed in lengthy texts. This phenomenon is also evident in subject indices that utilize controlled vocabulary. Terms within such a controlled vocabulary exhibit varying frequencies of occurrence; certain terms are highly prevalent, while others are rarely encountered. The usefulness of Zipf's law lies in its ability to quantify the richness of an author's vocabulary as shown in table 2.3.

2.8. Application of Scientometrics

Scientometrics is the scientific study of the measurement and analysis of scientific research, including citation analysis, co-citation analysis, bibliometric analysis, and content analysis. The primary objective of scientometrics is to provide quantitative information about the structure and dynamics of science, including the

growth of scientific knowledge, the spread of scientific information, and the use of scientific knowledge.

Figure 2.2 shows many practical applications, and it is used in a wide range of fields, including science policy, academic research, and industry. In this chapter, the most important applications of scientometrics are discussed, including their relevance in science policy, academic research, and industry.

2.8.1. *Science policy*

Scientometrics is used in science policy to evaluate and monitor the impact of scientific research. The primary goal of science policy is to improve the efficiency and effectiveness of scientific research by identifying areas of research that are most likely to yield important results.

Scientometrics is used to assess the scientific productivity of institutions, countries, and individual researchers. This information is then used to make decisions about funding, collaboration, and research priorities. For example, scientometrics is used to identify the areas of research that need more funding or to evaluate the effectiveness of existing research programs.

2.8.2. *Research evaluation*

Scientometrics is also used in academic research to evaluate the quality and impact of research. Researchers used scientometric tools to assess the impact of their work, identify important publications in their field, and evaluate the impact of different research methods.

Scientometrics is used to assess the quality of scientific journals and other publications. Citation analysis is used to determine the impact factor of a journal, which is a measure of the frequency with which articles in that journal are cited by other researchers.

2.8.3. *Industry*

Scientometrics is used in industry to assess the competitive landscape of a particular field or industry. Also, used to identify the key players, evaluate the quality and impact of their research, and identify potential competitors or partners.

The scientometric analysis is used to identify emerging trends in a particular industry and to identify areas of research that are most likely to yield important results. This information is used to develop new products or services or to improve existing products and services.

2.8.4. *Information management*

Scientometrics is also used in information management to help organize and manage large amounts of scientific literature. It identifies important publications and categorizes and classifies them according to subject matter, publication date, and other factors. This information is used to develop databases and other information management systems, facilitating rapid and efficient access and retrieval of scientific literature.

2.8.5. *Knowledge management*

Scientometrics is also used in knowledge management to identify and manage the knowledge assets of an organization. It identifies areas of expertise, key players, and important publications within an organization.

This information is used to develop strategies for knowledge sharing and collaboration and to develop training programs to help employees develop the skills needed to succeed in their jobs.

Scientometrics has many practical applications and is used in a wide range of fields, including science policy, academic research, industry, information management, and knowledge management. By providing quantitative information

about the structure and dynamics of science, scientometrics helps decision-makers make more informed decisions about funding, collaboration, and research priorities. It also helps researchers evaluate the quality and impact of their work and develop new research strategies that are more likely to yield important results.
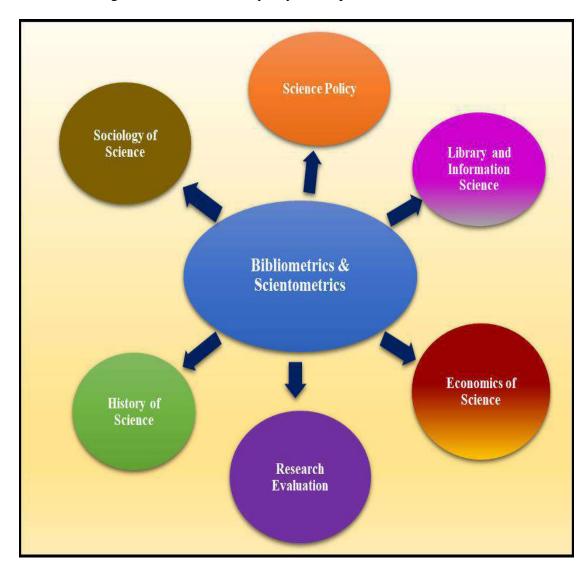
Figure 2.2: Major domains of application of Scientometrics and bibliometrics

2.9. Features and Characteristics of Scientometrics

Scientometrics is the quantitative analysis of science, technology, and innovation. It is a multidisciplinary field that uses statistical and mathematical methods to measure and analyse scientific activities. It has many features and characteristics that make it a unique field of study. These include:

2.9.1. *Quantitative*

The primary characteristic of scientometrics is its quantitative approach. Scientometrics relies heavily on statistical and mathematical models to analyse and measure scientific data. It uses various tools and techniques to collect and analyse data, including citation analysis, co-citation analysis, and bibliometric analysis.

2.9.2. *Interdisciplinary*

Scientometrics is an interdisciplinary field that combines knowledge from various fields, including mathematics, statistics, library science, information science, and computer science. It also draws on expertise from various fields of research, such as science, engineering, and medicine.

2.9.3. *Objective*

Scientometrics is an objective field of study. It relies on empirical data and facts, and it aims to provide an objective view of the scientific activities and their impact. The data used in scientometrics is unbiased, and the analysis is based on scientific evidence.

2.9.4. *Reproducible*

Scientometrics is a reproducible field of study. The methods and techniques used in scientometrics are well-established and standardized, allowing researchers to replicate studies and obtain similar results. This reproducibility ensures the reliability and validity of the results obtained.

2.9.5. *Universal*

Scientometrics represents a universal field of study with broad applicability across all areas of science and technology, encompassing social sciences, natural sciences, and engineering. Its scope includes the investigation of various scientific activities, such as research papers, patents, and books. By using quantitative methods

and analysis, scientometrics allows researchers to gain valuable insights into the structure and dynamics of scientific knowledge. Its interdisciplinary nature further enhances its utility in understanding the trends, impact, and collaboration patterns within different scientific domains.

2.9.6. *Contextual*

Scientometrics is a contextual field of study that considers the social, cultural, and economic factors influencing scientific activities. This approach provides a more accurate and comprehensive view of the dynamics within the scientific realm, allowing researchers to gain valuable insights into the broader implications and impact of scientific endeavors. Such contextual analysis is essential for shaping effective science policy, fostering collaborations, and guiding research priorities, as it considers the nuanced interplay of various factors that shape scientific output and advancement.

2.9.7. *Dynamic*

Scientometrics is a dynamic field of study. It aims to capture the ever-changing nature of scientific activities and their impact. The data used in scientometrics is constantly changing, as new research is published, and new technologies are developed.

2.9.8. *Multidimensional*

Scientometrics is a multidimensional field of study. It analyses scientific activities from multiple perspectives, including the quality, quantity, impact, and efficiency of scientific activities. This multidimensional approach helps to provide a more comprehensive view of scientific activities and their impact.

2.9.9. *Collaborative*

Scientometrics is a collaborative field of study. It encourages collaboration between researchers from different fields and institutions. This collaboration helps to improve the quality of research and facilitates the exchange of knowledge and expertise.

2.9.10. *Practical*

Scientometrics is a practical field of study. It has many practical applications, including science policy, academic research, and industry. By providing quantitative information about scientific activities, it helps decision-makers to make more informed decisions about funding, collaboration, and research priorities.

Scientometrics is a unique field of study that combines knowledge from various disciplines to analyse and measure scientific activities. Its quantitative, interdisciplinary, objective, reproducible, universal, contextual, dynamic, multidimensional, collaborative, and practical features and characteristics make it a valuable tool for understanding scientific activities and their impact. By providing objective and empirical data, scientometrics helps decision-makers to make informed decisions and improve the efficiency and effectiveness of scientific research.

2.10. Limitations of Scientometrics

Although scientometrics has many benefits and is an important field of study, it also has several limitations. Here are some of the limitations of scientometrics:

2.10.1. *Limited data coverage*

One of the main limitations of scientometrics is that it relies on data sources that may not be comprehensive or accurate. For example, scientometric studies often rely on citation data, which may not capture all the relevant publications or may be biased towards certain disciplines.

2.10.2. *Quality V/s Quantity*

Scientometric studies often focus on the quantity of scientific publications, citations, or collaborations, but may not capture the quality of research. This is problematic, as the quality of research is important in determining its impact and influence.

2.10.3. *Interpretation of data*

Scientometric studies relies on statistical methods and algorithms to analyse data, which may lead to misinterpretation or misrepresentation of data. For example, a high citation count may not necessarily indicate that a paper is of high quality or has had a significant impact.

2.10.4. *Neglect of non-scientific outputs*

Scientometrics focuses on scientific publications and their impact. However, it may neglect other important outputs of scientific research, such as patents, software, or policy reports.

2.10.5. *Disciplinary bias*

Scientometric studies are susceptible to bias towards certain disciplines. This is because some disciplines may have more publications, citations, or collaborations than others. This bias can lead to a misrepresentation of the scientific landscape and can impact funding and policy decisions.

2.10.6. *Overreliance on metrics*

Scientometric studies may overemphasize the importance of metrics, such as citation counts or h-indices, in evaluating the impact of research. This may lead to a narrow and incomplete understanding of the value and impact of scientific research.

2.10.7. *Ethical concerns*

The use of scientometric methods to evaluate research activities can raise ethical concerns, such as the potential for misuse of metrics, gaming the system, or unfair comparisons of researchers or institutions.

Overall, scientometrics remains a valuable tool for evaluating and measuring scientific activities, but it possesses inherent limitations. To overcome these constraints, multiple data sources are essential, considering both the quality and quantity of research outputs while interpreting data meticulously and avoiding disciplinary and metric biases. Adopting scientometrics thoughtfully and critically aids in gaining a deeper understanding of the scientific landscape, facilitating informed decisions about research funding and policy.

2.11. Scientometric Indicators

The researcher categorizes scientometric indicators and evaluation tools into several key categories for analysis as shown in Figure 2.3.

- *Quality metrics***:** Quality metrics focus on examining the cited references, analysing citations from sources such as the Web of Science (WoS), and conducting overall, year-wise, and journal-wise citation analyses. Additionally, this category investigates metrics such as the number of highly cited papers during the study period.

- *Basic metrics:* This category involves conducting year-wise, growth patterns, activity index, Relative Growth Rate (RGR) and Doubling Time (DT), calculating metrics such as Annual Ratio of Growth (ARoG) and Average Growth Rate (AGR), document type-wise analyses, language-wise, explore the most researched areas and most commonly used keywords.

- *Author metrics:* This category centers around analysing authorship patterns, measuring the degree of collaboration, size of a research team, prolific authors, impactful authors, collaborative authors, and co-authorship index (CAI).

- *Geo-metrics:* Geo-metrics involve examining the productivity of countries in terms of research output, analysing the year-wise distribution of the most productive countries, and identifying the most collaborative countries in scientific research.

- *Institution-cum-publisher metrics:* This category focuses on evaluating the research productivity of institutions and organizations, identifying enhanced organizations, productive publishers, exploring funding agencies, and examining grant numbers associated with research outputs.

- *Journal metrics:* This category focuses on productive sources by using Bradford's law of scattering and zone-wise distribution of journals.

- *Citation analysis:* This metric explores highly cited papers and the distribution of citations across the scientific literature in the discipline.

- *Forecasting metrics:* This category involves predicting future growth using time series analysis and assessing the applicability of Lotka's Law of scientific research output in the field. These metrics aim to provide insights into the future trajectory of collaboration index (CI), collaborative coefficient (CC), and compound annual growth rate (CAGR) research in the respective domain.

By organizing scientometric indicators and evaluation tools into these categories, researchers gain a comprehensive understanding of various aspects of research output, quality, collaboration, countries, institutions, and future trends within the field.
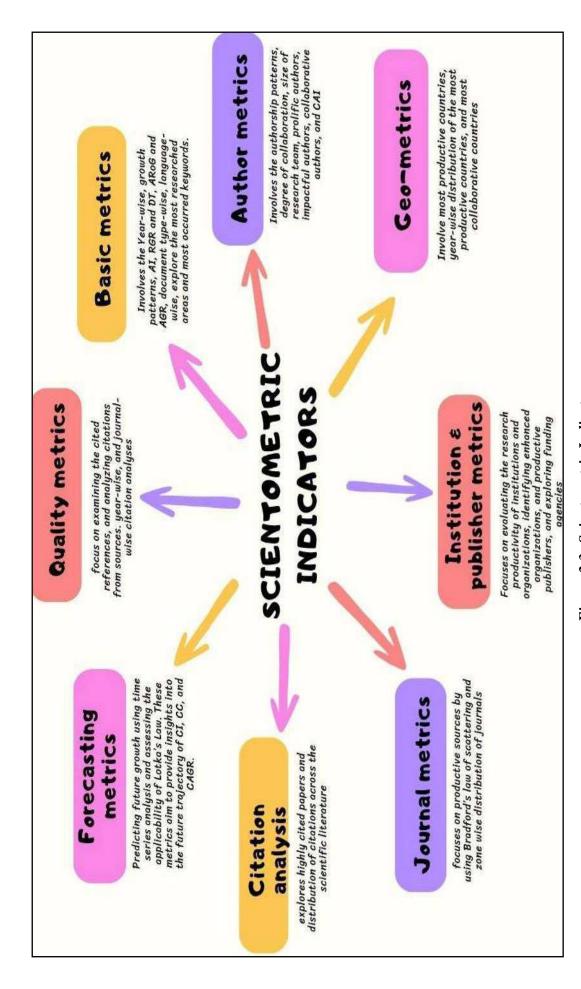
Figure 2.3: Scientometric Indicators

Activity Index (AI)	Activity Index accounted as the relative research effort of a particular country in a given field, and it is explained as AI= {(given field's share in the country's publication output)/ (given field's share in the world's publication output)} x 100.
Annual Ratio of Growth (ARoG)	Annual Ratio of Growth = Current year output/Last year output and Annual Growth Rate = (Current year output - Last year output)/last year output.
Average Author per Paper (AAPP)	The average number of authors associated with each published paper provides insights into collaboration patterns and authorship practices within a research field.
Annual Growth Rate (AGR)	Annual growth rate is a scientometric indicator that measures the rate of growth of a particular research field over a specified period of time, typically a year. It is used to track the growth and development of a particular field and to identify emerging trends and patterns.
Citation Count	Citation count is the number of times a research output (such as a paper or a book or a book chapter etc.) is cited by other publications. It is one of the most widely used scientometric indicators, as it is a direct measure of the impact and influence of research. High citation counts indicate that a publication is influential and has had an impact on the field.
Co-Authorship Index (CAI)	CAI = (number of single-authored papers in a year/total number of single-author papers of the study period)/(total papers in that year/total papers of the study period) X 100.
Collaboration Index (CI)	The collaboration index is the mean number of authors per joint-authored publication. Number of authors of total joint publications/total joint Publications.
Collaborative Coefficient (CC)	The methodology of the Collaboration Coefficient has been suggested by Ajiferuke. It is based on the counting of fractional productivity defined by Price and Beaver. Ajiferuke observes, that CC indicates the zero when a single-authored paper is dominated and counted 1-1/j than an authored paper being dominated single. This implication shows that a higher value of CC means a higher probability of multi or mega-authored papers.
Compound Annual Growth Rate (CAGR)	Compound Annual Growth Rate (CAGR) it is used to measure the average annual growth rate of published papers over a specific period of time, taking into account compounding effects.
Degree of Collaboration (DC)	It explains the prevalence of the proportion of single-authored articles and multi-authored research output publications,
Eigenfactor	The Eigenfactor is a measure of the influence of a journal. It takes into account not only the number of citations a journal receives but also the quality and influence of the citing publications. It is a more comprehensive measure of the impact of a journal than just the raw number of citations.

g-index	The g-index is a similar measure to the h-index, but it places more weight on highly cited papers. It is based on the number of papers and the number of citations per paper. A researcher has a g-index of g if they have g papers that together have at least g2 citations. The g-index gives more weight to highly cited papers, which can provide a more accurate assessment of the impact of research.
h-index	The h-index is a measure of both productivity and impact. It is based on the number of publications and the number of citations per publication. A researcher has an h-index of h if they have h publications that have been cited at least h times each. For example, a researcher with an h-index of 10 has 10 papers that have each been cited at least 10 times.
Impact Factor	The Impact Factor is a measure of the influence of a journal. It is based on the average number of citations per paper published in a journal over a certain period of time. It is widely used to rank journals by their impact but has been criticized for its limitations and biases.
Relative Growth Rate (RGR) and Doubling Time (DT)	The relative growth rate (RGR) is the increase in number of articles per unit of time. The mean relative growth rate (R) over the specific period of the interval.
Time Series Analysis (TSA)	TSA is a statistical method used to analyse and interpret patterns, trends, and relationships within a sequence of data points collected over time.

2.12. Conclusion

Scientometrics is a multidisciplinary field that offers a comprehensive overview of research output, trends, and issues within specific domains. It encompasses bibliometrics, scientometrics, and informetrics, which together provide valuable insights into the quantitative aspects of scientific information and communication processes. Bibliometrics focuses on the measurement and analysis of bibliographic records, while scientometrics extends this analysis to the broader scientific research landscape. Informetrics encompasses a broader perspective, examining information and communication processes beyond scholarly literature. Together, these fields provide a holistic understanding of the quantitative dimensions of research and knowledge dissemination.

Citation analysis is a fundamental application of scientometrics. It allows for the evaluation of the impact and influence of publications by examining the frequency of citations received by works. Citation analysis helps identify influential papers, researchers, and journals, facilitating the assessment of research impact and the identification of emerging trends within a specific field. Scientometric laws, such as Bradford's law and Lotka's law, contribute to our understanding of the patterns and distribution of scientific literature. Bradford's law describes the concentration of highly cited articles in a small number of core journals, while Lotka's law quantifies the productivity distribution among authors. Scientometrics finds application in various domains. It assists in evaluating research productivity and impact, identifying emerging research areas, facilitating research funding decisions, and informing policy-making in academia and beyond. By quantitatively analysing research output, collaborations, and citation patterns, scientometrics provides valuable indicators for assessing scholarly activities and understanding the dynamics of knowledge creation and dissemination.

However, scientometrics also has its limitations. Data collection and interpretation may be subject to biases, particularly in areas where alternative forms of publication or citation practices exist. Additionally, scientometrics may not capture qualitative aspects of research, such as the significance of individual contributions or the societal impact of scientific advancements. Despite these limitations, scientometrics continues to be a powerful tool in understanding the landscape of scientific research. Its quantitative nature and ability to provide insights into research trends, impact, and collaborations make it a valuable approach for researchers, policymakers, funding agencies, and other stakeholders.

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CHAPTER – III

REVIEW OF LITERATURE

3.1. Introduction

The literature review identifies, evaluates, and combines relevant literature in a specific research area, it shows how knowledge has evolved in a particular domain, what has been already done, accepted, and what has emerged and enlightened the current state of thinking on the subject. In addition, related literature of research-based texts i.e., secondary sources such as research articles, dissertations, and thesis identify a research gap and light on how a particular research project fills this gap. However, the review of literature not only offers a set of evidence, i.e., often not fully illustrated by the current knowledge situation, but some studies on others guide the researcher, what is known in statistical analysis as sample selection, bias -a type that results from choosing a non-random sample of data for further analysis. As a result, the narrative review offers a comprehensive investigation in the field for the development and testing of theory.

The idea of systematic evaluation of scientific literature is to collect, organise, present, and evaluate evidence according to pre-set criteria. Whereas, non-systematic evaluation of studies that the researcher deems appropriate (Tranfield et al., 2003). A systematic review as such can strike a balance between the comprehensive identification of a larger group of publications and the systematic identification of a smaller set of studies that meet the criteria for the research agenda.

The first paper on bibliometrics on 'Indian physics and astronomy research' was published in 1964 (Rajagopalan & Sen, 1964), six years before the publication of the first bibliometric research paper on Indian physics (Dutta & Rajagopalan, 1958).

Even though the above-mentioned manuscript was not a bibliometric study in the true sense, this article is a quantitative analysis of Physics Abstracts that covers the Indian physics literature. The author showed a gateway for quantitative analysis of research in Indian physics and astronomy, later which became bibliometric and scientometric studies on Physics and grabbed the attention of bibliometricians or scientometricians from the beginning of Indian bibliometric research.

Further, the 'International Society for Scientometrics and Infometrics (ISSI)' was founded in Berlin in 1993 during the international conference on bibliometrics, scientometrics, and informetrics. This is an exclusive association for researchers and professionals in the field of scientometrics. Whereas, the society started organising a biennial international conference in 1987 (*Conferences | International Society for Scientometrics and Informetrics*, 1987). The 18th international conference was held in KU Leuven, Belgium in 2021, and the 19th will be held at Indiana University, Bloomington, USA in 2023 (*Proceedings of ISSI 2021 | International Society for Scientometrics and Informetrics*, 2021).

In this chapter researcher attempted to study the "Growth and collaboration trends in the field of Indian Optics research publication: A Scientometric analysis". The researcher extracted related literature from various sources from peer-reviewed journals, and databases (Web of Science, SCOPUS, Emerald, Springer, JStore, IEEE, Taylor and Francies, Science direct, Wiley online library, DOAJ, and IRINS) were used to conduct systematic and Scientific literature review. Further, sources of the literature review were analysed, and the latest and most significant literature on the various aspects of scientometric research like scientometric tools, scientometric laws, techniques, and indicators were also studied. For the convenience of the study researcher carried literature review under the following headings:

- ✓ Growth of Publications Productivity Global Scenario;

- ✓ Growth of Publications Productivity Indian Scenario

- ✓ Scientometric analysis of various subjects and sources;

- ✓ Scientific research productivity of institutions/organizations and countries;

- ✓ Scientific research productivity collaborative works (Country level, Institutional level, and Individual level);

- ✓ Citation analysis (Country level, Institutional level, and Individual level);

- ✓ Bibliometric laws and various indicators.

3.2. Growth of Publications Productivity Global Scenario

Duplančić Leder et al., (2023) authors provide an overview of satellite-derived bathymetry (SDB), a promising and cost-effective method for determining shallow water depths. The authors conducted a bibliometric analysis of scientific articles on SDB using the Web of Science (WoS) and Scopus databases. The analysis revealed that empirical statistical methods have been predominantly used in SDB research, but there has been an increasing trend towards using automated artificial intelligence methods, particularly machine learning. The paper highlights the potential of SDB data as a low-cost source for bathymetric measurements in shallow coastal areas, with satellite methods proving effective up to 20 meters depth. However, limitations exist due to atmospheric and water column parameters and seafloor material properties. The study concludes that although significant progress has been made in SDB, further research is needed to meet international hydrographic survey standards.

Ming and Qin, (2023) conducted a bibliometric analysis and knowledge graph study on the trends in research related to ophthalmic microperimetry over a span of 30 years. The study employed various bibliometric analysis methods,

including publication counts, citation metrics, co-authorship networks, and keyword co-occurrence analysis. The results indicate a significant increase in research output, indicating a growing interest in ophthalmic microperimetry as a research topic. The study identifies key research areas within the field, particularly emphasizing the application of microperimetry in age-related macular degeneration, diabetic retinopathy, and glaucoma.

Zhang et al., (2023) conducted a bibliometric analysis to explore global research trends and hotspots in apoptosis-related studies within the context of glaucoma. The study examined articles and reviews published between January 1999 and November 2022 from the Web of Science Core Collection. Key findings include an increasing publication trend over time and the prominent contributions of the United States and China in terms of both publication output and citations. The analysis also revealed emerging advancements, such as the discovery of key regulatory mechanisms in retinal ganglion cell apoptosis, which hold promise for developing precise treatment strategies for glaucoma. This study offers valuable insights into the role of apoptosis in glaucoma and guides future research and potential therapeutic approaches in the field.

Zhu et al., (2023) conducted a bibliometric analysis of DOFS signal processing and pattern recognition using CiteSpace. The authors analysed 861 articles from 2010 to 2021 and found that the number of publications has increased significantly, with the USA, China, and Italy being the leading publishing countries. Key journals and highly cited references focused on OTDR, DAS, and DTS. Six key research areas were identified: data acquisition, data preprocessing, feature extraction, classification, localization, and damage detection. The research demonstrated

interdisciplinary collaborations. CiteSpace was used to visualize and analysed the interconnections between knowledge domains.

Hod et al., (2022) conducted a bibliometric analysis of digital pathology (DP) research publications from 1991 to 2021 using the Scopus database. The results of the analysis indicated a continuous growth in the number of publications on DP, with a total of 1848 documents analysed. The United States emerged as the most productive contributor to the publications, followed by the United Kingdom and European countries. The University of Pittsburgh Medical Center produced the highest number of publications. The keyword analysis revealed that DP research primarily focuses on medical imaging and engineering within the field of histopathology.

Zhao, J., et al., (2022) conducted a bibliometric analysis of the field of digital pathology using VOSviewer, CiteSpace, Gephi, and R. The study found that digital pathology research is primarily active in the journal groups of molecular, biological, and immunology; pharmaceutical, medical, and clinical; and psychology, education, and health. The study also found that the United States is a leading contributor to digital pathology research, with the top 10 publishing institutions being from the U.S. Over the past two decades, global research in digital pathology can be categorized into two major areas: system verification and optimization of whole slide imaging (WSI) and the application and development of artificial intelligence in digital pathology. Recent research has witnessed a concentration on deep neural network technologies, driven by advancements in computer technology and machine learning concepts.

Zhao, L., et al., (2022) conducted a bibliometric analysis of primary open-angle glaucoma (POAG) research from 2000 to 2021. They found that the number of publications on POAG has increased significantly over the past two decades, with the

United States being the leading publishing country. The 'Journal of Glaucoma' was the most productive journal, and American researchers had the highest h-index and the most citations. The authors identified seven key research areas in POAG: intraocular pressure, normal-tension glaucoma, risk factors, the trabecular meshwork, optical coherence tomography, surgery, and mutation. They also found that research on POAG has expanded beyond ophthalmology to include other disciplines such as biochemistry, molecular biology, and pharmacology.

Yang et al., (2022) present a comprehensive analysis of the research landscape of artificial intelligence (AI) in the field of retina. Using bibliometric methods, the study examines publication trends, countries, journals, authors, international collaborations, and keywords associated with AI in the retina. The findings reveal a significant interest in AI in retinas within the scientific and medical community, with publications steadily increasing over the past decade. The study highlights the contributions of countries such as the United States, China, and India, as well as influential authors from Austria, Singapore, and England. Notably, international collaborations were found to enhance the impact of research in this field. The analysis of keywords identifies popular topics, including diabetic retinopathy and optical coherence tomography, while noting that AI in retina research is predominantly published in engineering and computing-focused journals.

Yu, Z., et al., (2022) conducted a comprehensive analysis of global research trends in OCT for ophthalmic imaging. The study examined 4,270 articles published between 2011 and 2020, showing a significant annual growth rate of 11.5%. The USA was the leading country, with 2,094 articles, followed by China (622 articles) and the UK (512 articles). The University of California, Los Angeles, was the most active academic institution, with 134 publications. The University of California, Los

Angeles, emerged as the most active academic institution, and Investigative Ophthalmology and Visual Science (IOVS) was the most productive journal. SD-OCT and OCTA were identified as highly cited references, indicating increasing interest in these advanced OCT techniques for retinal imaging and vascular visualization. VOSviewer software facilitated visualized bibliometric analysis, generating maps for research trends, countries, publications, and researchers. Co-cited reference and co-authorship analyses were conducted, and CiteSpace software identified keywords with strong bursts, indicative of research frontiers.

Bitzenbauer (2021) a bibliometric analysis of the scientific outputs of the scientific and educational research community in the field of quantum physics in the period from 2000 to 2021. A sum of 1,520 research articles published in physics and science journals were collected from the Web of Science and SCOPUS database for bibliometric analysis. The analysis provides an overview of quantum physics scientific production, predominant publishing areas, most participating researchers and countries (including collaborative relations), and research areas. Results show that steady increase in research results in quantum physics over the last two decades. In addition, they show a shift across research efforts.

Marrugo et al., (2021) addressed the issue of correlation estimation between variables that are subject to an order restriction. Such restrictions commonly occur in scientometric indices, where higher values represent higher levels of research output. The researchers proposed a novel approach for calculating the correlation in such cases. Their method involved generating a random sample of variables that adhere to the same order restriction as the original variables. The correlation between the original variables was then estimated by assessing the correlation between the random variables. Through the application of their method to a dataset of scientometric

indices, the researchers demonstrated its efficacy in accurately estimating correlations, even when the variables were subject to an order restriction.

Marrugo, Bustos-González, and Rueda (2021) assessed the optics research publications from 1970 to 2002 in Colombia published in international journals using various scientometric indicators. The study extracted data from the SCOPUS belonging to the Atomic and Molecular Physics and Optics subject category and found that the research growth increased during the last two decades. A greater number of articles were published in high-impact journals, resulting in 10% of the publications appeared as highly cited papers in the world, and more than 25 institutions contributed significantly to the research with many collaborations (National and International). The normalized citation impact for Colombian optics research is 0.95, only five points below the world average, and ranked second in Latin America optics research is an established research area in Colombia with high impact, and many active groups from different institutions spread throughout the country.

Wu et al., (2021) performed a study on the contemporary research topics of the physics teacher in 2016 – 2021 using the CNKI database. The study analysed the 1,463 publications of the physics teachers and found the hotspots and directions. Among them, the main research hot spots in physics education are education, physics teaching aids, educational assessment, Newtonian mechanics, physics experiments, education policy and management, learning methods, electromagnetism, student development, history of physics, kinetics, engineering optics, etc.

Ain et al., (2020) present a bibliometric analysis of Dynamic Bandwidth Allocation (DBA) algorithms in the telecommunication field from 2009 to 2018. The analysis reveals that the number of publications and citations in this field has significantly increased in recent years, indicating an active research interest. The most

influential DBA algorithms are identified within three categories: EPON technology for meeting QoS requirements, DBAs for Elastic Optical Networks, and DBAs for long-reach PON. Prominent contributors in this field include Assi CM and Kramer G, and preferred journals include PlosOne and the Journal of Optical Communication and Networking. The analysis also shows that there is a strong correlation between research contribution and expenditures, with China and the Beijing University of Posts and Telecommunications making substantial contributions to DBA PON research globally. The paper provides valuable insights into the research trends and key players in the field of DBA algorithms.

del Río, Russell and Juárez (2020) conducted research on the development of Mexican scientific publications in applied physics during 1973 – 2017 from the WoS database using various bibliometric indicators (prolific authors, institutions, journals, and collaborating countries). The study examined 9,078 publications appended to applied physics that were retrieved and analysed. Results show that there is exponential growth in the production of Mexican papers in 45 years of the study, five Mexican institutions contributed the highest publications, further, a text mining technique was used to determine the most common words in the abstract elements from 1985 onwards.

Espiritu et al., (2020) conducted a systematic review to assess the scientific productivity in the Southeast Asian (SEA) region in the field of multiple sclerosis and neuromyelitis optica spectrum disorder (MS/NMOSD). The study found that the total number of publications in the SEA region related to MS/NMOSD was low in quantity, with only 142 articles meeting the eligibility criteria. Most studies were cross-sectional and case reports/series, which suggests that the overall quality of the published articles was low. The authors also found that there was a positive

correlation between% GDP for R&D and many productivity indices in the MS/NMOSD field. This suggests that countries with a higher investment in research and development tend to produce more high-quality publications in this field. The authors conclude that the scientific impact of MS/NMOSD in the SEA was considered low in quantity and quality.

Koh et al., (2020) conducted a bibliometric analysis of retinal OCT research using the Scopus database over a period of 31 years. The study employed various bibliometric indicators, including publication and citation counts, collaboration networks, and keyword co-occurrence analysis. The study aimed to provide a comprehensive overview of the scientific output, key research areas, and emerging trends in retinal OCT research. The analysis revealed a significant growth in the number of publications, with retinal diseases, retinal imaging technologies, and diagnostic applications as the prominent research areas. Emerging topics such as AI in retinal OCT and OCT angiography were also identified. International collaboration was a prevailing trend, with contributions from diverse countries and institutions.

Yu, Z.L., et al., (2017) conducted a ten-year scientometric analysis of global ophthalmology publications. The study identified a significant increase in published papers, indicating growing research interest. Collaborative research, particularly through international collaborations, showed an upward trend with more multi-authored papers. Citation analysis highlighted highly cited papers and influential researchers, revealing the impact of ophthalmology research. The study also identified key thematic areas receiving significant attention, providing insights into the evolving research landscape. Although the study's systematic approach, large sample size, and comprehensive analysis enhance its credibility, limitations include reliance on

bibliometric data and the exclusion of non-indexed or non-English publications. The ten-year study period may also restrict capturing long-term trends.

Yu, Z.L., et al., (2017) conducted a bibliometric analysis of ophthalmology research literature published between 2017 and 2021. The study identified four hotspots in ophthalmology research: epidemiological characteristics and treatment modalities of ocular diseases, artificial intelligence and fundus imaging technology, COVID-19-related telemedicine, and screening and prevention of ocular diseases. The study also found that research trends in the field included artificial intelligence, drug development, and fundus diseases. Additionally, the study showed increasing collaboration between ophthalmology and non-ophthalmology-related subject categories over time.

Jaedicke et al., (2013) conducted a comparative evaluation of metrics used in spectroscopic optical coherence tomography (OCT) for analysis and visualization purposes. The study focused on intensity-based, spectral slope, and spectral shape metrics, assessing their effectiveness in differentiating tissue types and detecting subtle spectral variations. Experimental data from biological tissue samples were analysed using these metrics to evaluate their accuracy and relevance in characterizing tissue composition and structural characteristics. The findings highlighted the strengths and limitations of each metric, providing valuable guidance for researchers and practitioners in selecting appropriate metrics for spectroscopic OCT applications.

A bibliometric study of optics research was done by **Takeda and Kajikawa (2009)** for the years 1991-2005. The authors built the network of article citations and performed a topological clustering method to examine the research structure and identify emerging research areas in optics. The authors found that optics consists of

five major sub-clusters, optical communications, quantum optics, optical computing, optical and laser analysis. Further explored the detailed structures of the subclusters within and found some emerging research areas such as nonlinearity in photonic crystal fibers, broadband parametric amplifiers, and in vivo imaging methods. The study also discussed the differences between the research front and the intellectual base in optics.

3.3. Growth of Publications Productivity Indian Scenario

Gupta et al., (2022) studied the quantum optics research output by Indian authors during 1996 – 2021 using the Scopus database. A total of 67,274 Global research publications were found on the topic of quantum optics. India contributed 3.13% (n=2108) to the global output. Nearly 30% of the Indian publications received funding with international collaboration. The study found that 455 institutions and 635 authors involved in Indian quantum optics research output, among the 'Indian Institute of Science, Bangalore' (n=96), 'Agarwal, GS' (n=33), and the 'Physical Review A' (n=233) are the top institute, author, and journal. The study concludes that during the last two decades, there have been a large number of publications in the field of "quantum optics" that have significantly influenced the development of many different quantum technologies both in India and abroad.

Gupta et al., (2022) examined the trends and characteristics of quantum sensing research worldwide. The paper provides a comprehensive analysis of research publications in the field from 1991 to 2020, offering valuable insights into the growth, collaboration patterns, and citation impact of quantum sensing research. The study utilizes scientometric techniques to assess publication patterns, identify leading countries and institutions, and explore key research themes and keywords.

Patel et al., (2022) conducted a bibliometric analysis to identify the top 100 most-disruptive articles in ophthalmology based on their impact on clinical practice, research methodologies, and patient outcomes. The study provides a historical overview of ophthalmology's development over the past six decades. The analysis underscores the substantial influence of the identified articles, which have significantly shaped the field through seminal discoveries, innovative techniques, and paradigm shifts. The research also delineates distinct research themes within ophthalmology, reflecting its increasing specialization and focused areas of inquiry. Moreover, the study examines authorship and collaboration patterns, revealing the global distribution of research networks and collaborative efforts in the field.

Mohan, B.S., and Mallinath Kumbar (2021) examine research publications on stellar and galactic astrophysics in India over the past 20 years using scientometric techniques. The analysis of 4,352 papers reveals significant growth in the literature. Key keywords include "galaxies: active," "stars: neutron," "galaxies: evolution," "galaxies: ism," and "radio continuum: galaxies." The Tata Institute of Fundamental Research (TIFR) contributes the most papers (26.03%), and Srianand R is the most published author (143 publications). Collaboration between India and the USA is prominent. "Monthly Notices of the Royal Astronomical Society" is the leading journal with 1,434 papers and 25,853 citations. The research received a total of 113,860 citations, resulting in an average of 26.16 citations per item and an h-index of 115. The highest Altmetric Attention Score achieved is 2411.

Das, Das and Dutta (2021) undertook a bibliometric study on 159 publications in Indian physics and astronomy during 1964 – 2020, contributed authors and unique subject areas were analysed. Hotspot research domains of physics and

astronomy were selected for the study and it was found that publications attention is necessary according to the requirements and relevance of time.

Dhawan et al., (2021) conducted a comprehensive analysis of research in quantum machine learning (QML) to evaluate its global status. Utilizing quantitative and qualitative methods, they examine research productivity and performance at various levels. Data from the Scopus database for 1999-2020 is analysed, encompassing 1374 publications and 22434 citations. The study includes bibliometric mapping to visualize relationships among countries, institutions, authors, and keywords. The findings reveal that the United States and China are the leading contributors, with 32.46% and 22.56% of global output, respectively. Top organizations and authors hold significant shares. Key research areas, contributors, keywords, and productive journals are identified. However, the study notes that despite QML's interdisciplinary nature, the existing literature remains limited and relatively insignificant, despite more than two decades of research. The authors conclude that QML is in its nascent stage of development.

Gupta, Dhawan, and Mamdapur (2021) present a scientometric assessment of global publications in Quantum Cryptography research from 1992 to 2019. By employing scientometric analysis techniques, the study provides valuable insights into the research landscape, key contributors, collaboration networks, and emerging themes within the field. The review highlights the significant growth in research output and identifies leading countries and institutions in Quantum Cryptography. It further analyses collaboration patterns, investigating authorship and citation patterns to identify influential researchers and publications. Additionally, the study employs keyword analysis to uncover emerging thematic trends, shedding light on the evolving research focus in Quantum Cryptography. The findings of this research contribute to a

comprehensive understanding of the evolution and trends in Quantum Cryptography research, supporting researchers, institutions, and policymakers in making informed decisions and advancing the field.

Memon et al., (2020) conduct a comprehensive analysis of the research landscape and trends in Passive Optical Networks (PONs). Authors utilise bibliometric techniques and the CiteSpace visualization tool to examine 3,381 Science Citation Index (SCI) publications worldwide from 2010 to 2019. The study focuses on 528 influential research articles, identifying key areas of PON research, including Modulation, WDM PON, Transmission, Semiconductor optical amplifier, and Dynamic bandwidth allocation. The analysis reveals recent research hotspots such as Energy efficiency, NG-EPON, and Chaotic encryption, while future trends are predicted to encompass TWDM PON issues, fronthaul implementation in NG-PON2, 5G-PON, and encryption methods for physical layer security. Additionally, the article highlights leading core authors, institutes, countries, and journals contributing to PON research.

Satish Kumar (2020) presents a comprehensive analysis of the research productivity in Astronomy and Astrophysics in India over a span of thirty years (1988-2017). The study involved the examination of 20,311 research publications obtained from the Web of Science database, employing scientometric tools and techniques. The main objectives were to assess the growth of astronomical literature, document types, open access publications, prolific source journals, collaborations with other countries, and research funding agencies, and identify the most productive institutions and authors in India. The findings encompassed publication patterns, compound annual growth rate (CAGR), degree of collaboration, H-Index, and the nature of research activities conducted within the field.

Kumar, Kumar KT and Biradar (2018) scientometrics study was conducted to analyse the Quantum Computing research output published during 2011 – 2017 using the Web of Science database. A total of 10, 551 papers were retrieved and found that with the consistent growth in the Quantum Computing research publications during the study period, a significant number of papers were published in good-impact journals. Peter A John (n=46) most productive author and the journal 'Physics Review B' (n=610) was the most productive journal. Further, the study used various indicators like Degree of collaboration, Relative Growth Rate, and doubling time. The degree of collaboration was 0.875 and Bradford's law was used and did not fit in this.

Gupta and Dhawan (2009) examined the state of physics research in India during 1993 – 2001 using the WoS database, in particular the nature of the research system, the institutions involved, funding, and characteristics of various government R&D institutes and related professional organizations. India has contributed a total of 27,018 papers in mainstream journals in physics with an annual growth rate of 2.5%. Also, the author studied the top 25 most productive institutions, among the Tata Institute of Fundamental Research (TIFR) was the top with 2008 publications. In terms of collaborative research, India collaborated with 60 countries, among USA, Germany, France, England, and Japan were its leading countries.

Dhawan and Gupta (2007) conducted a study on Indian physics publications and their subfields output during 1990 – 1998 using the INSPEC database. The study revealed that India's contribution to physics is remarkably high (86%) in journals covered by the Scientific Citation Index (SCI), of which 26.4 percent were in high-impact journals (IF = 1.5). Furthermore, the study also found that there were huge differences in the quantity and quality of publications in various broad and narrow

areas of physics. Physical research activities are led by selected national veterinary institutions. Out of the 435 institutions involved in physics research, only 20 accounted which is less than 50% of the total production.

Rajendiran, Ramesh Babu and Gopalakrishnan (2005) analysed the global productivity of "fiber optics" publications using the Ei-Tech index database from 1999 to 2003. The growth of publications, authorship pattern, bibliographic forms, ranking of core journals, and nature of the research was analysed. During the period, 8,302 papers were published, among 1761 highest papers published in 2001 and 1548 lowest papers published in 2003; 99.9% of the papers were published in the English language. Further, data reveals that the solo author contributed 11.37%, two authors contributed 19.72%, and five or more authors contributed 17.33% of the total publications. The USA was found the leading country with 27.8%, and the 'Journal of LightWave Technology' was the preferred source for the researchers.

3.4. Scientometric Analysis of Various Subjects and Sources

Kappi and Biradar (2022) conduct a comprehensive bibliometric analysis of the Journal of Optics to evaluate its research performance over 26 years. The objective of the study is to assess publication patterns, citation impact, collaboration networks, and prospects of the journal. Utilizing bibliometric analysis methods, the authors analyse various indicators, including publication counts, citation counts, authorship patterns, collaboration networks, and keyword analysis. The study examines trends and patterns within the journal's publications. The findings provide valuable insights into the research performance of the Journal of Optics over 26 years, highlighting growth in publication output, citation impact, and international collaboration.

Kappi and Biradar (2020) conducted a bibliometric analysis to identify the knowledge domain within Indian optics research using the Scopus database. Their study utilized bibliometric methods such as citation analysis, co-authorship analysis, and keyword analysis to uncover prominent research areas, influential authors, collaborations, and key research topics in Indian optics research. The analysis revealed that optical communications, optical materials, and optical imaging emerged as the most prominent research areas. Noteworthy authors in the field included C.N.R. Rao, G.V. Srinivasan, and K.L. Chopra, while active research collaborations were observed between Indian and foreign institutions. Key research topics encompass optical fibers, nonlinear optics, and metamaterials.

Kappi and Biradar (2020) conducted a bibliometric analysis of Indian optics research from 2008 to 2018 using the Web of Science (WOS) database. The objective of the study was to provide a comprehensive overview of the key trends and developments in the field of optics research in India during this specific timeframe. Employing bibliometric analysis techniques such as citation analysis, co-authorship analysis, and keyword analysis, the study aimed to identify prominent research areas, influential authors, collaborations, and emerging topics within Indian optics research. The findings of the study offer valuable insights into the growth and advancement of optics research in India, making the paper a significant resource for researchers, policymakers, and institutions.

Rai, Senger and Lohiya (2018) assessed and identified the research trends and knowledge growth in astronomy research. This study examined Indian astronomy research publications published between 1995-1991 and 2011-2015. The study analysed the astronomy research output using quantitative and qualitative indicators such as publication growth rate of research papers, authorship patterns, citation

patterns, prolific authors, international collaboration, preferred journals, and most cited articles over the period 1995 – 1991 and 2011-2015. Results found that there is no precise pattern of growth in publications in 2011 – 2015. The growth rate increased almost 300% in 2011-15 compared to 1991-95. The citations increased steadily each year, the 'Tata Institute of Fundamental Research (TIFR)' was the leading institute and IUCAA is an emerging institute in terms of publications and citations in the field of astronomy and astrophysics research in India. The Indian collaborative research was progressive and preferred to publish their papers in international journals.

Dhawan et al., (2017) have studied 9,858 papers retrieved from the SCOPUS database and conducted a systematic analysis of global publication's output on 'Metamaterial research' in terms of growth, average citation impact, collaboration works, and productive countries and organizations. The study found that 15.27% of research output growth and 10.08 CPP were counted during the study period. Further, China's share was highest to the global share i.e. (25.71%), similarly, Physics and Astronomy (59.36%) subjects produced the highest publication share. Top-20 most productive institutions and authors contributed 24.69% and 13.17% global share and received 35.72% and 25.96% of global citations respectively. Of the total output, 52 papers were identified as HCPs with an average citation value of 535.64 per paper in 10 years. The study concludes that India promotes the research and development of metamaterials for communal applications and technologies, and collaborative research was needed at national and international levels. Moreover, such support methods for the analysis of metamaterials will help to make the use of existing human resources more efficient.

Senthilkumar and Ulagannathan (2017) analysed the Astrophysics research output in India from the year 1989-2016 using the web of science database. The findings of the study revealed that The Tata Institute of Fundamental Research has contributed 2,725 records in astrophysics research during the study period of 1989 – 2016. This institute's h index based local citation score is (LCS) 23 and h-index based on the local citation score excluding self-citations is (LCSX)15 and the Global citation score (GCS) is 89. The time-series analysis study shows the future trend of growth in astrophysics research output in India tends to decrease over the years.

Velmurugan and Radhakrishnan (2015) attempted to quantify the 'DESIDOC Journal of Library and Information Technology' during 2007 – 2013. The study shows that the highest number of papers (n=181) were published in collaboration and, 121 papers were published in solo authorship. The highest number of papers (n=130) were published in 2012 and the lowest number of papers (n=58) were published in 2007. Further, it shows that the degree of collaboration varies from 0.36 to 0.77 and the mean DC is 0.59.

3.5. Scientific Research Productivity of Institutions/Organizations and Countries

Gupta and Dhawan (2007) analysed the overall performance of four key performance sectors, viz. universities, and colleges, earnest research and development, institutes of national importance, and industry, in physics research in India from 1993 to 2001 in terms of publication growth and impact on production and publication, using various bibliometric indicators. Further, the study showed a comparative analysis of the performance of different sectors involved in physics research in India. However, the academic (universities and colleges) sector along with the mission-oriented R&D sector continued to dominate the physics research landscape during the study period, contributing 42.4% and 43.1% respectively to the

country's total output in physics. Also, institutions in the mission-oriented R&D sector were more productive than institutions in the university and college sectors. This is because the institutional share for physics research was 71.8% from the university and college sector and 15.8% from the mission-oriented R&D sector, although both sectors contributed equally (42.4% and 43.1%) to the production of the country during the same period.

Jamali et al., (2015) analysed the publication trends in physics education using bibliometric tools research leads researchers to explain current scientific movements. This article examines how physicians focus on their publications, examining the production and development of research publications on the subject of physics education during 1980-2013. In the field of research of "education-education research", the Web of Science database was used to extract the data. A total of 1360 documents were analysed, including 840 articles, 503 conference papers, 22 review articles, 7 editorial articles, 6 books reviewed, and a biographical. The proportion of publications entitled "Physical Education" increased from 0.14% (n = 2) in 1980 to 16.54% (n = 225) in 2011 and a total of 8071 citations (CPP=5.93) were received. The results show that the publication and selection of physics education have increased significantly while the Malaysian population is well off. The results show that Malaysia's share is high, while physics education publications and citations have increased intensely.

The influence of interdisciplinarity on peer-review and bibliometric evaluation in physics research is studied by **Rinia et al., (2001)**. The study found that the degree of interdisciplinary does not considerable with peer judgments, only basic bibliometric indicators correlate, whereas, modern indicators do not correlate to the degree of interdisciplinarity. Finally, the study concludes that there is no general

evidence against inter-disciplinary research for peer review as well as bibliometric bias.

Kumar et al., (2009) studied the development and growth of engineering and physics research publications during 1999 – 2008 using the INSPEC database. A total of 1,677 papers with an average of 167.7 publications per year were published, and the highest (n=296) articles were published in the year 2006. The study examined the 'College of Information Science and Technology', USA, and the 'National Institute of Science, Technology and Development Studies', New Delhi with 23 publications each. 'Thelwall-M', UK (n=32) and 'Rousseau-R', Belgium (n=29) were prolific authors, the Scientometrics (n=291), the Journal of the American Society for Information Science (n=149) were the most productive institutions, authors and journals.

3.6. Scientific Research Productivity Collaborative Works (Country Level, Institutional Level & Individual Level)

Elango et al., (2021) analysed the scientific publications of India and South Korea as concealed in the Scopus database during 1998 – 2018 and compared the research performance. The study focused on the impact and quantity of publications, growth of publications and global share, international collaborative papers, publication quality, and open access pattern. Numerous bibliometric indicators were used and a new 'Relative Open Access Indicator (ROAI)' indicator was proposed to compare the number of publications in an open-access platform with all its scientific output. Among the prolific countries, India is fifth and South Korea is thirteenth in 2018. India has achieved eighth place whereas South Korea placed third during 1998 – 2018 at the global level. South Korea has performed well in international

collaboration compared to India. Both countries occupy better positions in a few areas like chemical engineering and material science.

Kappi et al., (2021) conducted a comprehensive analysis of the research productivity of three universities in Karnataka with CPEPA status. The study spanned from 2010 to 2019 and included a dataset of 8952 documents. The authors employed various metrics to assess research output, including publications, citations, h-index, Participative Index, RGR, and Dt. and conducted a keyword analysis to identify prominent research areas. Additionally, the utilization of VOSviewer and the Bibliometrix R Package for visualization purposes demonstrates the use of advanced tools for data analysis. The findings revealed that the University of Mysore exhibited the highest research productivity, followed by Karnatak University and Bangalore University. The authors recommend that these universities continue to invest in research and development, formulate a research policy, and establish repositories to augment the visibility of their publications. This paper makes a significant contribution to the literature on research productivity. It offers an extensive analysis of the research output of three universities with CPEPA status in Karnataka, identifies key research areas, and provides valuable recommendations for enhancing research productivity.

Kappi et al., (2021) present a bibliometric analysis of the top 10 pharmaceutical education institutions in India according to the NIRF rankings of 2020. Data sourced from the Scopus database (2016-2019) was analysed to examine publications, research output distribution, document types, prolific authors, preferred sources, funding agencies, highly cited papers, productive and cited countries, and frequent keywords. The Institute of Chemical Technology-Mumbai had the highest number of publications (2129), followed by Jamia Hamdard (1900) and the University

of Delhi (1833). The year 2017 showed the highest research productivity with 1508 publications, mostly articles (6067). Sekar N emerged as the most prolific author (194 papers, total citation 1954, h-index 22), and RSC Advance was the preferred source title (217 papers, total citation 2508, h-index 24). The University Grants Commission (UGC) was the top funding agency (609 papers). The United States was the most productive and cited country. This study provides valuable insights for monitoring and enhancing research in Indian pharmaceutical education institutions.

Bebi and Kumar (2018) conducted a scientometrics study on women faculty members' research publications contributing to the physics domain of selected institutions in Delhi and central universities in India during 2011 – 2015. The study focused on research performance, citations, women faculties research impact (h-index, i10-index), author's affiliation while doing research, authorship pattern, interested research areas, prolific authors, and most preferred sources to publish research results. Studies found that the women authors always preferred to be the first authors as well as corresponding authors. The University of Delhi and CSIR-National Physical Laboratory were leading institutions in total publications and Ratnamala Chatterjee from IIT Delhi was the most prolific women author.

Nagarkar and Kengar (2017) conducted a bibliometric study on 1629 publications of Savitribai Phule Pune University faculty members of the Department of Physics during 1990 – 2014 using the Scopus database. The publication data examined various aspects like year-wise growth, preferred journals, international collaboration, citations count, and so on and these publications received a total of 22618 citations. The study found that the faculties preferred to publish their research outputs in physics core journals. Among them, the Journal of Applied Physics (n=72) was the most preferred. Further, the faculty members collaborated with the USA, UK,

Germany, and Japan at the international level and with Baba Atomic Research Centre at the national level.

Alam and Shukla (2016) assessed India's research productivity in Solar Physics during 1960 – 2014 with the help of the Web of Science. A total of 2066 papers were published and received 22,254 citations. The average number of publications per year and CPP were 48.04 and 10.77 respectively. Further, the highest number of papers (n=168) was published in 2014 and the highest number of citations (1546) were counted in 2009. All these papers were published in 91 journals, among them, 'Solar Physics' (n=460; 22.26%) was the leading journal. Similarly, the 'Indian Institute of Astrophysics' (n=459) and the USA (n=420) are the most productive institutes and countries respectively in solar physics research during the study period.

Aswathy and Gopikuttan (2015) examine the productivity patterns of the faculty members of the physics department of the three universities in Kerala state. Analysis was done with various bibliometric indicators and techniques (authorship pattern, degree of collaboration (DC), Lotka's law), year-wise distribution of papers, and designation-wise. The study found that the degree of collaboration (DC) was high among the physics teachers at the universities. Lotka's law was applied and fitted in the University of Calicut (UoC) among three universities and the faculties preferred to publish the research results in closed-access journals. The study concluded that universities can achieve greater visibility, prestige, and credibility in the field of higher education by conducting quality research, which enhances the status of the university and provides greater opportunities to attract students and teachers.

Garg (2002) examined 1,223 laser science and technology papers published in the conferences and journals by India (n=347) and China (n=876) during 1993 – 1997 using the INSPEC database. Results showed that Chinese production was double

compared to India. However, the performance indicators (AI) for both countries during the study period were almost the same. Further, Chinese scientists preferred to publish in national journals, whereas, Indian scientists in international journals. The number of articles by Indian scientists in SCI journals (journals with a high-normalized impact factor) was higher than in China, therefore India had a better relationship with traditional science than China. The influence of Indian publications was greater than that of Chinese publications, as with the normalizing influence of each article, the share of articles in high-quality journals and effective publication index is evident. Indian publications are also cited more often than Chinese publications. China has better collaboration research than India, as reflected by the multi-authored publications produced by both countries.

Kim (2001) examined 4,665 research publications from physics association laboratories at Korea Universities on Physics. These publications were compared with internationally co-authored papers published in Science Citation Index. The study found that Korean authors tended to publish in Korean, Japanese, and U.K. journals, whereas, the rest of them preferred to publish in German, Dutch, and Swiss journals. Out of 18 authorship (first author) countries, 93 international collaborative papers by USA scholars received the highest citations, with a CPP of 15.9. The study concluded that Korea's research growth was considerable during the last two decades.

Davis et al., (1999) informetric study provides a valuable exploration of Australia's contribution to Ophthalmology and Optics within the Vision Science domain from 1991 to 1995. The paper's findings contribute to our understanding of Australia's research productivity, collaboration patterns, and publication trends in comparison to global counterparts. By employing scientometric and bibliometric methodologies, the authors shed light on Australia's relative strengths, publication

frequency, collaboration networks, and preferred journals. The study emphasizes the significance of tracking publication rates and emerging topics to shape the future of research in Vision Science. This informetric analysis serves as a foundation for further research and understanding of Australia's contributions in the field.

Dhawan and Arunachalam (1998) attempted to map India's contribution to the literature of physics by a physics research organization's during 1990 – 1994 using the INSPEC-Physics database. A total of 4552 in 1990 and 4211 in 1994 papers were retrieved. The study found that the contribution from the developed and developing countries, where India placed 10th rank in the global for its contribution to the world's physics research output. India's research trend declined from 2.91% in 1990 to 2.66% in 1994. Indian share in the global output by subject ranges between 2% and 3% in the 10 subfields of physics. Whereas, the USA share was 21.41% and 36.06% with the highest contribution to the global output. Materials science is the leading area of research in physics in India. Countries such as the USA, Japan, Germany, Russia, and France have increased their activity in this field. The study recommended, that to increase the financial support for physics research activities and the number of institutions.

3.7. Citation Analysis (Country Level, Institutional Level, and Individual Level)

Rahaman et al., (2021) conducted a comparative bibliometric study of research output in the physics domain in Bahrain and Kuwait during 2011–2020 using the Web of Science database. The results show that the physics research output gradually increased in both countries and 2019 was the leading year in publications (Bahrain 78) and (Kuwait 272). Concomitantly, Booudina M (n=189) was identified as the most contributed author in both countries' output. Optic (n=24) was the most preferred journal, and the most occurred keyword 'x-ray diffraction' (84 times) for

Bahrain, whereas AIP conference proceedings (n=54), and the most occurred keyword 'nano fluidics' (132 times) for Kuwait. The collaboration index was 2.2 for Bahrain and 4.82 for Kuwait.

Kappi et al., (2020) conducted a bio-bibliometric study analysis of Dr. Sonkawade's research output and citation impact. The analysis used a variety of bibliometric indicators, such as publication count, citation count, and h-index, to quantify Dr. Sonkawade's research productivity and impact. The analysis found that Dr. Sonkawade has published extensively in the field of optical and condensed matter physics, with an average citation rate of 10.5 citations per paper. His work has been published in a range of high-impact journals, and he has collaborated with researchers from around the world.

Koh et al., (2020) conducted a bibliometric analysis of the top 100 most-cited articles in ophthalmology in Asia since 1970. The study utilized the Scopus database to identify these articles, categorizing them as ophthalmology-specific (T100-Eye) or published in non-ophthalmology journals (T100-General). The findings revealed that while T100-Eye articles exhibited higher citation counts than T100-General articles, the latter were published in journals with higher impact factors and produced more landmark papers. Notably, three journals accounted for most T100-Eye publications. The analysis encompassed disease categories, author demographics, and emerging research topics.

Teli and Dutta (2016) paper makes a correlation between the number of citations received (top-10 HCPs and others) and the number of publications accessed from the Web of Science database in the selected area of astrophysics during 1990 – 2014. A total of eighteen search terms were selected from the selected area of astrophysics using a systematic review method. Four important variables related to

each search term are measured for this study. These are; total documents accessed; total citation counts of the documents (including self-citations); top-10 HCPs' citation counts (including self-citations) and the publication age of the accessed documents. Based on these four key variables, five new variables were defined as follows, i.e., the CPP of all publications; citation counts of top-10 HCP; Citation growth; Citation growth index, and temporary Citation growth. It is found that the graduation value depends directly relative to the number of accesses.

3.8. Bibliometric Laws and Various Indicators

Suprapto et al., (2021) have attempted to analyse the research publications output of physics of photography during 2000-2020 by referring SCOPUS database. A total of 432 documents were accessed, analysed, and visualized. Bibliometric techniques like year-wise, language, affiliation, countries, sources, type, authors, and keywords were used to map the results. The study predicted quinquennial growth in the research productivity on the physics of photography in 2021-2025. The USA (n=142), 'The University of Cambridge' (n=26), and the 'Kontis, K' and 'Proud WG' (n=8 each) were identified as the most productive country, institutes, and authors respectively in physics photography. The key factor of the paper was VOSviewer software, with this software visualizing the co-occurrence of keywords.

Aria and Cuccurullo (2017) the study of bibliometrics is slowly spreading across all domains. Coincidentally the modern scientific division emphasizes that outstanding contributions create critical, divided, and controversial research. Scientific mapping is multi-step and often complex and cumbersome as it requires many different software tools, but not all of them are free. Although automated workflows and integration of these software tools into structured data streams emerge, the authors propose in this article a unique open-source tool, developed by the

authors, called bibliometrix to perform a comprehensive analysis of science mapping. Bibliometrix supports a standard operating procedure for conducting bibliometric analysis. As configured in R, the recommended tool is flexible and can be updated quickly and integrated with other statistical R packages. Therefore, it is useful in ever-changing sciences such as bibliometrics.

Hiremath et al., (2016) analysed the 'Materials Science' related literature during 1995 – 2014 using 'Bradford's law of scattering' which is one of the significant laws of bibliometrics. A total of 42,383 bibliographic data which are published in English language journals were retrieved from the Web of Science database for the study. All these retrieved documents were spread over 465 journals. These journals were arranged accordingly and found that the 'Journal of Alloys and Compounds' published the highest number of (n=1,939) papers in the 'Materials Science' domain followed by the journal 'Materials Letters' which published 1,146 papers, and the journal 'Materials Chemistry and Physics' published 1,111 papers. The study tested with 'Bradford's law of scattering' and was found to be inconsistent. Whereas, the 'Leimkuhler model' was tested and found to fit most 'Bradford Multiplier (k)' at 14.71. Bradford's law was also tested through the formulation of the graphic by drawing Bradford's bibliography, and all three functions are confirmed.

Reyes-Gonzalez et al., (2016) study proposes a novel method for assessing research group performance based on their self-organizing characteristics. The method utilizes knowledge footprints, derived from backward citations, to measure and compare research group productivity. The study applies this method to rank research groups in Physics, Applied Physics/Condensed Matter/Materials Science, and Optics in leading institutions in Mexico, demonstrating its effectiveness in providing a more accurate assessment of group performance. The proposed method

has the potential to better understand the self-organizing mechanisms of research groups and could facilitate more precise assessments within subfields of science.

Joshi et al., (2015) investigated the applicability of Bradford's Law to the field of stellar physics. They analysed 2,738 articles published in English-language journals between 1988 and 2013. The findings revealed that the Astrophysical Journal is the most productive journal in publishing stellar physics literature. The study also confirmed the characteristics of Bradford's Law through graphical formulation.

Sudhier (2013) studied the distribution of authorship in physics publications and examined the validity of Lotka's law in the scientific literature. The study compiled a list of journal papers on numerous features of physics publications cited in the Ph.D. thesis of the University of Kerala. Using the "exact number" of authors, a total of 1,665 authors and 3,367 authors were identified using the "total number". The K-S statistical test and the Chi-square tests were used to verify the relevance of Lotka's law in both cases and found that Lotka's law did not fit.

Sudhier (2010) conducted a study on journals cited by the 'Indian Institute of Science Bangalore' physics researchers during 2004 – 2008 using 'Bradford's law of scattering. This article describes the scientific contribution to various aspects of Bradford law and as well application of law in various subject domains. This study was conducted on 690 journals covering 11,319 cited references from 79 Ph.D. thesis during 2004 – 2008. Journals were ranked accordingly, the journal 'Physical Review-B' ranked top with 9.53% citations, followed by 'Physical Review-A' with 7.69% citations, and 'Astrophysical Journal' with 5.47% citations were the most preferred journals. The journal's scattering pattern of the IISc Ph.D. dissertations does not fit the Bradford distribution law. The 'Bradford multipliers' were calculated and the law with a value of k equals 1.2. The journals were divided into three regions and then the

number of references in each region was estimated. The application of the 'Leimkuhler model' has also been tested with current data.

Gupta et al., (2002); Hadagali and Anandhalli (2015); Neelamma and Anandhalli (2020) three studies were conducted on 'Modelling the growth of literature' in world Social Science, Neurology (n=291,702), and Crystallography (n=45,320) publications during 1963 – 1998), 1962 – 2010, and 1989 – 2013 respectively. Studies show that the 'Relative Growth Rate (RGR)' and 'Doubling Time (Dt)' of publications found an increasing trend. The literature's growth was calculated with exponential, linear, and logistic models, and found that the growth of both literatures does not follow linear or logistic models. However, the growth of the literature closely follows the exponential growth model. All the authors concluded that there has been a consistent trend toward progressive growth of literature in the respective field of study.

Van Eck and Waltman (2010) VOSviewer is an open-source software application for building and viewing bibliometric networks, that has been developed by authors. Unlike most software used for bibliometric visualisation or mapping, VOSviewer gives special attention to bibliometric mapping. The VOSviewer function is especially useful for displaying large bibliometric maps in an easy-to-understand way. The authors interpreted an outline of the VOSviewer functions for bibliometric mapping, the technical implementation of certain parts of the program, and finally, VOSviewer's ability to manage large maps using the program to build and visualize co-citation maps of more than 5,000 prominent scientific journals.

3.9 Conclusion

The review of literature has been conducted on several groups such as studies based on country, individual journals, Individual Subjects, databases, bibliometric laws, citation analysis, authorship patterns, mapping of the literature using various software, and the study based on optics, physics, and related domain literature. The analysis of the reviewed articles reveals that with the help of scientometric measures, several studies have been done. The application of scientometric techniques to scientific literature shows exponential growth to the scientific literature. It has been observed that collaboration is gradually increasing in scientific publications. The considerable number of the article has been reported on journal productivity. It has been found that several scientometric studies have been done in science at the micro-level. Below are the significant observations found while doing the literature review:

The use of scientometric/bibliometrics is gradually spreading to the all-subject domains, whereas it is exclusively suitable for science mapping.

Earlier scientometrics/bibliometric studies were done by a single author whereas the trend has diverted towards collaboration studies.

Indian authors significantly contributed to the scientometrics/bibliometric domain, they began to emerge with the advent of automated workflows for compiling specialized software into a comprehensive and organized bibliographic data stream. These are particularly suitable for multi-step analysis with a variety of software tools. Due to this our LIS researchers and research publications remarkably identified at the global level in the scientometrics domain. The highest studies are exclusively used databases such as Web of Science, SCOPUS, INSPEC, Science direct, and individual journals. Further, found that studies were conducted at a global level rather than in individual countries. Hence, the researcher selected the Indian Optics research publications indexed in the Web of Science database.

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CHAPTER – IV

DATA ANALYSIS AND INTERPRETATION

4.1. Introduction

Data tabulation and elucidation are significant parts of any research process. Instead of raw data, the researcher used processed data, such as verified and authenticated information, for compelling insights. Bibliometric analysis quantitatively examines the progress of research in any subject and provides a comprehensive assessment of scientific research trends, widely used for mapping knowledge in various scientific fields. Further, the collaboration network maps (among authors, organizations, countries, highly cited papers, and keywords) were created by VOSviewer (van Eck & Waltman, 2010) and bibliometrix R (Aria & Cuccurullo, 2017) package software.

4.2. Summary of the Retrieved Data

Table 4.1 summarises the bibliographic data obtained from the web of science database for the study. A total of 89342 Indian optics bibliometric records published during 1992 – 2021 were included in this study, authored by 120786 authors and 4.91 authors per document, and were classified into the main direction of science (Table 4.1). Of the total documents, Articles accounted for the largest share (91.51%), followed by review articles (3.14%), conference papers (2.95%), and the remaining have less than 1%. These papers have counted a total of 1676529 citations with an average of 18.79 citations per paper. The highest number of works (97.10%) were published in collaboration, among the international collaboration rate was 25.57% and the collaboration index was 4.98 in the study period. The annual growth rate is

observed at 3.68% and these documents were published in 4427 sources. Further, all these documents contain the 112426 author keywords.

Table 4.1: Summary of the retrieved data

Description	Results
Timespan	1992 – 2021
Documents	89342
Sources (Journals, Books, etc)	4427
Annual Growth Rate%	3.68
Document Average Age	8.34
Average citations per doc	18.79
DOCUMENT CONTENTS	
Keywords Plus (ID)	73601
Author's Keywords (DE)	112426
AUTHORS	
Authors	120786
Authors of single-authored docs	1504
AUTHORS COLLABORATION	
Single-authored docs	2583
Co-Authors per Doc	4.90
Collaboration index	4.98
International co-authorships%	25.57
DOCUMENT TYPES	
Article	81756 (91.51%)
Review Articles	2807 (3.14%)
Conference Papers	2634 (2.95%)
Editorial Materials	707 (0.79%)
Letter	655 (0.73%)
Meeting Abstract	426 (0.48%)
Note	156 (0.17%)
Correction	140 (0.16%)
Book Chapter	34 (0.04%)
Others	27 (0.03%)

The analysis and interpretation of the retrieved data are presented in the following broad categories of various scientometrics indicators.

4.3. Basic Metrics Indicators

4.3.1. *Optics research performance during 1992 – 2021*

The data presented in table 4.2 reveals interesting insights into global research output in the field of Optics and India's contribution to it from 1992-2021. The global research output in Optics has been consistently increasing over years, which indicates the growth of field and interest of researchers worldwide in this area. India's research output in the field of Optics has also increased, indicating a growing interest in this field among Indian researchers. Additionally, India's share of global research output in Optics has increased from 1.883% in 1992 to 8.140% in 2021, which suggests that India has becomes a significant contributor to global research output in this field.

The data also indicates an improvement in the quality of research being conducted in India, as evidenced by the increasing number of citations received by Indian research papers over the years. The number of citations for Indian publications has also been increasing over the years, from 7,388 in 1992 to 34,508 in 2021. This trend is indicative of the growing impact of Indian research in the field of Optics. However, India's share of global optics research output has also increased over the years, from 1.88% in 1992 to 8.14% in 2021. Analysis suggests that India's contribution to global optics research is increasing over time and gaining more recognition and influence in the global research community. This could be attributed to various factors such as changes in funding, policies, and research priorities.

Table 4.2 and Figure 4.1 highlight the growth of Optics research globally and India's increasing contribution to it. This indicates that India is investing in research and development in this field and has the potential to become a significant player in the global Optics research community. The data can be used to inform further research and investment in Optics in India, which could result in continued growth and progress in the field.

Table 4.2: Optics Research Output (India and World) During 1992-2021

Year	Global (TP)	India (TP)	India's Share	Citations India
1992	23957	451	1.883	7388
1993	25197	492	1.953	7969
1994	27036	526	1.946	8723
1995	28741	521	1.813	10335
1996	31652	622	1.965	11882
1997	34211	640	1.871	13679
1998	34950	695	1.989	17849
1999	36320	763	2.101	18166
2000	36696	738	2.011	27020
2001	37516	860	2.292	25698
2002	39130	958	2.448	28279
2003	41742	1132	2.712	49781
2004	45523	1283	2.818	39800
2005	48810	1416	2.901	43068
2006	52505	1757	3.346	53875
2007	54647	2116	3.872	61798
2008	58628	2513	4.286	71820
2009	62404	2682	4.298	81822
2010	65715	3085	4.695	75784
2011	69326	3388	4.887	86289
2012	72945	3718	5.097	97384
2013	79025	4458	5.641	103180
2014	82809	5107	6.167	112945
2015	85138	5226	6.138	107283
2016	89684	5862	6.536	114451
2017	92480	6170	6.672	113075
2018	97888	6955	7.105	97708
2019	103871	7584	7.301	84953
2020	108546	8241	7.592	70017
2021	115269	9383	8.140	34508
1992-2021	**1782361**	**89342**	**5.013**	**1676529**

TP= Total Publications
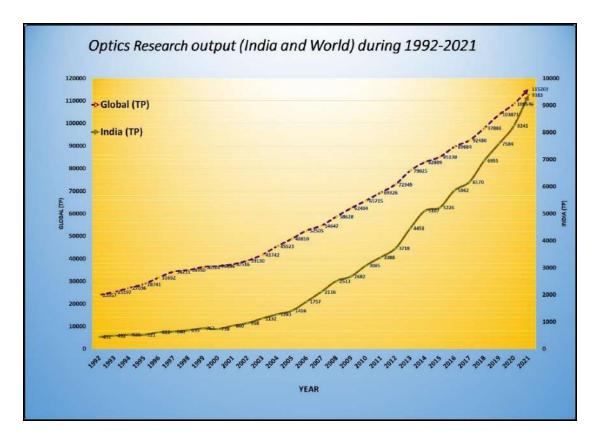
Figure 4.1: Research output (India and World) during 1992-2021

4.3.2. *Exponential Growth v/s Linear Growth Pattern*

The data on a graph and examine the shape of the curve to determine whether the Indian optics research output during 1992 – 2021 follows an exponential or linear growth pattern, figures 4.2 and 4.3 plot. Looking at the graph, it appears that the data follows an exponential growth pattern rather than a linear one. The curve has a steep slope, especially in the later years, which indicates that the rate of growth is increasing over time. This is characteristic of exponential growth.

To confirm this, the researcher performed a regression analysis on the data. Here are the results:

➢ Exponential Regression**:**

The exponential regression equation for the data is: $y = 332.69 * e^{(0.1128x)}$

where 'y' is the research output and 'x' is the year.

The coefficient of determination (R-squared) for the exponential regression is 0.992, which indicates a very good fit of the data to the exponential model.

➤ Linear Regression:

The linear regression equation for the data is: $y = 205.18x + 273.77$

where 'y' is the research output and 'x' is the year.

The coefficient of determination (R-squared) for the linear regression is 0.914, which is also quite good, but not as good as the exponential model.

Overall, both the visual inspection of the graph and the regression analysis suggest that the Indian optics research output follows an exponential growth pattern rather than a linear one. This means that the rate of growth is increasing over time, and researchers can expect the output to continue to increase at an accelerating rate in the future.
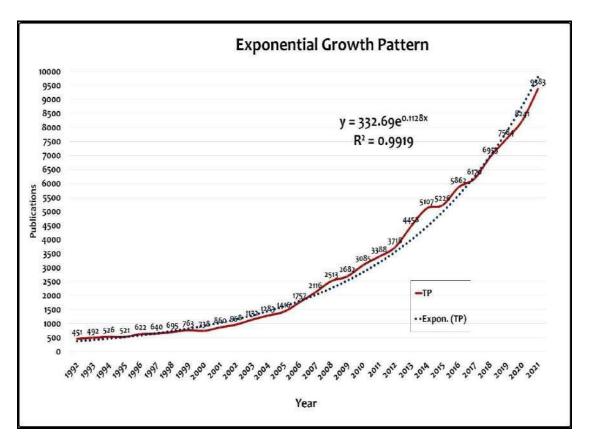
Figure 4.2: Exponential Growth Pattern
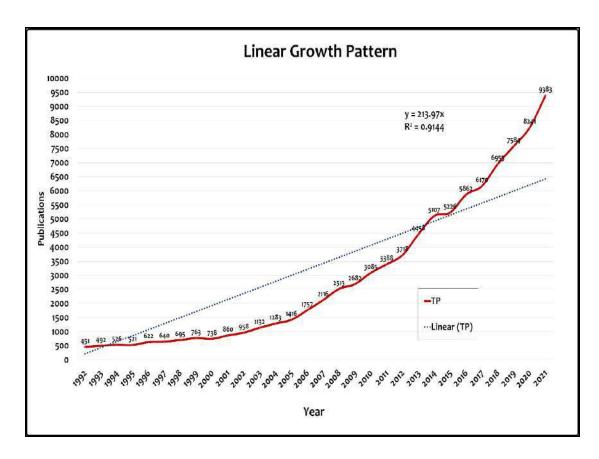
Figure 4.3: Linear Growth Pattern

4.3.3. *Activity Index of Indian Optics Research Output*

Table 4.3 provides a year-wise analysis of the activity index of Indian optics publications from 1992 to 2021. The activity index is calculated by dividing the number of Indian publications by the total number of Global publications and multiplying the result by 100. The formula first suggested by Frame and used among others (Schubert & Braun, 1986), (de Solla Price, 1981) and (Karki & Garg, 1997). The formula for calculating the 'Activity Index' is:

$$AI = \frac{Ii/Io}{Wi/Wo} \times 100$$

Where,

Ii=Indian output of year 'i'

Io= Indian total output

Wi= World Output of year 'i'

Wo=Total output of the world

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Table 4.3 shows that the global research activity in optics has been increasing steadily over the years, as evidenced by the rising number of publications worldwide. Meanwhile, the number of publications from India has also been increasing, which is reflected in the rising trend of the Indian activity index.

During the study period, the Indian activity index increased from 37.556 in 1992 to 162.394 in 2021. This indicates that India's research productivity in optics has been growing consistently over the years, and it is making a significant contribution to the global research community. The year-wise analysis of the table reveals that the Indian activity index has been increasing steadily over the years, with occasional fluctuations.

The increasing trend of the Indian activity index reflects the country's growing research infrastructure and funding in the field of optics. It also indicates that the researchers in India are actively participating in the global research community and are producing high-quality research output.

The year-wise analysis of the activity index of Indian optics publications suggests that India's research productivity in optics has been growing consistently over the years. The rising trend of the Indian activity index indicates that India is becoming an essential player in the global research community and is making significant contributions to the field of optics.

Table 4.3: Year-wise Activity Index

Year	Global (TP)	India (TP)	AI
1992	23957	451	37.556
1993	25197	492	38.954
1994	27036	526	38.814
1995	28741	521	36.164
1996	31652	622	39.204
1997	34211	640	37.321
1998	34950	695	39.671
1999	36320	763	41.910
2000	36696	738	40.122
2001	37516	860	45.732
2002	39130	958	48.842
2003	41742	1132	54.102
2004	45523	1283	56.226
2005	48810	1416	57.875
2006	52505	1757	66.759
2007	54647	2116	77.248
2008	58628	2513	85.512
2009	62404	2682	85.741
2010	65715	3085	93.655
2011	69326	3388	97.496
2012	72945	3718	101.684
2013	79025	4458	112.542
2014	82809	5107	123.035
2015	85138	5226	122.458
2016	89684	5862	130.398
2017	92480	6170	133.100
2018	97888	6955	141.745
2019	103871	7584	145.661
2020	108546	8241	151.463
2021	115269	9383	162.394
1992-2021	**1782361**	**89342**	**81.446**

TP= Total Publications; AI= Activity Index

4.3.4. *Year-wise research performance with various parameters*

Table 4.4 shows year-wise data on India's Optics research performance with various parameters. Analysing these parameters provides insights into the growth and development of optics research in India.

- *Total Publications (TP):* The total number of publications in optics research has steadily increased from 451 in 1992 to 9383 in 2021. The TP percentage, which indicates the share of optics research publications in the overall research output,

has also increased, reaching 10.53% in 2021. This indicates the growing importance of optics research in India's overall research landscape.

- *Total Citations (TC):* The total number of citations received by optics research publications has been increasing consistently, reaching a peak of 114451 in 2016, followed by a slight decline in recent years. The TC percentage, which measures the share of citations received by optics research publications in the overall citation count, has been increasing, reaching 6.83% in 2021. This indicates the growing influence of optics research in the broader research community.

- *Highly Cited Publications (HCP):* The number of highly cited publications (i.e., publications that have received a high number of citations from other researchers) has also been increasing, from 10 in 1992 to 43 in 2019, and then dropping to 21 in 2020 and rising again to 75 in 2021. The HCP percentage, which measures the share of highly cited publications in the overall optics research output, has fluctuated over the years, ranging from 0.47% in 1993 to 9.16% in 2021. However, it is important to note that HCPs are an important measure of research impact. Total citations (TC) and field-weighted citation impact (FWCI) are other important indicators of research impact that should be considered alongside HCPs. Additionally, it is vital to consider the growth growth in overall research output over the years. While the percentage of HCPs has been increased, the total number of publications has increased at an even higher rate, from 451 in 1992 to 9383 in 2021. Therefore, while the impact of India's optics research has grown, it is also important to consider the overall growth in research output.

- *Total Authors (TA):* The total number of authors involved in optics research publications has been increasing, reaching 41996 in 2020. This can be attributed to various factors, including the increasing number of institutions and research

groups involved in optics research, the growing interest and funding in the field, and the emphasis on collaborative research. With the advent of new technologies and advanced research tools, it has become easier for researchers to collaborate and publish their findings. This has led to an increase in multi-authored papers, where researchers from different institutions and disciplines come together to contribute their expertise. Additionally, the increasing emphasis on interdisciplinary research has also led to collaborations between researchers from different fields, leading to a higher number of authors in publications. Overall, the increase in the number of authors is a positive trend that reflects the growth and development of optics research in India.

- *Cited Papers (CP) and Non-Cited Papers (NCP):* Citations serve as a vital measure of research impact and recognition in the scientific community. They indicate the extent to which a research article has been referenced by other scholars, underscoring its influence or contribution to others' work. Citations also reflect the quality and significance of research, signifying the relevance and visibility of scholarly work within the scientific community, and can assist in identifying emerging research trends and areas of interest.

The number of cited papers published over the years indicates an increasing impact and recognition of Indian research in this field. The consistent upward trend in the number of cited papers from 1992 to 2021 reveals that Indian research in optics has gained considerable visibility and recognition over the years. This trend further underscores the growing importance of Indian research in the global scientific community and its contribution to the advancement of the field. The table presented below portrays the year-wise performance of India's optics research concerning cited and non-cited papers from 1992 to 2021, accompanied by the total number of papers

published each year. The data has been categorized into three periods, namely, 1992-2001, 2002-2011, and 2012-2021, to facilitate a comparative analysis.

A detailed examination of the table reveals that the number of cited papers has consistently increased over the years, from 394 in 1992 to 7026 in 2019, while the number of non-cited papers exhibited a fluctuating trend. Similarly, the total number of papers published each year showed a remarkable increase from 451 in 1992 to 8241 in 2021. Comparing the three blocks, the period from 2012-2021 witnessed a significant surge in the number of cited papers, with 56800 cited papers. This is almost thrice the number of cited papers during the period from 2002-2011, which had 19361 cited papers. In contrast, the period from 1992-2001 recorded the lowest number of cited papers, with only 5672 cited papers.

Overall, the table underscores the growth in India's optics research, with a substantial increase in the number of cited papers published over the years, alongside a remarkable surge in the total number of papers published. Moreover, it shows that the period from 2012-2021 was particularly fruitful in terms of research output. However, the fluctuation in the number of non-cited papers suggests that there is scope for further improvement in the quality of research being conducted in this field.

- *Funded Papers (FP):* The number of funded papers in optics research has been increasing, reaching 4791 (11.42%) in 2020. Funding plays a critical role in the success of scientific research and publication. In the context of optics research in India, the increase in funding for publications over the years has enabled researchers to carry out more advanced and innovative studies, leading to an overall increase in research productivity. The data shows a steady increase in funding for publications from 1992 to 2021, with a significant increase in the last

decade. This increase in funding has also led to a rise in the number of highly cited publications and international collaborations.

Additionally, funding has provided opportunities for researchers to attend conferences and workshops, leading to enhanced networking and collaborations. The significance of funding for publications in optics research cannot be overstated, as it has allowed for the growth and development of the field, leading to new discoveries and advancements that can benefit society as a whole.

Overall, the analysis of the various parameters indicates India's optics research performance has been consistently improving over the years, with a significant increase observed in the last two decades (Figure 4.4). India's growing contribution to the world's optics research and impact in the field is an indication of the country's growing capabilities in science and technology.

4.3.5. *Relative Growth Rate (RGR) and Doubling Time (DT)*

Relative growth rate (RGR) measures speed at which a population or organism grows relative to its initial size (Hoffmann & Poorter, 2002; Mahapatra, 1985). It is calculated as natural logarithm of final population size divided by initial population size, divided by the time elapsed. In mathematical terms, RGR can be expressed as:

$$RGR = \ln\left(\frac{Nf}{Ni}\right)/t$$

where '*Nf*' is the final number of publications, '*Ni*' is the initial number of publications, and '*t*' is the time elapsed.

Doubling Time is a related concept that is often used to describe the growth rate of populations. It is the amount of time it takes for a population to double in size. Doubling Time can be calculated using the following formula:

$$Dt = \ln(2)/RGR$$

Table 4.4: Year-wise research performance with various parameters

Years	TP	TP (%)	HCP	HCP (%)	TC	TC (%)	TA	TA (%)	CP	NCP	FP	FP (%)
1992	451	0.505	10	0.525	7388	0.441	1325	0.305	394	57	2	0.005
1993	492	0.551	9	0.472	7969	0.475	1577	0.363	442	50	2	0.005
1994	526	0.589	8	0.420	8723	0.520	1687	0.388	463	63	4	0.010
1995	521	0.583	17	0.892	10335	0.616	1611	0.370	464	57	2	0.005
1996	622	0.696	18	0.945	11882	0.709	1974	0.454	539	83	6	0.014
1997	640	0.716	27	1.417	13679	0.816	2141	0.492	560	80	3	0.007
1998	695	0.778	25	1.312	17849	1.065	2348	0.540	624	71	5	0.012
1999	763	0.854	29	1.522	18166	1.084	2674	0.615	702	61	5	0.012
2000	738	0.826	41	2.152	27020	1.612	2500	0.575	685	53	7	0.017
2001	860	0.963	39	2.047	25698	1.533	3273	0.753	799	61	4	0.010
2002	958	1.072	46	2.415	28279	1.687	3460	0.796	904	54	10	0.024
2003	1132	1.267	59	3.097	49781	2.969	4389	1.009	1058	74	9	0.021
2004	1283	1.436	72	3.780	39800	2.374	5071	1.166	1200	83	3	0.007
2005	1416	1.585	69	3.622	43068	2.569	5748	1.322	1350	66	13	0.031
2006	1757	1.967	96	5.039	53875	3.213	6693	1.539	1684	73	14	0.033
2007	2116	2.368	96	5.039	61798	3.686	8059	1.853	2000	116	27	0.064
2008	2513	2.813	110	5.774	71820	4.284	12646	2.908	2403	110	495	1.180
2009	2682	3.002	122	6.404	81822	4.880	10420	2.396	2560	122	1221	2.911
2010	3085	3.453	111	5.827	75784	4.520	17276	3.973	2950	135	1542	3.677
2011	3388	3.792	115	6.037	86289	5.147	13926	3.203	3252	136	1912	4.559
2012	3718	4.162	114	5.984	97384	5.809	15417	3.545	3572	146	2119	5.053
2013	4458	4.990	106	5.564	103180	6.154	18252	4.197	4232	226	2502	5.966
2014	5107	5.716	122	6.404	112945	6.737	25820	5.938	4878	229	2955	7.046
2015	5226	5.849	111	5.827	107283	6.399	23593	5.426	4994	232	3084	7.354
2016	5862	6.561	103	5.407	114451	6.827	33166	7.627	5564	298	3393	8.091
2017	6170	6.906	93	4.882	113075	6.745	41878	9.631	5858	312	3750	8.942
2018	6955	7.785	66	3.465	97708	5.828	38754	8.912	6552	403	4194	10.000
2019	7584	8.489	43	2.257	84953	5.067	38616	8.880	7026	558	4388	10.463
2020	8241	9.224	21	1.102	70017	4.176	41996	9.658	7289	952	4791	11.424
2021	9383	10.502	7	0.367	34508	2.058	48553	11.166	6835	2548	5476	13.057
1992-2001	**6308**	**7.060**	**223**	**11.710**	**148709**	**8.870**	**21110**	**4.855**	**5672**	**636**	**40**	**0.095**
2002-2011	**20330**	**22.760**	**896**	**47.030**	**592316**	**35.330**	**87688**	**20.165**	**19361**	**969**	**5246**	**12.509**
2012-2021	**62704**	**70.180**	**786**	**41.260**	**935504**	**55.800**	**326045**	**74.980**	**56800**	**5904**	**36652**	**87.396**
Total	**89342**	**100.000**	**1905**	**100.000**	**1676529**	**100.000**	**434843**	**100.000**	**81833**	**7509**	**41938**	**100.000**

TP=Total Publications; HCP=Highly Cited Papers; TC=Total Citations; TA=Total Authors; CP=Cited Papers; NCP=Non-Cited Papers; FP=Funded Papers
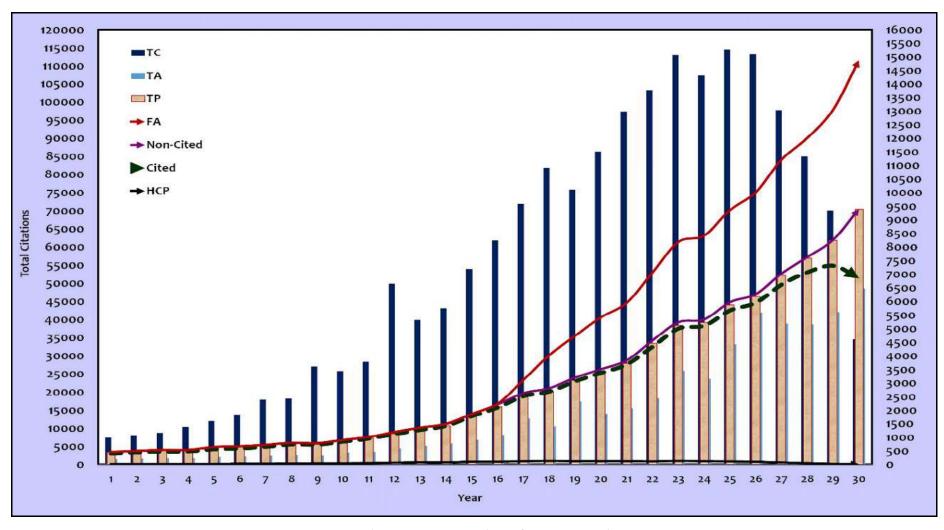
Figure 4.4: Year-wise India Optics research performance with various parameters

Where, ln (2) is the natural logarithm of 2 (approximately 0.693), and RGR is the relative growth rate.

Looking at the table 4.5, the RGR values are generally decreasing over time, indicating a slower rate of growth. The RGR value was 0 in 1992, which means that there was no growth that year. The RGR value was highest in 1993 at 0.738, indicating a rapid growth rate. The RGR values gradually decreased after that, with the lowest value of 0.109 in 2020. The Doubling Time values are generally increasing over time, indicating that it is taking longer for the population to double in size. The Doubling Time was shortest in 1993 at 0.940 years, meaning that the population doubled in size in less than a year. The Doubling Time was the longest in 2020 at 6.371 years, meaning that it took over six years for the population to double in size.

Table 4.5: Relative Growth Rate (RGR) and Doubling Time (DT)

Year	TP	Cumulative	log Ni	log Nf	RGR	DT	Mean RGR	Mean DT
1992	451	451	0.000	6.111				
1993	492	943	6.111	6.849	0.738	0.940		
1994	526	1469	6.849	7.292	0.443	1.563		
1995	521	1990	7.292	7.596	0.304	2.283		
1996	622	2612	7.596	7.868	0.272	2.548	**0.440**	**1.830**
1997	640	3252	7.868	8.087	0.219	3.162		
1998	695	3947	8.087	8.281	0.194	3.578		
1999	763	4710	8.281	8.457	0.177	3.921		
2000	738	5448	8.457	8.603	0.146	4.761		
2001	860	6308	8.603	8.750	0.147	4.728	**1.687**	**0.806**
2002	958	7266	8.750	8.891	0.141	4.901		
2003	1132	8398	8.891	9.036	0.145	4.786		
2004	1283	9681	9.036	9.178	0.142	4.874		
2005	1416	11097	9.178	9.314	0.137	5.077		
2006	1757	12854	9.314	9.461	0.147	4.715	**1.835**	**0.974**
2007	2116	14970	9.461	9.614	0.152	4.547		
2008	2513	17483	9.614	9.769	0.155	4.466		
2009	2682	20165	9.769	9.912	0.143	4.856		
2010	3085	23250	9.912	10.054	0.142	4.868		
2011	3388	26638	10.054	10.190	0.136	5.094	**1.982**	**0.953**
2012	3718	30356	10.190	10.321	0.131	5.304		
2013	4458	34814	10.321	10.458	0.137	5.057		
2014	5107	39921	10.458	10.595	0.137	5.063		
2015	5226	45147	10.595	10.718	0.123	5.633		
2016	5862	51009	10.718	10.840	0.122	5.677	**2.117**	**1.069**
2017	6170	57179	10.840	10.954	0.114	6.069		
2018	6955	64134	10.954	11.069	0.115	6.037		
2019	7584	71718	11.069	11.180	0.112	6.200		
2020	8241	79959	11.180	11.289	0.109	6.371		
2021	9383	89342	11.289	11.400	0.111	6.246	**2.236**	**1.237**

TP = Total Publications; RGR = Relative Growth Rate; DT = Doubling Time

The Relative Growth Rate between 1992-2001 and 2002-2011 was 1.441, which means it grew 44.1% between those two periods. The Doubling time between those two periods was 0.479, which means that the number of publications doubled in just under eight months. For the period between 2012-2021, the Relative Growth Rate was 1.210, and the Doubling time was 0.570, which means that the number of publications grew by 21% and doubled in just under a year (Table 4.6).

Table 4.6: Relative Growth Rate (RGR) and Doubling Time (DT) Block period wise

Period	TP	Cumulative	log *Ni*	log *Nf*	RGR	DT
1992-2001	6308	6308	0	8.750		
2002-2011	20330	26638	8.750	10.190	1.441	0.479
2012-2021	62704	89342	10.190	11.400	1.210	0.570

TP = Total Publications; RGR = Relative Growth Rate; DT = Doubling Time

4.3.6. *Annual Ratio of Growth (ARoG) and Annual Growth Rate (AGR)*

Table 4.7 shows Total Publications (TP), Annual Ratio of Growth (ARoG), and Annual Growth Rate (AGR) of Indian optics research publications – 1992-2021.

Annual Ratio of Growth (ARoG) measures the ratio of the total number of publications in a year to the total number of publications in the previous year, and it is calculated using the following formula:

$$ARoG = TP(year) / TP(year - 1)$$

Annual Growth Rate (AGR) measures the percentage change in total number of publications from previous year, and it is calculated using the following formula:

$$AGR = \frac{(TP(year) - TP(year - 1))}{TP(year - 1)}) \; x \; 100\%$$

The Annual Ratio of Growth (ARoG) and Annual Growth Rate (AGR) of Indian optics research publications from 1992 to 2021. Table 4.7 indicates that the total number of publications has been increasing over the years, with the highest number of publications recorded in 2021 at 9,383. Most years had an Annual Ratio of Growth (ARoG) above 1, indicating that the number of publications was increasing

from year to year. However, the Annual Growth Rate (AGR) varied from year to year, with some years recording a positive growth rate and others recording a negative growth rate. The lowest Annual Ratio of Growth (ARoG) was recorded in 1992, with a value of 0, indicating that the number of publications did not increase from the previous year. On the other hand, the highest Annual Ratio of Growth (ARoG) and Annual Growth Rate (AGR) was recorded in 2006, with values of 1.241 and 0.241, respectively. The data suggests that there has been a consistent increase in the number of Indian optics research publications over the years, although the growth rate has been fluctuating as shown in Figure 4.5.

Table 4.7: Year-wise Annual Ratio of Growth and Annual Growth Rate

Year	TP	ARoG	AGR	ARoG
1992	451	0	0	0
1993	492	1.091	0.091	1.091:1
1994	526	1.069	0.069	1.069:1
1995	521	0.990	-0.010	0.990:1
1996	622	1.194	0.194	1.194:1
1997	640	1.029	0.029	1.029:1
1998	695	1.086	0.086	1.086:1
1999	763	1.098	0.098	1.098:1
2000	738	0.967	-0.033	0.967:1
2001	860	1.165	0.165	1.165:1
2002	958	1.114	0.114	1.114:1
2003	1132	1.182	0.182	1.182:1
2004	1283	1.133	0.133	1.133:1
2005	1416	1.104	0.104	1.104:1
2006	1757	1.241	0.241	1.241:1
2007	2116	1.204	0.204	1.204:1
2008	2513	1.188	0.188	1.188:1
2009	2682	1.067	0.067	1.067:1
2010	3085	1.150	0.150	1.150:1
2011	3388	1.098	0.098	1.098:1
2012	3718	1.097	0.097	1.097:1
2013	4458	1.199	0.199	1.199:1
2014	5107	1.146	0.146	1.146:1
2015	5226	1.023	0.023	1.023:1
2016	5862	1.122	0.122	1.122:1
2017	6170	1.053	0.053	1.053:1
2018	6955	1.127	0.127	1.127:1
2019	7584	1.090	0.090	1.090:1
2020	8241	1.087	0.087	1.087:1
2021	9383	1.139	0.139	1.139:1

TP=Total Publications; ARoG= Annual Ratio of Growth; AGR= Annual Growth Rate
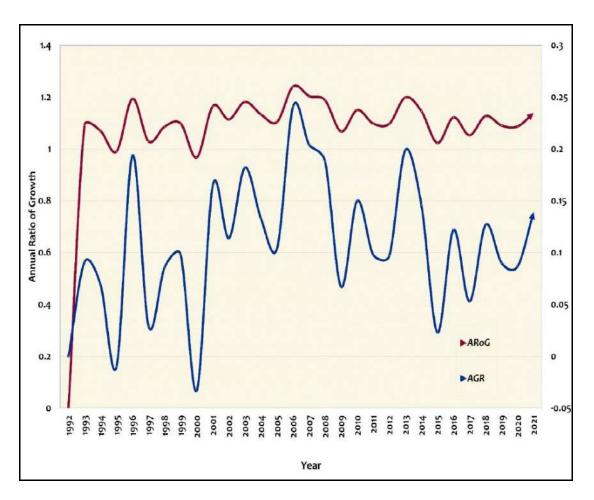
Figure 4.5: Year-wise Annual Ratio of Growth and Annual Growth Rate

4.3.7. Types of documents preferred for communication

The present study examined the publications output from 1992 to 2021 and their classification according to various document types indexed in the Web of Science. The results revealed that out of the 89342 documents, 91.51% were articles, 3.14% were review articles, 2.95% were conference papers, and the remaining 2.40% consisted of other document types, such as editorial materials, letters, meeting abstracts, notes, corrections, book chapters, and others. Notably, articles were found to be the most prevalent form of communication, contributing the highest share of research documents as displayed in the Figure 4.6.

Table 4.8 presents the year-wise distribution of the different document types showed that out of the 81746 articles, the highest number of 8466 were published in

2021, followed by 7506 in 2020, 6910 in 2019, 6408 in 2018, and 5750 in 2017. The growth trend of articles demonstrated an increasing trend, except for the period between 1992 and 2001. Review articles, on the other hand, had a fluctuating growth trend during the study period, with the highest number of 621 published in 2021, followed by 384 in 2020, 308 in 2019, 213 in 2018, and 203 in 2017. Conference papers also showed a fluctuating growth trend, with the highest number of 186 published in 2008, followed by 166 in 2018, 156 in 2010, 154 in 2009, and 152 in 2007. The other document types showed minimal significant year-wise growth during the study period.

Furthermore, the study explored the citation pattern of different document types, indicating that review articles are often cited more frequently than general articles and considered a general indicator of the quality of scientific output. The increase in reviews in scientific literature can have significant implications for evaluating individual research results, often based on citation counts. All the 89342 Indian optics documents received a total of 1676529 citations during the study period, with articles receiving the highest number of citations (TC=1471467; CPP=18), followed by review articles (TC=157256; CPP=56.02) and conference papers (TC=40543; CPP=15.39). In contrast, other document types such as editorial materials, letters, meeting abstracts, notes, corrections, book chapters, and others were less frequently cited. The study provides valuable insights into the distribution of different document types in India's optics research output, highlighting the dominance of articles and the fluctuating growth trends of review articles and conference papers. Moreover, the citation pattern indicates the high impact of review articles, providing a valuable measure for evaluating the quality of scientific output (Miranda & Garcia-Carpintero, 2018; Teixeira et al., 2013).

Table 4.8: Types of documents preferred for communications in optics research

Year	A	ATC	R	RTC	CP	CPTC	EM	EMTC	L	LTC	MA	MATC	N	NTC	C	CTC	BC	BCTC	Oth	Oth TC	TP	TC
1992	379	6200	8	479	18	174	0	0	8	142	1	0	36	393	0	0	0	0	1	0	451	7388
1993	407	7140	10	134	24	217	0	0	10	216	1	1	37	247	3	14	0	0	0	0	492	7969
1994	440	7285	13	555	11	183	1	0	9	222	5	0	47	478	0	0	0	0	0	0	526	8723
1995	431	8485	12	1126	30	210	0	0	9	87	2	0	36	427	0	0	0	0	1	0	521	10335
1996	551	11400	9	110	48	254	2	0	9	118	2	0	0	0	1	0	0	0	0	0	622	11882
1997	562	11906	11	1159	60	525	0	0	5	89	0	0	0	0	2	0	0	0	0	0	640	13679
1998	629	14075	18	2646	38	854	1	5	6	269	0	0	0	0	2	0	0	0	1	0	695	17849
1999	683	15746	14	1032	51	1178	2	1	8	206	2	0	0	0	2	0	0	0	1	3	763	18166
2000	648	23408	19	2552	56	955	4	16	4	88	6	0	0	0	0	0	0	0	1	1	738	27020
2001	748	22138	7	1452	98	2013	4	65	3	30	0	0	0	0	0	0	0	0	0	0	860	25698
2002	845	24820	26	2043	73	1327	2	1	6	84	4	0	0	0	2	4	0	0	0	0	958	28279
2003	969	29258	12	17282	131	2979	7	188	5	65	2	0	0	0	5	5	0	0	1	4	1132	49781
2004	1122	33520	29	4234	115	1577	3	16	8	453	5	0	0	0	1	0	0	0	0	0	1283	39800
2005	1223	36394	33	4121	136	2431	7	39	12	83	4	0	0	0	1	0	0	0	0	0	1416	43068
2006	1553	48303	35	2450	150	3061	3	15	12	42	2	0	0	0	2	4	0	0	0	0	1757	53875
2007	1882	50792	47	8046	152	2824	12	45	12	82	6	0	0	0	4	2	1	7	0	0	2116	61798
2008	2243	59707	55	8531	186	3424	7	24	13	128	6	0	0	0	2	0	1	6	0	0	2513	71820
2009	2406	66241	76	13248	154	2108	10	17	16	84	9	2	0	0	4	2	4	35	3	85	2682	81822
2010	2822	68601	46	4326	156	2715	10	28	26	79	20	1	0	0	3	11	1	23	1	0	3085	75784
2011	3180	81238	59	3509	104	1448	11	19	21	71	4	0	0	0	8	4	0	0	1	0	3388	86289
2012	3474	89523	93	6586	74	1014	23	81	31	97	14	1	0	0	5	3	4	79	0	0	3718	97384
2013	4244	95296	88	7283	49	426	20	40	16	68	28	2	0	0	7	17	6	48	0	0	4458	103180
2014	4860	106390	92	5444	63	922	29	74	24	46	31	12	0	0	7	12	1	45	0	0	5107	112945
2015	4940	98910	112	7420	61	718	43	118	30	69	28	3	0	0	7	5	4	39	1	1	5226	107283
2016	5475	106245	154	6979	109	1000	38	166	42	47	35	5	0	0	7	5	0	0	2	4	5862	114451
2017	5750	99366	203	12651	76	893	41	116	32	30	56	7	0	0	8	2	1	10	3	0	6170	113075
2018	6408	86966	213	7933	166	2581	73	157	51	66	29	0	0	0	12	3	0	0	3	2	6955	97708
2019	6910	72677	308	10284	133	1670	107	195	56	78	54	2	0	0	12	7	1	32	3	8	7584	84953
2020	7506	60693	384	8133	68	781	155	237	78	156	31	1	0	0	11	1	6	15	2	0	8241	70017
2021	8466	28744	621	5508	44	81	92	51	93	110	39	3	0	0	22	2	4	7	2	2	9383	34508
1992-2021	81756	1471467	2807	157256	2634	40543	707	1714	655	3405	426	40	156	1545	140	103	34	346	27	110	89342	1676529

A=Articles; ATC=Articles Total Citations; RA=Review Articles; RATC= Review Articles Total Citations; CP= Conference Papers; CPTC= Conference Papers Total Citations; EM=Editorial Materials; EMTC= Editorial Materials Total Citations; L=Letters; LTC= Letters Total Citations; MA=Meeting Abstract; MATC= Meeting Abstract Total Citations; N=Note; NTC= Note Total Citations; C= Corrections; CTC= Corrections Total Citations; BC=Book Chapters; BCTC= Book Chapters Total Citations; Oth=Others; OthTC= Others Total Citations; TP=Total Papers; TC=Total Citations.
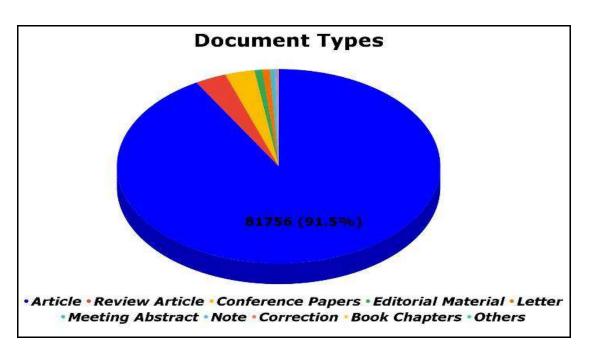
Document Types

81756 (91.5%)

• Article • Review Article • Conference Papers • Editorial Material • Letter
• Meeting Abstract • Note • Correction • Book Chapters • Others

Figure 4.6: Types of Documents Preferred for Communication

4.3.8. Language wise distribution of Optics Publications

Table 4.9 presents the distribution of publications based on language. Most of the publications, totalling 89,331, are in English, making up 99.989% of all publications. The remaining 11 publications are in various other languages, including Chinese, Russian, Estonian, French, German, Hungarian, Polish, Portuguese, and Turkish. While the number of publications in these languages is relatively small, it highlights the importance of multilingualism in the global scientific community. Having publications in different languages allows for broader dissemination of knowledge and facilitates collaborations among researchers from different countries and regions. It also acknowledges the importance of recognizing and promoting diversity and inclusivity in scientific research as shown in figure 4.7.

Table 4.9: Language-wise distribution Optics Publications

S No	Languages	TP	Cumulative	% TP
1	English	89331	89331	99.989
2	Chinese	2	89333	0.002
3	Russian	2	89335	0.002
4	Estonian	1	89336	0.001
5	French	1	89337	0.001
6	German	1	89338	0.001
7	Hungarian	1	89339	0.001
8	Polish	1	89340	0.001
9	Portuguese	1	89341	0.001
10	Turkish	1	89342	0.001
	Total		**89342**	**100.000%**

TP= Total Publications
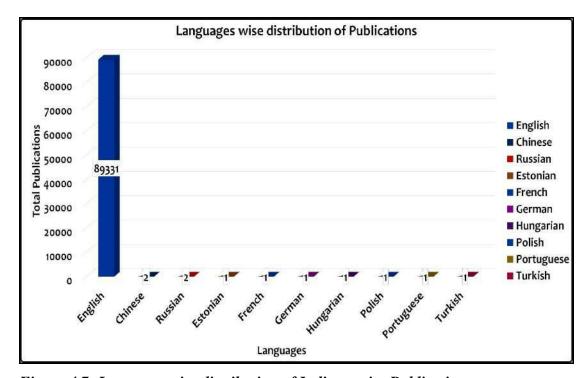
Figure 4.7: Language wise distribution of Indian optics Publications

4.3.9 Research Area-wise Distribution of Papers

Table 4.10 and Figure 4.8 present data on the distribution of papers across various research areas. The study identified the 20 major broad subjects with more than 1000 publications as per the Web of Science database classification. The research areas are listed in descending order of the number of published papers, starting with materials science and ending with meteorology and atmospheric sciences.

Materials Science and Physics are the two most significant research areas, accounting for almost 60% of the total number of papers published in India in the field of Optics. These research areas are closely related to Optics and have numerous applications in various industries, including electronics, telecommunications, and medical devices. The high citation rates for both Materials Science and Physics, with CPP values of 21.054 and 21.636 respectively, highlight the importance and impact of these research areas in the field of Optics.

Chemistry is the third most significant research area, contributing around 22% of the total papers published in Indian Optics Research. Chemistry research is vital for developing new optical materials and technologies, such as quantum dots and nanophotonics, and has numerous applications in various industries. The high CPP value of 26.773 for Chemistry indicates that this research area is highly cited and significantly impacts the scientific community. Optics contributes 14.4% of the total papers published in India. However, despite its more miniature representation, the field of Optics has generated over 172,000 total citations, with an average of 13.4 citations per paper (CPP). This indicates that Optics research in India is highly cited and has a significant impact on the scientific community.

Engineering, Ophthalmology, and Science Technology other topics are also essential to research areas, each contributing around 10% or less to the total number of papers published in Indian Optics research. Engineering research is crucial for the development of new optical devices and technologies, while Ophthalmology research focuses on vision-related issues and the development of new eye-care technologies. Science Technology other topics includes interdisciplinary research in various fields, including optics, and have the potential to bring about new and innovative applications for optical technologies.

The table highlights the significant research areas in the field of Indian Optics Research, with Materials Science, Physics, and Chemistry being the most prominent. However, Optics research in India is highly cited, indicating its importance and impact on the scientific community.

Table 4.10: Research Area Wise Distribution of Papers

S No	Research Areas	TP	TC	CPP	% TP
1	Materials Science	26597	559971	21.054	29.770
2	Physics	26558	574608	21.636	29.726
3	Chemistry	19620	525286	26.773	21.961
4	Optics	12857	172464	13.414	14.391
5	Engineering	10265	148726	14.489	11.490
6	Ophthalmology	7408	105989	14.307	8.292
7	Science Technology other topics	6584	167406	25.426	7.369
8	Metallurgy and Metallurgical Engineering	2739	64294	23.474	3.066
9	Astronomy and Astrophysics	2377	68919	28.994	2.661
10	Crystallography	2347	41232	17.568	2.627
11	Instruments and Instrumentation	1881	58877	31.301	2.105
12	Polymer Science	1785	35862	20.091	1.998
13	Spectroscopy	1762	35845	20.343	1.972
14	Biochemistry and Molecular Biology	1702	38191	22.439	1.905
15	Environmental Sciences Ecology	1570	37729	24.031	1.757
16	Telecommunications	1477	17458	11.820	1.653
17	Computer Science	1460	22108	15.142	1.634
18	Energy and Fuels	1302	42239	32.442	1.457
19	Electrochemistry	1206	41591	34.487	1.350
20	Meteorology and Atmospheric Sciences	1028	30400	29.572	1.151
	India Total	**89432**	**1676529**		**100.000**

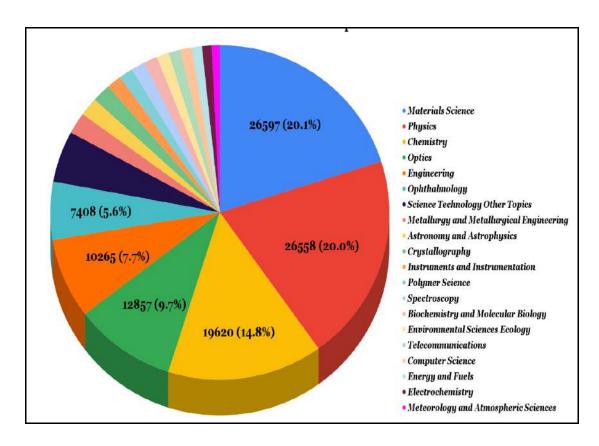*TP= Total Publications; TC= Total Citations; CPP= Citations per Paper*

Figure 4.8: Research Area Wise Distribution of Papers

4.3.10. Keywords Analysis

One of the critical aspects of bibliometrics is keyword analysis. Keyword analysis involves identifying the most commonly used keywords in a set of publications and examining their frequency and co-occurrence (Gupta, Kappi, et al., 2023). Table 4.11 shows a list of keywords that occurred 500 or more times in Indian optics publications and the TLS measures the total frequency of co-occurrence of a keyword with other keywords in the same publication. The higher the TLS, the more frequently the keyword is combined with other keywords in the same publication.

The keyword "Optical-Properties" occurred the most with a total of 9683 occurrences and 30535 total link strength, followed by "Nanoparticles" with 5718 occurrences and 20817 total link strength. Other frequently occurring keywords include "Photoluminescence" "Growth" "Optical Properties" "Thin-Films" and "Temperature". Several keywords related to specific materials and techniques also

appeared frequently, such as "Raman" "Single-Crystals" "Nanowires" "Silver Nanoparticles" "Zinc-Oxide" and "Quantum Dots". Other keywords related to specific research areas and applications included "Photocatalysis", "Green Synthesis", "Glaucoma", "Eye", and "Cells".

The co-occurrence of these keywords also reveals important information about the research trends and interests in a particular field. For example, there is a strong co-occurrence between the "nanoparticles" and "photocatalysis" keywords, indicating a lot of research interest in using nanoparticles for photocatalytic applications. Similarly, the co-occurrence of "Raman spectroscopy" and "semiconductor" suggests that much research is focused on using Raman spectroscopy to study semiconductor materials.

Overall, keyword analysis is an important tool in bibliometrics that helps identify research trends, interests, and gaps in a particular field. It can also help researchers and institutions make informed decisions about research priorities and funding. Further, the list of keywords in Table 4.11 provides insight into the major research areas, materials, and techniques that are being studied in the field of optics in India. These keywords can be helpful for researchers who are interested in exploring the trends and topics of research in this field.

Table 4.11: List of Keywords Occurred (500 or More Times) in Indian Optics Publications

S No	Keyword	Occ.	TLS	S No	Keyword	Occ.	TLS	S No	Keyword	OCC	TLS
1	Optical-Properties	9683	30535	46	Particles	1038	3173	91	Band-Gap	671	2522
2	Nanoparticles	5718	20817	47	Raman	1038	3552	92	Polarization	653	906
3	Photoluminescence	5126	19506	48	Generation	1005	1816	93	Single-Crystals	647	1596
4	Growth	4733	14845	49	Scattering	1005	2077	94	Crystals	644	1650
5	Optical Properties	4005	14054	50	Complexes	971	2340	95	Sem	642	2315
6	Thin-Films	3500	12322	51	Energy-Transfer	967	3336	96	Molecules	641	1359
7	Temperature	3241	10992	52	DFT	966	2272	97	Dispersion	640	1121
8	Luminescence	2890	10888	53	Nanowires	956	4096	98	Efficient	628	1810
9	Absorption	2688	7770	54	Gold Nanoparticles	946	2543	99	Luminescence Properties	624	2369
10	Films	2394	7400	55	Transition	943	2486	100	Photocatalysis	615	2462
11	X-Ray Diffraction	2270	7778	56	Mechanical-Properties	942	2005	101	Optical-Absorption	613	1781
12	Emission	2121	6773	57	Dynamics	911	1685	102	Raman Spectroscopy	609	2285
13	Nanocrystals	2083	8356	58	Phase	902	2094	103	Recognition	608	890
14	Nanostructures	2047	8721	59	Silver Nanoparticles	896	2709	104	Chemistry	607	1489
15	Fabrication	2021	7019	60	Mechanism	893	2695	105	Green Synthesis	606	1866
16	Spectroscopy	1947	5262	61	Stability	888	2230	106	Photoluminescence Properties	606	2528
17	Electrical-Properties	1801	6757	62	Transport	872	2008	107	Optical Absorption	589	1653
18	Deposition	1783	6282	63	Parameters	871	2117	108	Zinc-Oxide	589	2762
19	Spectra	1745	5185	64	Tio2	864	3435	109	Band Gap	587	2000
20	Design	1656	2673	65	Acid	833	1963	110	Chemical Synthesis	587	2782
21	Thin Films	1631	5487	66	Ftir	829	2689	111	Polymer	583	1635
22	Microstructure	1565	3988	67	Dependence	827	2701	112	Crystal	582	1557
23	Fluorescence	1560	4416	68	Evolution	813	1720	113	Glaucoma	577	331
24	Sensor	1500	3284	69	Electronic-Structure	788	2349	114	Silicon	577	1397
25	Degradation	1449	5721	70	Graphene	786	2189	115	Z-Scan	573	1528
26	Quantum Dots	1417	5016	71	Energy	783	2093	116	Optimization	571	1010
27	ZNO	1393	5779	72	Photocatalytic Activity	777	3292	117	Eye	569	361

S No	Keyword	Occ.	TLS	S No	Keyword	Occ.	TLS	S No	Keyword	OCC	TLS
28	XRD	1373	4847	73	Physical-Properties	770	2631	118	Copper	568	1569
29	Water	1339	3693	74	Polymers	768	1613	119	Adsorption	567	1689
30	Light	1327	2404	75	Composites	758	2576	120	Spectroscopic Properties	566	1964
31	Semiconductors	1310	4465	76	Laser	751	1590	121	Cells	561	1138
32	Morphology	1300	4453	77	Nonlinear-Optical Properties	744	1646	122	Optical Materials	560	2149
33	Surface	1297	3853	78	Hydrothermal Synthesis	737	2888	123	Prevalence	557	342
34	Nanorods	1288	5772	79	Nanocomposite	736	2756	124	Nonlinear Optics	543	1153
35	Ions	1269	4150	80	Crystal-Structure	732	1857	125	Ferromagnetism	535	2125
36	Oxide	1227	4443	81	Oxidation	726	2233	126	Layer	524	1613
37	Model	1218	1617	82	Reduction	722	2207	127	Diagnosis	523	358
38	System	1217	2036	83	Composite	708	2629	128	States	521	1034
39	Derivatives	1159	2336	84	Dielectric-Properties	708	2498	129	Facile Synthesis	519	1880
40	Magnetic-Properties	1133	4182	85	Glasses	706	2544	130	Ab-Initio	518	1239
41	Conductivity	1085	3534	86	Thickness	700	1940	131	Optical Band Gap	515	1494
42	Solar-Cells	1071	3394	87	Optical Coherence Tomography	698	325	132	Field	511	858
43	Efficiency	1056	3178	88	Defects	692	2336	133	2nd-Harmonic Generation	508	1113
44	Nanocomposites	1056	3855	89	Sensitivity	687	1420	134	Dye	504	1826
45	Crystal Growth	1045	2705	90	Sol-Gel	680	2555	135	Transmission	500	537

OCC= Occurrence; TLS= Total Link Strengths

4.4. AUTHOR METRICS

4.4.1. *Authorship Pattern*

Table 4.12 and Figure 4.9 show the authorship pattern in Indian optics publications over 30 years from 1992 to 2021. Table presents the number of articles published by the number of authors, ranging from single-author publications to publications with ten or more authors. The authorship pattern in Indian optics publications shows a gradual increase in publications over the years. In 1992, the number of single-authored papers was 51, which increased to 196 in 2021. Similarly, the number of papers with two authors increased from 148 in 1992 to 1457 in 2021.

Single Author: The number of single-author publications remained relatively constant throughout the period, representing about 3% to 5% of the total publications. Single-authored papers in Indian optics publications signify the contribution of an individual researcher who has independently conducted research and produced results. Such papers indicate high expertise and mastery in a particular research area. Single-authored papers also indicate that the researcher clearly understands the research problem, has independently designed the methodology, and analysed the data. These papers can also demonstrate the creativity and innovativeness of a researcher.

Two Authors: The number of publications with two authors has been consistently high, with an average of 586 per year. Papers with two authors are the most common authorship pattern in Indian optics publications. These papers represent a collaboration between two researchers, which can bring together complementary skills and knowledge. Such collaborations can also help produce more impactful research, as the co-authors can bring different perspectives, expertise, and experiences. In some cases, co-authorship can also help to establish a professional network and build a reputation in the field.

Three to Four Authors: The number of publications with three to four authors has also been consistently high, with an average of 463 per year. Papers with three to four authors represent a significant collaboration effort and signify the involvement of multiple researchers from different institutions. Such papers often involve large-scale research projects requiring substantial resources and expertise. Papers with three to four authors can also indicate the importance of interdisciplinary research, which brings together researchers from different fields and disciplines to solve complex problems. This indicates that many Indian optics publications have resulted from the collaboration between three to four authors.

Five to Nine Authors: The number of publications with five to six authors has increased over the years. This authorship pattern accounts for over 25% of all publications, totalling 33,799. Papers with five to nine authors represent a highly collaborative effort, often involving researchers from multiple institutions, disciplines, and countries. Such papers can signify the importance of international collaborations and the need for global cooperation to tackle complex research problems. Papers with five or more authors can also help establish a researcher's reputation and influence in the field, as they significantly contribute to the research community. The involvement of more authors can bring diverse perspectives, expertise, and resources to a study. This authorship pattern suggests that the research was conducted as part of a larger research group or project, which may have more funding and resources. However, having more authors can also lead to challenges in assigning credit and determining individual contributions to the research. It may also lead to challenges in communication and decision-making, as well as issues with authorship disputes and conflicts of interest.

Ten or More Authors: The number of publications with ten or more authors has been relatively low, with an average of 49 per year. These papers represent a significant collaboration effort, often involving researchers from multiple institutions, disciplines, and countries. Papers with ten or more authors can signify the importance of large-scale, interdisciplinary research projects requiring substantial resources and expertise. These papers also indicate the ability of researchers to work in large teams and collaborate effectively.

Overall, the authorship pattern in Indian optics publications shows a gradual increase in publications over the years. The most common authorship pattern is papers with two authors. The authorship pattern signifies the contribution of individual researchers, collaboration between researchers, and teamwork in large-scale research projects. The authorship pattern in Indian optics publications indicates the importance of interdisciplinary research, global cooperation, and the ability of researchers to work in teams to tackle complex research problems.
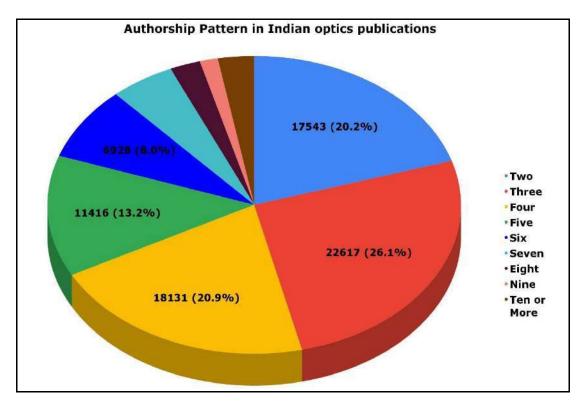
Figure 4.9: Authorship pattern in Indian Optics publications

Table 4.12: Authorship Pattern in Indian optics publications

Year	Single	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten or More	Total
1992	51	148	127	74	28	13	4	1	4	1	**451**
1993	33	166	141	93	36	9	5	5	2	2	**492**
1994	50	173	126	106	52	11	2	2	1	3	**526**
1995	35	171	152	100	39	8	5	6	2	3	**521**
1996	42	193	176	125	59	9	8	4	4	2	**622**
1997	48	172	172	139	64	24	9	5	2	5	**640**
1998	57	198	182	135	67	23	14	5	4	10	**695**
1999	70	209	190	154	74	26	18	5	4	13	**763**
2000	45	218	174	162	70	41	13	7	2	6	**738**
2001	44	222	219	159	120	41	28	9	5	13	**860**
2002	50	229	231	208	136	49	34	12	4	5	**958**
2003	51	280	266	247	169	49	31	19	6	14	**1132**
2004	55	316	310	322	162	49	33	13	5	18	**1283**
2005	45	332	356	324	194	89	34	18	8	16	**1416**
2006	68	397	429	405	217	124	51	27	12	27	**1757**
2007	60	455	603	444	261	153	72	31	10	27	**2116**
2008	107	478	709	574	308	162	89	36	16	34	**2513**
2009	87	564	706	612	326	174	108	34	33	38	**2682**
2010	92	590	852	663	404	224	129	58	24	49	**3085**
2011	101	702	884	717	401	278	150	66	30	59	**3388**
2012	115	721	979	799	462	289	145	77	36	95	**3718**
2013	128	907	1202	944	543	318	181	93	53	89	**4458**
2014	133	974	1378	1038	630	380	258	108	77	131	**5107**
2015	119	994	1366	1131	673	379	258	125	68	113	**5226**
2016	137	1146	1485	1219	748	478	276	114	79	180	**5862**
2017	132	1160	1583	1184	831	480	349	169	99	183	**6170**
2018	125	1257	1730	1295	982	631	427	196	104	208	**6955**
2019	149	1331	1858	1502	998	675	444	199	131	297	**7584**
2020	158	1383	1938	1541	1085	788	543	267	181	357	**8241**
2021	196	1457	2093	1715	1277	954	655	360	218	458	**9383**
1992-2021	**2583**	**17543**	**22617**	**18131**	**11416**	**6928**	**4373**	**2071**	**1224**	**2456**	**89342**

4.4.2. *Degree of Collaboration (DC)*

The Degree of Collaboration (DC) is a metric used to measure the extent of collaboration among authors in research publications. It is calculated as the ratio of the number of publications with multiple authors (Nm) to the total number of publications (Ns + Nm) in a given time period.

The formula for calculating the Degree of Collaboration suggested by Subramanyam (Subramanyam, 1983) and it is:

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

Where Ns is the number of single-authored publications, Nm is the number of multi-authored publications, and DC is the Degree of Collaboration.

For example, in 1992 there were 451 publications in a given time period, and 400 of them had multiple authors while 51 were single-authored, then the Degree of Collaboration would be calculated as follows:

$$DC = \frac{400}{51+400} \qquad\qquad DC = \frac{400}{451} \qquad\qquad DC = 0.887$$

Therefore, in this case, the Degree of Collaboration is 0.887 or 88.7%.

Table 4.13 and Figure 4.10 show that the DC has consistently remained above 0.9 during the study period, indicating that more than 90% of the publications have involved multiple authors. This trend has been consistent, with only a slight increase in DC observed over the years. In 1992, only 11% of the publications were single-authored; in 2021, this figure decreased to less than 3%. On the other hand, the number of publications with multiple authors has steadily increased, from 400 in 1992 to 9187 in 2021.

This high degree of collaboration in Indian Optics publications can be attributed to several factors, including the field's multidisciplinary nature, the need for

expertise from various disciplines, and the availability of research funding for collaborative projects. Collaborative research has also become more accessible with the advancements in communication and technology, making it easier for researchers to connect and work together.

Table 4.13: Degree of Collaboration in Indian Optics publications

Year	Single Author (Ns)	Multiple Authors (Nm)	Total Authors	DC
1992	51	400	451	0.887
1993	33	459	492	0.933
1994	50	476	526	0.905
1995	35	486	521	0.933
1996	42	580	622	0.932
1997	48	592	640	0.925
1998	57	638	695	0.918
1999	70	693	763	0.908
2000	45	693	738	0.939
2001	44	816	860	0.949
2002	50	908	958	0.948
2003	51	1081	1132	0.955
2004	55	1228	1283	0.957
2005	45	1371	1416	0.968
2006	68	1689	1757	0.961
2007	60	2056	2116	0.972
2008	107	2406	2513	0.957
2009	87	2595	2682	0.968
2010	92	2993	3085	0.970
2011	101	3287	3388	0.970
2012	115	3603	3718	0.969
2013	128	4330	4458	0.971
2014	133	4974	5107	0.974
2015	119	5107	5226	0.977
2016	137	5725	5862	0.977
2017	132	6038	6170	0.979
2018	125	6830	6955	0.982
2019	149	7435	7584	0.980
2020	158	8083	8241	0.981
2021	196	9187	9383	0.979
Total	**2583**	**86759**	**89342**	**0.971**
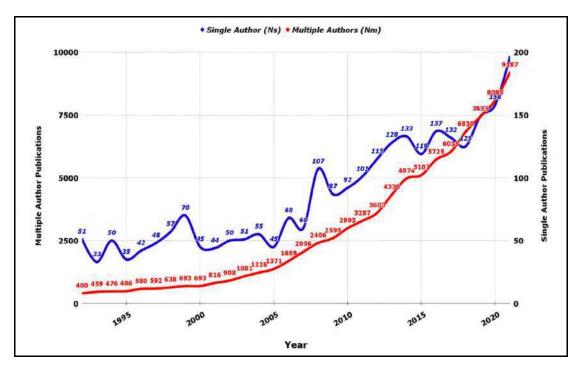
Figure 4.10: Degree of Collaboration

4.4.3. Size of Research Team (Group of Authors)

Table 4.14 provides information on the size of research teams involved in Indian optics research. The data presented in the table shows that teams of three or more researchers authored most research papers (73.1%), while only about 2.9% of the papers were authored by a single researcher. The most common team size was minimal, including teams of 3-4 authors, accounting for 45.6% of the published papers. The second most common team size was duets, which included teams of two authors and contributed to 19.6% of the published papers. The small team size category, which included teams of 5-10 authors, accounted for 29.9% of published papers. However, the more prominent teams were less common, with medium-sized teams, which included teams of 11-25 authors, contributing to only 1.4% of the total papers, and large teams, which included teams of 26 or more authors, contributing to only 0.5% of the total papers.

Overall, the data suggest that Indian optics research is primarily conducted by small research teams, with the majority of the papers authored by teams of 3-10

researchers. This may reflect the collaborative culture in the field and the availability of funding for smaller research projects. The data also suggests that larger research teams are less common, which may reflect challenges in coordinating and managing larger teams or difficulties in securing funding for more extensive research projects as displayed in Figure 4.11.

Table 4.14: Size of the Research Team (Group of Authors)

Research Team Size	Authors involved	Total Papers	Total Citations	CPP	TP Share%
Solo	1	2583	34618	13.402	2.891
Duet	2	17543	292585	16.678	19.636
Very Small	3 to 4	40748	718169	17.625	45.609
Small	5 to 10	26697	519819	19.471	29.882
Medium	11 to 25	1283	45456	35.429	1.436
Large	26 and more	488	65882	135.004	0.546
Total		**89342**	**1676529**		**100**
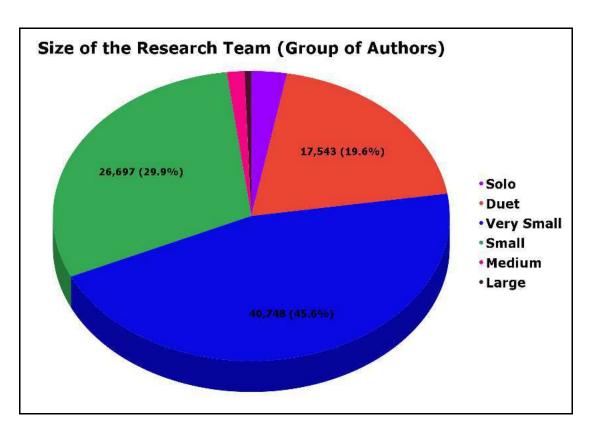
Figure 4.11: Size of Research Team

4.4.4. Most Productive/Prolific Authors (Top 50)

Table 4.15 lists top 50 most productive/prolific authors in Indian optics, with their affiliation, TP, % of TP, TC, CPP and h-index. Authors are ranked based on the total number of publications they have produced, with most productive author at the top of list. The % of TP column shows percentage of total publications each author has contributed to the field. The authors who contributed more than 250 publications and the above top 50 authors who contributed 27.32% (n=24410) of the total publications received 503658 citations at 21.05 CPP during the study period.

Of the total 24410 publications by the top 50 most prolific authors in Indian optics, the first 15 authors have contributed 50.95% (n= 12437) of the publications, following 15 authors, i.e., (16 to 30) have contributed 25.09% (n=6124) of the publications and the last 20 authors have contributed the remaining 23.96% share.

The most prolific authors on the list are Kumar A from IIT Kanpur with 1741 publications, Kumar S from Kurukshetra University with 1720 publications, Kumar R from Lucknow University with 928 publications, Singh S from Maharshi Dayanand University with 900 publications, Kumar P from Maharshi Dayanand University with 786 publications, Kumar V from National Institute of Technology with 751 publications, Das S from Indian Institute of Technology with 731 publications, Sharma S from Homi Bhabha National Institute with 717 publications, Ghosh S from IIT Roorkee with 689 publications, and Kumar M from Maharishi Markandeshwar University with 674 publications.

Of the top 50 prolific authors, 17 authors contributed 250 – 350 publications, 25 authors contributed 351 – 700 publications, 6 authors contributed 700 – 1000 publications and two authors contributed more than 1000 publications (Kumar A=1741 and Kumar S=1720).

Table 4.15: Most Productive/Prolific Authors (Top 50)

S No	Authors	Affiliation	TP	% Of TP	TC	CPP	h index
1	Kumar A	IIT, Kanpur	1741	1.949	32344	18.578	67
2	Kumar S	Kurukshetra University, Haryana	1720	1.925	35744	20.781	71
3	Kumar R	Lucknow University, Lucknow	928	1.039	22382	24.119	58
4	Singh S	Maharshi Dayanand University, Haryana	900	1.007	14815	16.461	55
5	Kumar P	Maharshi Dayanand University, Haryana	786	0.880	15876	20.198	52
6	Kumar V	National Institute of Technology, Kurukshetra	751	0.841	15509	20.651	54
7	Das S	Indian Institute of Technology System	731	0.818	17145	23.454	53
8	Sharma S	Homi Bhabha National Institute, Mumbai	717	0.803	14849	20.710	50
9	Ghosh S	IIT, Roorkee	689	0.771	14586	21.170	53
10	Kumar M	Maharishi Markandeshwar University, Haryana	674	0.754	12944	19.205	53
11	Sharma A	L. V. Prasad Eye Institute, Hyderabad	624	0.698	13278	21.279	46
12	Singh A	Bhabha Atomic Research Center, Mumbai	608	0.681	12102	19.905	46
13	Gupta A	PGIMER, Chandigarh	554	0.620	12256	22.123	46
14	Singh R	University of Delhi, New Delhi	514	0.575	10047	19.547	44
15	Gupta V	PGIMER, Chandigarh	500	0.560	9870	19.740	48
16	Singh P	Indian Institute of Technology System	469	0.525	8808	18.780	45
17	Singh M	Delhi Technological University, New Delhi	464	0.519	5489	11.830	33
18	Singh V	Kurukshetra University, Haryana	433	0.485	6324	14.605	36
19	Singh K	Thapar Institute of Engineering & Technology, Patiala	430	0.481	8682	20.191	43
20	Gupta S	AIIMS, New Delhi	423	0.473	5301	12.532	34
21	Sharma N	AIIMS, New Delhi	421	0.471	6630	15.748	39
22	Singh AK	IIT, Kharagpur	417	0.467	10136	24.307	49
23	Agarwal A	PGIMER, Chandigarh	408	0.457	8207	20.115	46
24	Ghosh A	IISc, Bangalore	401	0.449	11007	27.449	43
25	Sharma P	Shri Mata Vaishno Devi University, Jammu and Kashmir	393	0.440	6641	16.898	38

S No	Authors	Affiliation	TP	% Of TP	TC	CPP	h index
26	Ramasamy P	SSN College of Engineering, Chennai	388	0.434	7505	19.343	43
27	Sharma R	Tata Institute of Fundamental Research, Mumbai	388	0.434	6935	17.874	40
28	Gupta SK	Bhabha Atomic Research Center, Mumbai	371	0.415	8327	22.445	44
29	Singh N	Maulana Azad National Institute of Technology, Bhopal	362	0.405	6643	18.351	42
30	Roy S	Indian Institute of Technology System	356	0.398	5609	15.756	36
31	Sharma AK	Indian Institute of Technology System	356	0.398	6559	18.424	38
32	Kumar D	Madan Mohan Malaviya University of Technology, Gorakhpur	354	0.396	5301	14.975	36
33	Srivastava AK	Deen Dayal Upadhyaya Gorakhpur University, Gorakhpur	353	0.395	14710	41.671	51
34	Kumar N	Homi Bhabha National Institute, Mumbai	332	0.372	4920	14.819	37
35	Das D	Sri Sankaradeva Nethralaya, Gauhati	331	0.370	6821	20.607	41
36	Patil PS	Shivaji University, Kolhapur	309	0.346	11949	38.670	60
37	Gupta R	Himachal Pradesh University, Shimla	302	0.338	5520	18.278	31
38	Mukherjee S	IISc, Bangalore	295	0.330	9571	32.444	42
39	Sharma V	IISER, Mohali	288	0.322	7525	26.128	34
40	Chatterjee S	MGM Eye Institute, Raipur	278	0.311	4233	15.227	31
41	Das A	NIT, Arunachal Pradesh	274	0.307	7080	25.839	31
42	Basu S	L. V. Prasad Eye Institute, Hyderabad	273	0.306	8045	29.469	39
43	Bhattacharya S	Maharaja Jitendra Narayan Medical College & Hospital, West Bengal	273	0.306	7689	28.165	31
44	Pal S	University of Delhi, New Delhi	270	0.302	3976	14.726	30
45	Sarkar S	Tripura University, Suryamaninagar	268	0.300	9727	36.295	37
46	Sharma M	India Meteorological Department, New Delhi	263	0.294	4896	18.616	34
47	Singh G	National Institute of Technology, Jaipur	263	0.294	3976	15.118	31
48	Veeraiah N	Acharya Nagarjuna University, Guntur	258	0.289	6970	27.016	48
49	Sen S	Indian Association for the Cultivation of Science, Jadavpur	255	0.285	4207	16.498	32
50	Singh RK	Indian Institute of Technology System	254	0.284	3992	15.717	29

TP=Total Publications; TC= Total Citations; CPP= Citations per Paper; h index= Hirsch Index

4.4.5. Most Impactful Authors (Top 50)

Table 4.16 presents the top 50 most impactful authors in Indian Optics research publications based on their h-index, g-index, total papers, total citations, and citation per paper. The h-index measures the productivity and impact of an author's research output. It is the highest number of author publications that have been cited at least h times each. The g-index is like the h-index but considers the distribution of citations among the author's publications. The g-index gives more weight to highly cited papers.

The top author in the table is Kumar S, with an h-index of 71 and a g-index of 122. He has published 1721 papers and has a total of 35650 citations, with an impressive citation per paper score of 20.715. The second top author is Kumar A, with an h-index of 68 and a g-index of 131. He has published 1708 papers and has a total of 34729 citations, resulting in a citation per paper ratio of 20.333. Like Kumar S, Kumar A's work is highly cited and has had a significant impact on the field. The third top author is Patil PS, with an h-index of 59 and a g-index of 87, Patil PS is a highly impactful author in Indian optics research publications, despite having published fewer papers than Kumar S and Kumar A. Patil PS has published 269 papers and has a total of 10802 citations, resulting in a citation per paper ratio of 40.156, which is the highest among the top 50 authors in this list. Fourth toper Kumar R has an h-index of 58 and a g-index of 116. He has published 922 papers and has a total of 22341 citations, resulting in a citation per paper ratio of 24.231.

Singh S, with an h-index of 56 and a g-index of 102, Singh S is another highly impactful author in Indian optics research publications. He has published 918 papers and has a total of 18346 citations, resulting in a citation per paper ratio of 19.985. Kumar V has an h-index of 55 and a g-index of 94. He has published 737 papers and

has a total of 16280 citations, resulting in a citation per paper ratio of 22.090. Lokhande CD with an h-index of 55 and a g-index of 94, Lokhande CD is tied with Kumar V as the 6th most impactful author. He has published 197 papers and has a total of 10433 citations, resulting in a citation per paper ratio of 52.959, the highest among the top 50 authors in this list. Das S has an h-index of 53 and a g-index of 105. He has published 725 papers and has a total of 17209 citations, resulting in a citation per paper ratio of 23.737. Ghosh S has an h-index of 52 and a g-index of 101 and is a highly impactful author. He has published 650 papers and has a total of 15089 citations with a CPP of 23.214.

The top 50 authors in the table have a wide range of h-index, g-index, total papers, total citations, and citation per paper scores. Some authors, such as Ghosh A, Srivastava AK, and Rao GN, have a high h-index and g-index but a lower citation per paper score. This suggests that they have published many papers, but their individual papers have received less attention.

Table 4.16: Top 50 Most Impactful Authors

S No	Author	h_index	g_index	TP	TC	CPP
1	Kumar S	71	122	1721	35650	20.715
2	Kumar A	68	131	1708	34729	20.333
3	Patil PS	59	87	269	10802	40.156
4	Kumar R	58	116	922	22341	24.231
5	Singh S	56	102	918	18346	19.985
6	Kumar V	55	94	737	16280	22.090
7	Lokhande CD	55	94	197	10433	52.959
8	Das S	53	105	725	17209	23.737
9	Ghosh S	52	101	650	15089	23.214
10	Kumar M	52	79	643	12539	19.501
11	Kumar P	51	97	772	15682	20.313
12	Sharma S	50	96	701	14728	21.010
13	Agarwal A	49	72	450	9709	21.576
14	Gupta BD	49	78	141	7063	50.092
15	Jayasankar CK	49	74	164	6965	42.470
16	Manikandan A	49	70	105	5224	49.752
17	Gupta A	48	90	532	12275	23.073
18	Srivastava AK	48	104	301	12917	42.914
19	Ghosh A	47	103	399	13079	32.779
20	Rao GN	47	73	148	5929	40.061
21	Singh AK	46	71	391	8434	21.570
22	Gupta V	45	74	448	9071	20.248
23	Sharma A	45	93	595	12589	21.158
24	Singh A	45	74	601	10399	17.303
25	Moorthy KK	44	72	140	6106	43.614
26	Singh P	44	72	474	8759	18.479
27	Rai SB	43	62	183	5759	31.470
28	Singh R	43	78	491	9585	19.521
29	Veeraiah N	43	56	214	5602	26.178
30	Singh K	42	74	426	8611	20.214
31	Babu SS	41	71	120	5727	47.725
32	Das D	41	64	317	6572	20.732
33	Gupta SK	41	67	329	7372	22.407
34	Marimuthu K	41	55	85	3570	42.000
35	Singh N	41	62	329	6187	18.805
36	Sharma R	40	64	383	6814	17.791
37	Bhosale CH	39	58	90	3770	41.889
38	Rajpure KY	39	60	89	4011	45.067
39	Ramasamy P	39	56	332	6418	19.331
40	Satheesh SK	39	74	102	5659	55.480
41	Sharma N	39	57	405	6534	16.133
42	Singh RP	39	67	175	5399	30.851
43	Umar A	39	59	93	3862	41.527
44	Basu S	38	68	255	6025	23.627
45	Kumar N	38	57	338	5080	15.030
46	Moholkar AV	38	58	79	3651	46.215
47	Mukherjee S	38	78	264	7538	28.553
48	Patra A	38	58	130	4034	31.031
49	Rao DN	38	64	146	4914	33.658
50	Sharma P	38	76	388	8420	21.701

TP=Total Publications; TC= Total Citations; CPP= Citations per Paper

4.4.6 Most Collaborative Authors

Table 4.17 presents the comprehensive ranking of the top 50 authors in Indian Optics Research Publications based on their collaboration and Total Link Strengths (TLS). The authors were ranked based on four metrics; TP, TC, CPP and TLS. Among the top 50 authors, Kumar, A; Kumar, S; Kumar, R; Kumar, P; Singh, A; Gupta, A; Gupta, V; Sharma, A; Singh, R; and Singh, S. were identified as having a robust collaborative network in Indian Optics Research Publications.

Kumar, A and Kumar, S were found to have the highest number of total publications, with 1756 and 1741 publications, respectively. Both authors demonstrated a strong TLS of 1044 and 1034, respectively. Kumar, R had a relatively lower number of total publications, with 960 publications and TLS of 672. Kumar, P. had 829 TP and a TLS of 537, while Singh, A had 635 TP and a TLS of 537. Gupta, A had a similar number of total publications, with 567 and a TLS of 529, while Gupta, V had a similar number of total citations, with 10413 and a TLS of 525. Sharma, A had a higher number of total publications with 684 and a TLS of 517. Singh, R had 588 TP and a TLS of 476, and Singh, S had a higher number of total citations with 15549 and a TLS of 463.

The table shows a wide range of total publications, with the top author having 1756 publications and the 50th author having 277 publications. Similarly, there is a considerable range of total citations, with the top author having 29576 citations and the 50th author having 4322 citations. The CPP ranged from 12.165 to 84.443, with an average CPP of approximately 19. TLS varied from 141 to 1044, indicating the authors' collaboration level.

Collaboration plays a crucial role in advancing research, and the findings from this study emphasize the importance of collaboration in the field of optics. The top authors in this study demonstrated a high level of collaboration and strong total link strengths. The higher the total link strength, the stronger the collaboration between authors. Thus, the results from this study suggest that collaboration is a critical aspect of research and can lead to higher productivity, increased citation rates, and, ultimately, more remarkable advancement of the field.

The study's results highlight the significance of collaboration and total link strengths among the top authors in Indian Optics research publications. Collaboration plays a critical role in research, and the analysis highlights the significance of establishing robust collaborative networks to propel the progress of optics research. These findings have practical implications for researchers, institutions, and policymakers, who can encourage and facilitate collaborations to achieve greater research productivity and impact.

Table 4.17: Most collaborative Authors

Sl.No.	Author	TP	TC	CPP	TLS
1	Kumar, A	1756	29576	16.843	1044
2	Kumar, S	1741	35052	20.133	1034
3	Kumar, R	960	22029	22.947	672
4	Kumar, P	829	16104	19.426	537
5	Singh, A	635	11223	17.674	537
6	Gupta, A	567	10802	19.051	529
7	Gupta, V	521	10413	19.987	525
8	Sharma, A	684	11777	17.218	517
9	Singh, R	588	11820	20.102	476
10	Singh, S	933	15549	16.666	463
11	Sharma, S	794	12674	15.962	455
12	Kumar, M	707	13736	19.429	417
13	Kumar, V	786	16305	20.744	414
14	Singh, P	485	9212	18.994	376
15	Ghosh, S	720	13795	19.160	323
16	Ghosh, A	420	9487	22.588	288
17	Sharma, P	399	6793	17.025	288
18	Singh, K	460	9004	19.574	285
19	Gupta, S	521	8082	15.512	278
20	Kumar, D	360	5555	15.431	278
21	Mukherjee, S	300	8220	27.400	270
22	Das, S	755	14368	19.030	261
23	Sharma, V	309	4283	13.861	255
24	Singh, N	368	6780	18.424	250
25	Singh, M	490	5961	12.165	236
26	Srivastava, AK	326	9010	27.638	235
27	Agarwal, A	410	8279	20.193	232
28	Kumar, N	337	5222	15.496	225
29	Singh, V	462	7743	16.760	223
30	Singh, AK	403	9875	24.504	218
31	Sharma, N	428	6913	16.152	214
32	Singh, D	270	4907	18.174	211
33	Sharma, R	424	7470	17.618	209
34	Gupta, R	322	5875	18.245	198
35	Singh, J	263	5565	21.160	191
36	Sharma, M	270	5017	18.581	179
37	Gupta, P	243	4320	17.778	179
38	Gupta, SK	311	6038	19.415	170
39	Singh, RK	230	3903	16.970	162
40	Das, D	339	7025	20.723	158
41	Singh, G	269	4097	15.230	157
42	Roy, S	380	6159	16.208	148
43	Sen, S	262	4473	17.073	148
44	Singh, H	207	3485	16.836	141
45	Kaur, S	200	3187	15.935	131
46	Pal, S	279	4338	15.548	126
47	Banerjee, S	235	19844	84.443	121
48	Saha, S	225	4877	21.676	121
49	Kumar, B	230	4687	20.378	120
50	Bhattacharya, S	277	4322	15.603	119

TP= Total Publications; TC= Total Citations; CPP= Citation per Paper;
TLS= Total Link strengths

4.4.7. Co-Authorship Index (CAI)

Co-Authorship Index (CAI) is a measure of collaborative research in bibliometrics (Schubert & Braun, 1986). It evaluates degree of collaboration between authors in a particular field or discipline. The CAI is calculated by dividing the total number of publications with multiple authors by the total number of publications.

The formula for the Co-Authorship Index (CAI) is:

$$CAI = \frac{\text{single author papers in a year}/\text{total number of single author papers of the study period}}{\text{total papers in that year}/\text{total papers of the study period}} \times 100$$

In other words, the CAI represents the percentage of publications with multiple authors. The higher the CAI, the greater the degree of collaboration among authors in a particular field. CAI is a useful measure of collaborative research because it reflects the trend of multi-authorship in scientific publications. It can also be used to track changes in collaboration patterns over time.

Table 4.18 provides data on the CAI for Indian Optics research publications from 1992 to 2021. The data indicates that the total number of papers has increased steadily over the years, from 451 in 1992 to 9383 in 2021. The number of single-author papers has decreased over the years, from 51 in 1992 to 196 in 2021. On the other hand, the number of papers with two or more authors has increased, with a noticeable increase in papers with three or more authors.

In 1992, there were 51 single-author publications with a CAI of 391.133. There were 148 publications with two authors, a CAI of 167.123 and 252 publications with three or more authors, and a CAI of 259.543. The total number of publications in that year was 451. In 1993, there were 33 single-author publications with a CAI of 231.996. There were 166 publications with two authors, a CAI of 171.828, 293 with three or more authors, and 276.623. The total number of publications in that year was 492. In 1994, there were 50 single-author publications with a CAI of 328.788. There were 173 publications with two authors and a CAI of 167.499 and 303 publications

with three or more authors and a CAI of 267.573. The total number of publications in that year was 526. In 1995, there were 35 single-author publications with a CAI of 232.360. There were 171 publications with two authors, a CAI of 167.151 and 315 publications with three or more authors, and a CAI of 280.840. The total number of publications in that year was 521. In 1996, there were 42 single-author publications with a CAI of 233.556. There were 193 publications with two authors, a CAI of 158.022 and 387 publications with three or more authors, and 289.006. Total number of publications in that year was 622. In 1997, there were 48 single-author publications with a CAI of 259.413. There were 172 publications with two authors and a CAI of 136.867 and 420 publications with three or more authors and a CAI of 304.828. The total number of publications in that year was 640. In 1998, there were 57 single-author publications with a CAI of 283.675. There were 198 publications with two authors, a CAI of 145.088, 440 with three or more authors, and a CAI of 294.072. The total number of publications in that year was 695. In 1999, there were 70 single-author publications with a CAI of 317.325. There were 209 publications with two authors, a CAI of 139.500, 484 with three or more authors, and a CAI of 294.650. The total number of publications in that year was 763. In 2000, there were 45 single-author publications with a CAI of 210.905. There were 218 publications with two authors and a CAI of 150.436 and 475 publications with three or more authors and a CAI of 298.967. The total number of publications in that year was 738. In 2001, there were 44 single-author publications with a CAI of 176.964. There were 222 publications with two authors and a CAI of 131.464 and 594 publications with three or more authors and a CAI of 320.829. The total number of publications. The CAI for single-author papers has also decreased over years, from 391.133 in 1992 to 72.251 in 2021. This suggests a decrease in the proportion of single-author papers in the field of

Optics research in India. In contrast, CAI for papers with two authors has remained relatively stable, from 79.081 in 2021 to 171.828 in 1993. Interestingly, the CAI for papers with three or more authors has shown an increasing trend over the years, from 259.543 in 1992 to 382.669 in 2021. This indicates a rise in degree of collaboration among authors in Optics research publications in India. The table suggests an increase in collaboration and a decrease in the proportion of single-author papers in Optics research publications in India. The findings are consistent with the trend observed in other research fields, with a growing emphasis on collaborative research.

Table 4.18: Co-Authorship Index (CAI)

Year	Single Author	CAI	Two Authors	CAI	Three or More Authors	CAI	Total
1992	51	391.133	148	167.123	252	259.543	451
1993	33	231.996	166	171.828	293	276.623	492
1994	50	328.788	173	167.499	303	267.573	526
1995	35	232.36	171	167.151	315	280.840	521
1996	42	233.556	193	158.022	387	289.006	622
1997	48	259.413	172	136.867	420	304.828	640
1998	57	283.675	198	145.088	440	294.072	695
1999	70	317.325	209	139.500	484	294.650	763
2000	45	210.905	218	150.436	475	298.967	738
2001	44	176.964	222	131.464	594	320.829	860
2002	50	180.524	229	121.737	679	329.223	958
2003	51	155.831	280	125.969	801	328.679	1132
2004	55	148.275	316	125.433	912	330.183	1283
2005	45	109.921	332	119.406	1039	340.830	1416
2006	68	133.865	397	115.072	1292	341.568	1757
2007	60	98.077	455	109.508	1601	351.449	2116
2008	107	147.273	478	96.870	1928	356.370	2513
2009	87	112.200	564	107.096	2031	351.753	2682
2010	92	103.149	590	97.398	2403	361.813	3085
2011	101	103.112	702	105.523	2585	354.408	3388
2012	115	106.984	721	98.759	2882	360.056	3718
2013	128	99.312	907	103.614	3423	356.659	4458
2014	133	90.078	974	97.128	4000	363.815	5107
2015	119	78.761	994	96.865	4113	365.574	5226
2016	137	80.836	1146	99.561	4579	362.836	5862
2017	132	73.998	1160	95.747	4878	367.234	6170
2018	125	62.165	1257	92.043	5573	372.201	6955
2019	149	67.955	1331	89.378	6104	373.854	7584
2020	158	66.314	1383	85.466	6700	377.643	8241
2021	196	72.251	1457	79.081	7730	382.669	9383
Total	**2583**	**100**	**17543**	**100**	**19234**	**100**	**89342**

CAI= Co-Authorship Index

4.5 Geo-Metrics

4.5.1 Most Collaborative Countries (Top 50)

Table 4.19 lists the most collaborative countries in optics research publications based on their TP, TC and ACPP. India tops the list with 89,342 publications and 1,676,529 total citations, averaging 18.765 citations per paper. India has actively collaborated with 168 countries respectively. Despite having a much lower TP than India, the USA has the second-highest TC in the table at 224,967, indicating highly cited research. The collaboration between India and the USA in optics research is evident, with a relatively high TP of 5,996, ranking second after India, and an ACPP of 37.520, the highest among the top collaborative countries.

South Korea with a TP of 2,620 and a TC of 72,377, ranking third in the table. The ACPP of 27.625 is relatively lower than some of the other collaborative countries, but the high volume of publications indicates fruitful collaboration. It is the fourth-highest country in terms of TC with 113,141, a TP of 2,219 and an ACPP of 50.987. With a TP of 1,892 and a TC of 104,179, England is an important collaborator with India in optics research, ranking fifth in the table. The ACPP of 55.063 is impressive, indicating that English researchers produce highly impactful research. Japan with a TP of 1,750 and a TC of 81,792, ranking seventh in the table. The ACPP of 46.738 is also impressive, indicating that Japanese researchers produce high-quality research. France ranks ninth in the table with a TP of 1,511 and a TC of 87,848. The ACPP of 58.139 indicates that French researchers produce high-quality research, and their collaboration with India is an important contributor to this. China ranks eighth in the table with a TP of 1,699 and a TC of 60,158. The ACPP of 35.408 is relatively lower than some of the other collaborative countries, but the volume of publications indicates that the collaboration between the two countries is fruitful. Australia ranks

tenth in the table with a TP of 1,332 and a TC of 62,535. Italy with a TP of 1,257 and a TC of 84,324, ranking eleventh in the table. The ACPP of 67.084 is one of the highest among the collaborative countries, indicating that Italian researchers produce highly impactful research in optics.

The rankings are based on the total number of publications, total citations, and average citations per paper, indicating the productivity and impact of each country's optics research. Countries with fewer publications may still have a high impact if their average citations per paper are high. Conversely, countries with more publications but low average citations per paper may not significantly impact the field.

Figure 4.12: Most Collaborative Countries in Optics Research Publications

Table 4.19: Most Collaborative Countries

Rank	Country	TP	TC	ACPP
1	India	89342	1676529	18.765
2	USA	5996	224967	37.520
3	South Korea	2620	72377	27.625
4	Germany	2219	113141	50.987
5	England	1892	104179	55.063
6	Saudi Arabia	1850	38071	20.579
7	Japan	1750	81792	46.738
8	China	1699	60158	35.408
9	France	1511	87848	58.139
10	Australia	1332	62535	46.948
11	Italy	1257	84324	67.084
12	Spain	895	64315	71.860
13	Taiwan	868	37649	43.374
14	Canada	866	62949	72.689
15	Russia	755	52817	69.956
16	Singapore	756	26937	35.631
17	Malaysia	732	15029	20.531
18	Poland	720	34144	47.422
19	South Africa	718	39704	55.298
20	Brazil	588	34491	58.658
21	Netherlands	573	56098	97.902
22	Switzerland	532	53197	99.994
23	Sweden	470	27089	57.636
24	Mexico	401	15927	39.718
25	Israel	386	17245	44.676
26	Chile	384	23765	61.888
27	Turkey	379	16739	44.166
28	Egypt	360	5669	15.747
29	Czech Republic	358	11288	31.531
30	Portugal	348	14367	41.284
31	Finland	341	42058	123.337
32	Belgium	327	12385	37.875
33	Greece	317	13255	41.814
34	Scotland	302	16917	56.017
35	Vietnam	269	5133	19.082
36	Denmark	268	27616	103.045
37	Norway	245	19339	78.935
38	Iran	222	18117	81.608
39	Ireland	226	19000	84.071
40	Thailand	222	7056	31.784
41	United Arab Emirates	202	4779	23.658
42	Austria	180	15433	85.739
43	Pakistan	158	3194	20.215
44	Hungary	157	29654	188.879
45	Ukraine	149	10114	67.879
46	Bulgaria	138	6006	43.522
47	Argentina	136	7386	54.309
48	Wales	138	19973	144.732
49	Algeria	134	2264	16.896
50	Bangladesh	129	2747	21.295

TP= Total Publications; TC= Total Citations; ACPP= Average Citation per Paper

4.6. Institutions and Publisher Metrics

4.6.1. Most Productive Organisations

Table 4.20 and Figure 4.13 provide an overview of the top 50 organizations contributing to optics research in India, out of a total of 24,169 organizations that contributed to this field. Interestingly, most of these organizations (over 13,892) have only published a single paper in the study period. The Indian Institute of Technology (IIT) System leads the list with a total of 13,478 publications, representing 15.086% of the total productivity. The Council of Scientific Industrial Research (CSIR) and the Department of Science Technology (DST) rank second and third, respectively. Other top 10 organizations include the National Institute of Technology System, Anna University Chennai, Indian Institute of Science (IISc) Bangalore, Indian Institute of Technology (IIT) Delhi, Bhabha Atomic Research Center (BARC) Mumbai, Department of Space India, L V Prasad Eye Institute Hyderabad, and All India Institute of Medical Sciences (AIIMS) New Delhi.

It is worth noting that certain organizations stand out due to their impact, as measured by CPP. The Tata Institute of Fundamental Research (TIFR), Mumbai, has the highest CPP among the top 50 organizations, with a value of 40.046. This suggests that the research produced by this institution is highly cited by other researchers in the field. Other institutions with a CPP above the table average (20.55) include Shivaji University Kolhapur (CPP=36.41), Sri Venkateswara University Tirupati (CPP=28.49), Panjab University Chandigarh (CPP=27.82), Physical Research Laboratory (PRL) Ahmedabad (CPP=26.74), and others.

The significance of these institutions in optics research output in India is noteworthy. For example, the Indian Institute of Technology (IIT) System has been instrumental in advancing the field of optics research in India, and its research output accounts for a significant portion of the total publications in this field. Similarly, the Council of Scientific Industrial Research (CSIR) and the Department of Science Technology (DST) have played crucial roles in supporting and funding research in optics, leading to their high productivity in this field. The presence of other prominent institutions, such as the Indian Institute of Science (IISc) Bangalore, the Bhabha Atomic Research Center (BARC) Mumbai, and the Indian Space Research Organisation, further illustrates the breadth and depth of optics research in India. Ultimately, the contributions of these organizations have helped establish India as a major player in the global optics research community.
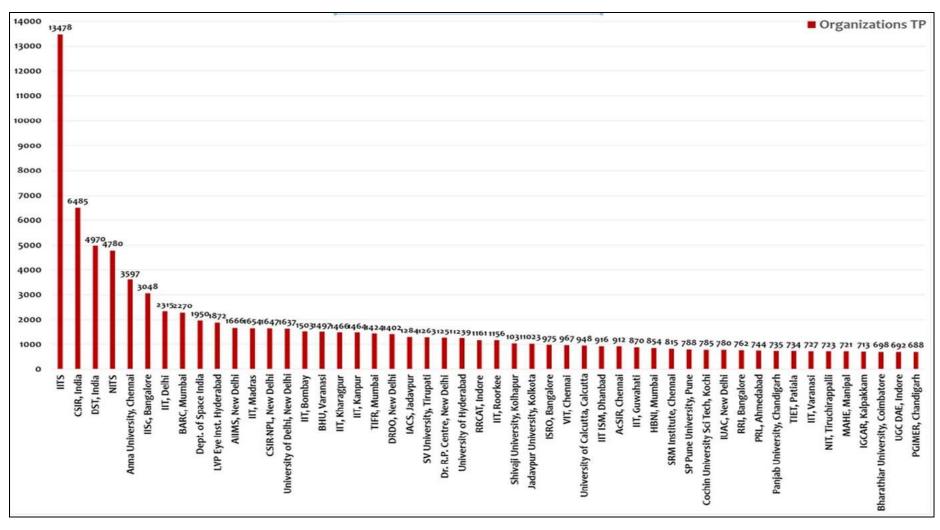
Figure 4.13: Top 50 Most Productive Organisations

Table 4.20: Top 50 Most Productive Organisations

S No	Institution Name	TP	% TP	TC	CPP
1	Indian Institute of Technology System	13478	15.086	272656	20.230
2	Council of Scientific Industrial Research (CSIR), India	6485	7.259	171663	26.471
3	Department of Science Technology (DST), India	4970	5.563	120632	24.272
4	National Institute of Technology System	4780	5.350	72213	15.107
5	Anna University, Chennai	3597	4.026	60194	16.735
6	Indian Institute of Science (IISc), Bangalore	3048	3.412	71869	23.579
7	Indian Institute of Technology (IIT), Delhi	2315	2.591	49158	21.235
8	Bhabha Atomic Research Center (BARC), Mumbai	2270	2.541	46453	20.464
9	Department of Space India	1950	2.183	41638	21.353
10	L V Prasad Eye Institute, Hyderabad	1872	2.095	39752	21.235
11	All India Institute of Medical Sciences (AIIMS), New Delhi	1666	1.865	22265	13.364
12	Indian Institute of Technology (IIT), Madras	1654	1.851	35609	21.529
13	CSIR National Physical Laboratory (CSIR-NPL), New Delhi	1647	1.843	37853	22.983
14	University of Delhi, New Delhi	1637	1.832	31719	19.376
15	Indian Institute of Technology (IIT), Bombay	1503	1.682	31026	20.643
16	Banaras Hindu University, Varanasi	1497	1.676	30236	20.198
17	Indian Institute of Technology (IIT), Kharagpur	1466	1.641	33914	23.134
18	Indian Institute of Technology (IIT), Kanpur	1464	1.639	31344	21.410
19	Tata Institute of Fundamental Research (TIFR), Mumbai	1424	1.594	57025	40.046
20	Defence Research Development Organisation (DRDO), New Delhi	1402	1.569	28279	20.170
21	Indian Association for the Cultivation of Science (IACS), Jadavpur	1284	1.437	32623	25.407
22	Sri Venkateswara University, Tirupati	1263	1.414	35981	28.489
23	Dr Rajendra Prasad Centre for Ophthalmic Sciences, New Delhi	1251	1.400	16801	13.430
24	University of Hyderabad, Hyderabad	1239	1.387	29742	24.005
25	Raja Ramanna Centre for Advanced Technology (RRCAT), Indore	1161	1.300	19973	17.203

S No	Institution Name	TP	% TP	TC	CPP
26	Indian Institute of Technology (IIT), Roorkee	1156	1.294	28637	24.772
27	Shivaji University, Kolhapur	1031	1.154	37543	36.414
28	Jadavpur University, Kolkota	1023	1.145	19523	19.084
29	Indian Space Research Organisation (ISRO), Bangalore	975	1.091	20835	21.369
30	Vellore Institute of Technology, Chennai	967	1.082	15975	16.520
31	University of Calcutta, Calcutta	948	1.061	12894	13.601
32	IIT Indian School of Mines, Dhanbad	916	1.025	13652	14.904
33	Academy of Scientific Innovative Research (AcSIR), Chennai	912	1.021	14887	16.323
34	Indian Institute of Technology (IIT), Guwahati	870	0.974	15426	17.731
35	Homi Bhabha National Institute (HBNI), Mumbai	854	0.956	11088	12.984
36	SRM Institute of Science Technology, Chennai	815	0.912	12024	14.753
37	Savitribai Phule Pune University, Pune	788	0.882	17502	22.211
38	Cochin University Science Technology, Kochi	785	0.879	13798	17.577
39	Inter University Accelerator Centre, New Delhi	780	0.873	13581	17.412
40	Raman Research Institute (RRI), Bangalore	762	0.853	17027	22.345
41	Physical Research Laboratory (PRL), Ahmedabad	744	0.833	19893	26.738
42	Panjab University, Chandigarh	735	0.823	20448	27.820
43	Thapar Institute of Engineering Technology (TIET), Patiala	734	0.822	9290	12.657
44	Indian Institute of Technology (IIT), Varanasi	727	0.814	12976	17.849
45	National Institute of Technology (NIT), Tiruchirappalli	723	0.809	13891	19.213
46	Manipal Academy of Higher Education (MAHE), Manipal	721	0.807	11424	15.845
47	Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam	713	0.798	15253	21.393
48	Bharathiar University, Coimbatore	698	0.781	13624	19.519
49	UGC DAE Consortium for Scientific Research, Indore	692	0.775	12823	18.530
50	Post Graduate Institute of Medical Education Research (PGIMER), Chandigarh	688	0.770	10059	14.621

TP= Total Publications; TC= Total Citations; CPP= Citation per Paper

4.6.2. Most Productive Publishers of Indian Optics Publications

Table 4.21 presents the most productive publishers of Indian optics publications during the study period. A total of 1036 publishers published all 89342 documents. The table includes 55 publishers who have published 100 or more publications, with the top 10 being Elsevier, Springer, Wiley, Taylor & Francis, IOP Publishing Ltd, The Royal Society of Chemistry, American Chemical Society, Amer Chemical Society, Optical Society Amer, Amer Institute Physics, and Wolters Kluwer Medknow Publications.

Elsevier is the top publisher in terms of both TP, with a total of 30,466 publications accounting for 34.1% of all Indian optics publications. They also have a relatively high CPP of 23.55, indicating that their papers are cited frequently. Springer is the second-highest publisher in terms of TP, with 10,159 publications accounting for 11.4% of all Indian optics publications. They have a lower CPP than Elsevier at 10.94 but still have a respectable TC of 111,109.

Wiley has a total of 4,167 publications, accounting for 4.7% of all Indian optics publications. They have a relatively high CPP of 17.87 but a lower TC than the top two publishers. Taylor & Francis has similar publications as Wiley, with 4,081 papers accounting for 4.6% of all Indian optics publications. They have a relatively low CPP of 10.88 but a higher TC than Wiley. IOP Publishing Ltd has a total of 3,551 publications, accounting for 4% of all Indian optics publications. They have a high CPP of 19.54 and a relatively high TC. The Royal Society of Chemistry has a total of 3,428 publications, accounting for 3.8% of publications. They have a high CPP of 26.28, indicating that their papers are highly cited. The American Chemical Society has a total of 2,940 publications, accounting for 3.3% of publications. They have the

highest CPP of any publisher on this list at 40.89, indicating that their papers are highly cited but have a relatively low TP.

The Optical Society of America has a total of 2,268 publications, accounting for 2.5% of all Indian optics publications. They have a moderate CPP of 15.64. The American Institute of Physics has a total of 1,815 publications, accounting for 2% of all Indian optics publications. They have a moderate CPP of 23.25. Wolters Kluwer Medknow Publications has a total of 1,782 publications, accounting for 2% of all Indian optics publications. They have a relatively low CPP of 5.83 and a low TC.

Overall, Elsevier and Springer are the top publishers in terms of TP, while the American Chemical Society has the highest CPP. The Royal Society of Chemistry and IOP Publishing Ltd also have high CPP values. The American Chemical Society, Wiley, and Taylor and Francis have lower TP values but higher CPP values, while the Optical Society of America and American Institute of Physics have moderate CPP values and lower TP values. Wolters Kluwer Medknow Publications has a relatively low TP and CPP value. The data provided in the table can help researchers and institutions understand the publishing landscape in the field of Indian optics and make informed decisions regarding where to publish their research. Further, it is important to note that the performance of a publisher can depend on various factors, such as the size and scope of their portfolio and the field of study.

Table 4.21: Most Productive Publishers

S No	Publisher	TP	% TP	TC	CPP
1	Elsevier	30466	34.100	717483	23.550
2	Springer	10159	11.371	111109	10.937
3	Wiley	4167	4.664	74469	17.871
4	Taylor & Francis	4081	4.568	44391	10.877
5	IOP Publishing Ltd	3551	3.975	69396	19.543
6	Royal Society Chemistry	3428	3.837	90077	26.277
7	Amer Chemical Society	2940	3.291	120203	40.885
8	Optical Society Amer	2268	2.539	35469	15.639
9	Amer Institute Physics	1815	2.032	42193	23.247
10	Wolters Kluwer Medknow Publications	1782	1.995	10387	5.829
11	IEEE Publishers	1552	1.737	25727	16.577
12	Indian ACAD Sciences	1234	1.381	13997	11.343
13	Amer Physiological Society	1199	1.342	29520	24.621
14	Lippincott Williams & Wilkins	1106	1.238	15247	13.786
15	Society of Photographic Instrumentation Engineers (SPIE)	1018	1.139	9254	9.090
16	NISCAIR	914	1.023	5664	6.197
17	Oxford University Press	809	0.906	14008	17.315
18	Amer Scientific Publishers	797	0.892	9612	12.060
19	Medknow Publications	741	0.829	5308	7.163
20	Nature Publishing Group	707	0.791	22416	31.706
21	National Institute of Optoelectronics	594	0.665	2667	4.490
22	Sage Publications	590	0.660	3966	6.722
23	World Scientific Publication Ltd	576	0.645	3676	6.382
24	MDPI	444	0.497	5146	11.590
25	EDP Sciences S A	413	0.462	19143	46.351
26	Indian Assoc Cultivation Science	367	0.411	1918	5.226
27	Association Research Vision Ophthalmology Inc	366	0.410	6586	17.995
28	Slack Inc	339	0.379	3531	10.416
29	BMJ Publishing Group	314	0.351	7630	24.299
30	National Institute of R&D Materials Physics	271	0.303	2622	9.675
31	Amer Geophysical Union	267	0.299	12934	48.442
32	Indian Academy Sciences	258	0.289	2928	11.349
33	Hindawi Ltd	238	0.266	3208	13.479
34	Institute of Engineering Technology-IET	230	0.257	1873	8.143
35	Walter De Gruyter GMBH	207	0.232	1532	7.401
36	Public Library Science	206	0.231	4857	23.578
37	AIP Publishing	194	0.217	1852	9.546
38	Cambridge University Press	177	0.198	2469	13.949
39	Blackwell Publishers	176	0.197	3525	20.028
40	Bentham Science Publication	172	0.193	2464	14.326
41	Council Scientific Industrial Research	152	0.170	623	4.099
42	Copernicus Gesellschaft MBH	146	0.163	4857	33.267
43	Electrochemical Society Inc	133	0.149	1750	13.158
44	Frontiers Media SA	132	0.148	1493	11.311
45	All India Ophthalmological Society	130	0.146	1420	10.923
46	Amer Medical Association	129	0.144	6530	50.620
47	Pleiades Publishing Inc	120	0.134	620	5.167
48	Asian Journal of Chemistry	119	0.133	363	3.050
49	Kluwer Academic Publication	117	0.131	1760	15.043
50	American Physical Society	116	0.130	4459	38.440
51	BMC	108	0.121	2323	21.509
52	Current Science Association	107	0.120	998	9.327
53	Scientific Publishers India	104	0.116	145	1.394
54	International Union Crystallography	103	0.115	1028	9.981
55	Mary Ann Liebert Inc	101	0.113	2017	19.970

TP= Total Publications; TC= Total Citations; CPP= Citation per Paper

4.6.3. Global Funding Agencies

Table 4.22 lists the top 41 global funding agencies that funded 100 or more Indian optics research publications. The National Science Foundation (NSF) of the USA is the largest funder, supporting 982 research publications, accounting for 1.099% of the total publications. The European Commission, UK Research and Innovation, and the National Aeronautics and Space Administration (NASA) of the USA are the next largest funders, supporting 838 (0.938%), 734 (0.822%), and 595(0.666%) publications respectively.

The United States Department of Health and Human Services and the National Institutes of Health (NIH), also from the USA, have provided funding for 525(0.588%) and 522 (0.584%) publications, respectively. The National Natural Science Foundation of China has supported 476 publications (0.533%), followed by the United States Department of Energy, which has funded 454 publications (0.508%). The Department of Science and Technology of the Philippines and Japan's Ministry of Education, Culture, Sports, Science, and Technology round out the top 10 funders, supporting 430 (0.481%) and 423 (0.473%) publications, respectively.

It is evident that the top funding agencies for Indian optics research are predominantly from the USA, with the NSF being the largest funder by a significant margin. However, it is important to note that each funding agency's contribution is relatively small compared to the total number of publications in Indian optics. However, these funding agencies play a crucial role in supporting research and promoting scientific progress, and their contributions are precious to the field's growth. Additionally, the fact that multiple countries are represented among the top funders reflects the global nature of scientific research and the importance of collaboration and partnerships in advancing knowledge.

Table 4.22: Global Funding Agencies

Sl.No.	Funding Agencies	Country	TP	% TP
1	National Science Foundation	USA	982	1.099
2	European Commission	Belgium	838	0.938
3	UK Research Innovation	UK	734	0.822
4	National Aeronautics Space Administration	USA	595	0.666
5	United States Department of Health Human Services	USA	525	0.588
6	National Institutes of Health	USA	522	0.584
7	National Natural Science Foundation of China	China	476	0.533
8	United States Department of Energy	USA	454	0.508
9	Department Of Science Technology	Philippines	430	0.481
10	Ministry Of Education Culture Sports Science and Technology	Japan	423	0.473
11	German Research Foundation	Germeny	372	0.416
12	National Research Foundation of Korea	South Korea	336	0.376
13	Spanish Government	Spain	325	0.364
14	King Saud University	Saudi Arabia	322	0.36
15	Japan Society for The Promotion of Science	Japan	316	0.354
16	Science Technology Facilities Council	UK	311	0.348
17	National Eye Institute	USA	276	0.309
18	Engineering Physical Sciences Research Council	UK	255	0.285
19	European Research Council	UK	204	0.228
20	Australian Research Council	Australia	199	0.223
21	NSF Directorate for Mathematical Physical Sciences	USA	197	0.221
22	Ministry of Science and Technology	Taiwan	196	0.219
23	Russian Foundation for Basic Research	Russia	191	0.214
24	Conselho Nacional De Desenvolvimento Cientifico E Tecnologico	Brazil	185	0.207
25	Grants in Aid for Scientific Research Kakenhi	Japan	172	0.193
26	Max Planck Society	Germany	163	0.182
27	Natural Sciences and Engineering Research Council of Canada	Canada	158	0.177
28	Ministry of Education Science Technology	South Korea	155	0.173
29	Alexander Von Humboldt Foundation	Germany	150	0.168
30	Research to Prevent Blindness	USA	148	0.166
31	Deanship of Scientific Research at King Khalid University	Saudi Arabia	147	0.165
32	French National Research Agency	France	135	0.151
33	Alfred P Sloan Foundation	USA	121	0.135
34	Korean Government	South Korea	117	0.131
35	Wellcome Trust	UK	117	0.131
36	Portuguese Foundation for Science and Technology	Portugal	106	0.119
37	United States Department of Defense	USA	105	0.118
38	Federal Ministry of Education Research	Germany	102	0.114
39	Ohio State University	USA	102	0.114
40	Chinese Academy of Sciences	China	100	0.112
41	National Research Foundation South Africa	South Africa	100	0.112

TP= Total Publications

4.6.4. Indian Funding Agencies Funded for Optics Research

Table 4.23 lists all 35 funding agencies for Indian optics publications and provides valuable insights into the sources of financial support for scientific research in India. The top three funding agencies funded for Indian optics research are the Department of Science and Technology (DST), the University Grants Commission (UGC), and the Council of Scientific and Industrial Research (CSIR), collectively account for almost 30% of the total publications. This highlights the significance of government-funded institutions in supporting research and innovation in India.

Apart from the top three, other funding agencies such as the Science and Engineering Research Board, Department of Atomic Energy, and Board of Research in Nuclear Sciences occupy the fourth, fifth, and sixth positions with 2.889%, 1.648%, and 1.166%, respectively. The Defence Research Development Organisation, Department of Biotechnology, and Ministry of Human Resource Development also feature in the list with 0.947%, 0.894%, and 0.842%, respectively. The presence of multiple funding agencies helps to diversify the sources of financial support for researchers, which can be crucial in ensuring the sustainability of scientific research. The Indian Council of Medical Research, Hyderabad Eye Research Foundation, Department of Space, University of Delhi, and Department of Science Technology Nano Mission are some other funding agencies in the list.

Overall, the availability of funding from these agencies plays a critical role in driving the progress of scientific research in India. It helps to attract and retain talented researchers, facilitate the purchase of equipment and materials necessary for conducting research, and support the publication of research findings. These funds are also essential in ensuring that scientific research in India remains competitive and innovative in a global context. Further, funding agencies are crucial in promoting

scientific research and innovation in India, and the government-supported institutions play a vital role in supporting research in optics and related fields. The availability of diverse funding sources helps sustain research and ensure that scientific progress continues in India.

Table 4.23: Indian Funding Agencies

S No	Funding Agencies	TP	% TP
1	Department of Science Technology, India	10780	12.066
2	University Grants Commission, India	7468	8.359
3	Council of Scientific Industrial Research, India	6757	7.563
4	Science and Engineering Research Board, India	2581	2.889
5	Department of Atomic Energy, India	1472	1.648
6	Board of Research in Nuclear Sciences, India	1042	1.166
7	Defence Research Development Organisation, India	846	0.947
8	Department of Biotechnology, India	799	0.894
9	Ministry of Human Resource Development, India	752	0.842
10	Indian Council of Medical Research, India	349	0.391
11	Hyderabad Eye Research Foundation, India	333	0.373
12	Department of Space, India	159	0.178
13	University of Delhi	150	0.168
14	Department of Science Technology Nano Mission	136	0.152
15	Ministry of Electronics and Information Technology, India	132	0.148
16	Ministry of New and Renewable Energy, India	124	0.139
17	Inter University Accelerator Centre, New Delhi	96	0.107
18	Indian Space Research Organization, India	95	0.106
19	Indian Institute of Science Education and Research, Kolkata	66	0.074
20	Ministry of Earth Science, India	63	0.071
21	Indian Institute of Technology, Delhi	59	0.066
22	Department of Industry Innovation and Science	58	0.065
23	Indian Institute of Science Education and Research, Mohali	58	0.065
24	Indian Institute of Technology, Madras	56	0.063
25	Indian Institute of Technology, Kharagpur	53	0.059
26	Indian Council of Agricultural Research, India	52	0.058
27	Indian Institute of Technology, Bombay	51	0.057
28	Department of Science Technology Inspire Fellowship	50	0.056
29	Kerala State Council for Science, Technology and Environment, India	50	0.056
30	All India Council for Technical Education, India	50	0.056
31	Indian Institute of Science Education and Research, Pune	48	0.054
32	Indian Institute of Technology, Indore	48	0.054
33	Indian Institute of Technology, Dhanbad	46	0.051
34	University of Calcutta	44	0.049
35	India Alliance	43	0.048

TP= Total Publications

4.7. Journal Metric Indicators

4.7.1. Most Productive Sources

Sources played a significant role in the transmission of scientific research output. Scientific journals are the most important means of disseminating research results and often specialise in different academic disciplines or sub-disciplines. Various journals transmit scientific research results, allowing other researchers/ scientists to respond to their published research. A total of 4427 sources were published for 87342 Indian optics research results during the study period. Of the 4427 journals, 1585 (35.80%) journals published only one paper each and 1455(32.86%) journals published 2-5 papers each.

Table 4.24 provides a comprehensive list of the top 50 most productive journals published 310 or more papers publishing Indian optics research publications from 1992-2021, ranked based on various indicators such as Journal Citation Indicator (JCI), SCImago Journal Rank (SJR), H-Index, Total Publications (TP), Total Citations (TC), Citations per Paper (CPP), Highly Cited Paper (HCP), and Total Authors (TA).

'Optik' ranks first in the table with a JCI 2021 of 0.89, SJR 2021 of 0.523, and an H-Index of 79. Elsevier GMBH publishes it in Germany and has a total of 1805 publications with 15095 citations and a CPP of 8.363. Optik has the highest number of total publications and the second-highest number of citations per paper in the top 10. These statistics indicate that Optik is a highly impactful journal in the field of optics research, and its publications have a significant impact on the scientific community. The 'Journal of Materials Science-Materials in Electronics ranks second in the table with a JCI 2021 of 0.51, SJR 2021 of 0.464, and an H-Index of 80. Springer publishes it in the Netherlands and has a total of 1751 publications with

19850 citations and a CPP of 11.336. This journal has the highest H-Index in the top 10, which suggests that its publications have been highly cited and influential in the field of optics research. The 'Indian Journal of Ophthalmology' ranks third in the table with a JCI 2021 of 0.85, SJR 2021 of 0.75, and an H-Index of 59. Wolters Kluwer Medknow Publications in India publish it and has a total of 1732 publications with 13011 citations and a CPP of 7.512. Although it has a lower H-Index than the top two journals, it has the highest SJR in the top 10, indicating that its publications are considered more influential per article.

The 'Journal of Alloys and Compounds ranks fourth in the table with a JCI 2021 of 1.19, SJR 2021 of 1.027, and an H-Index of 185. Elsevier Science Sa publishes it in Switzerland and has a total of 1296 publications with 38941 citations and a CPP of 30.047. It has the highest JCI and H-Index in the top 10, indicating that its publications are highly respected and influential in the field of optics research. The 'Spectrochimica Acta Part A-Molecular and Biomolecular Spectroscopy' ranks fifth in the table with a JCI 2021 of 1.86, SJR 2021 of 0.59, and an H-Index of 132. Elsevier publishes it in the Netherlands and has a total of 1184 publications with 26467 citations and a CPP of 22.354. Despite having a lower SJR compared to other journals in the top 10, its high JCI and H-Index indicate that its publications have a significant impact in the field of optics research.

The top 50 most productive journals in Indian Optics research output during 1992-2021 provide insights into the most influential journals in this field of study. The significance of this table lies in the fact that it highlights the most popular and well-cited journals in the field of optics research, which can be helpful for researchers to identify the journals in which they can publish their research papers. The various important indicators included such as the Journal Citation Indicator (JCI), SCImago

Journal Rank (SJR), H-Index, Total Publications (TP), Total Citations (TC), Citations per Paper (CPP), Highly Cited Paper (HCP), and Total Authors (TA) for each journal. These indicators provide valuable information for researchers and institutions to assess the quality and impact of research published in these journals.

Elsevier and Springer are the dominant publishers in Indian optics research, with many journals appearing in the top 50. The Indian Journal of Ophthalmology, published by Wolters Kluwer Medknow Publications, is the top Indian journal in the field, ranking third in the table. Furthermore, the table highlights the multidisciplinary nature of optics research, with journals from materials science, ophthalmology, chemistry, and physics in the top 50. This diversity of journals indicates the broad scope of optics research, encompassing several disciplines and study areas.

Table 4.24: Most productive Sources

Rank	Sources	JCI 2021	SJR 2021	H Index	Publisher	Country	TP	TC	CPP	HCP	TA
1	Optik	0.89	0.523	79	Elsevier GMBH	Germany	1805	15095	8.363	1	5698
2	Journal of Materials Science-Materials in Electronics	0.51	0.464	80	Springer	Netherlands	1751	19850	11.336	7	6968
3	Indian Journal of Ophthalmology	0.85	0.75	59	Wolters Kluwer Medknow Publications	India	1732	13011	7.512	6	6999
4	Journal of Alloys and Compounds	1.19	1.027	185	Elsevier Science Sa	Switzerland	1296	38941	30.047	53	5434
5	Spectrochimica Acta Part A-Molecular and Biomolecular Spectroscopy	1.86	0.59	132	Elsevier	Netherlands	1184	26467	22.354	25	4579
6	RSC Advances	0.57	0.667	167	Royal Society of Chemistry	UK	984	24103	24.495	23	4223
7	Journal of Applied Physics	0.57	0.668	331	American Institute of Physics	USA	928	25541	27.523	31	3782
8	Optical Materials	0.85	0.583	109	Elsevier	Netherlands	848	19042	22.455	13	3539
9	Materials Chemistry and Physics	0.86	0.749	162	Elsevier BV	Netherlands	820	23161	28.245	27	3099
10	Applied Optics	0.64	0.581	203	The Optical Society	USA	814	11835	14.539	12	2725
11	Applied Surface Science	1.32	1.147	204	Elsevier	Netherlands	742	24150	32.547	37	3117
12	Optics Communications	0.81	0.589	139	Elsevier	Netherlands	733	12726	17.362	10	2319
13	Materials Research Express	0.33	0.403	43	IOP Publication	UK	730	5375	7.363	0	2769
14	Journal of Molecular Structure	0.52	0.48	110	Elsevier	Netherlands	715	12203	17.067	6	3054
15	Physica B-Condensed Matter	0.47	0.452	117	Elsevier	Netherlands	696	14578	20.945	8	2683
16	Monthly Notices of The Royal Astronomical Society	1.12	1.678	340	OUP	UK	659	13746	20.859	12	7116
17	Materials Letters	0.71	0.658	155	Elsevier	Netherlands	642	13662	21.28	14	2356
18	Journal of Luminescence	1.22	0.64	119	Elsevier	Netherlands	623	15636	25.098	13	2545
19	Journal of Crystal Growth	0.51	0.43	155	Elsevier	Netherlands	581	14193	24.429	16	2182

Rank	Sources	JCI 2021	SJR 2021	H Index	Publisher	Country	TP	TC	CPP	HCP	TA
20	Optical Engineering	0.35	0.184	179	Society Of Photo-Optical Instrumentation Engineers (SPIE)	USA	556	4599	8.272	1	1631
21	Indian Journal of Pure & Applied Physics	0.18	0.226	42	NISCAIR	India	548	3773	6.885	2	1782
22	Ceramics International	1.31	0.887	126	Elsevier	UK	538	13912	25.859	11	2311
23	Materials Research Bulletin	0.94	0.818	115	Elsevier	UK	534	13556	25.386	10	2091
24	Thin Solid Films	0.42	0.486	199	Elsevier	Netherlands	527	15588	29.579	22	2069
25	Applied Physics A-Materials Science & Processing	0.5	0.444	154	Springer Heidelberg	Germany	515	5492	10.664	0	2003
26	Journal of Physical Chemistry C	0.63	0.795	401	American Chemical Society	USA	513	18870	36.784	34	2145
27	Bulletin of Materials Science	0.29	0.333	76	Indian Academy of Sciences	India	488	7962	16.316	9	1657
28	Journal of Nanoscience and Nanotechnology	0.14	0.235	108	American Scientific Publishers	USA	463	5670	12.246	1	1929
29	Physical Review B	0.76	1.537	460	American Physical Society	USA	428	12943	30.241	23	1802
30	Materials Science in Semiconductor Processing	0.92	0.687	68	Elsevier	UK	417	7979	19.134	4	1689
31	Sensors and Actuators B-Chemical	1.86	1.39	211	Elsevier	Netherlands	410	18543	45.227	34	1650
32	Optics and Laser Technology	1.18	0.848	83	Elsevier	UK	409	6710	16.406	2	1493
33	Journal of Physics and Chemistry of Solids	0.77	0.664	112	Elsevier	UK	408	9409	23.061	8	1601
34	Molecular Crystals and Liquid Crystals	0.17	0.214	54	Taylor And Francis	UK	405	3052	7.536	1	1280
35	Applied Physics Letters	0.8	1.025	452	American Institute of Physics	USA	402	10438	25.965	13	1791
36	Journal of Non-Crystalline Solids	0.85	0.751	150	Elsevier	Netherlands	401	9276	23.132	4	1642
37	New Journal of Chemistry	0.61	0.628	126	Royal Society of Chemistry	UK	388	6429	16.57	0	1694

Rank	Sources	JCI 2021	SJR 2021	H Index	Publisher	Country	TP	TC	CPP	HCP	TA
38	Physical Review A	NA	1.183	269	American Physical Society	USA	384	7854	20.453	9	1254
39	Optics Letters	1.22	1.263	277	Optical Society	USA	379	7627	20.124	3	1398
40	Superlattices and Microstructures	0.48	0.494	80	Academic Press	USA	365	5695	15.603	2	1332
41	Journal of Physics D-Applied Physics	0.61	0.717	207	IOP Publication	UK	360	8944	24.844	11	1412
42	Pramana-Journal of Physics	0.6	0.481	54	Springer	India	360	2972	8.256	4	1136
43	Astrophysical Journal	1.05	1.901	445	American Astronomical Society	UK	357	10354	29.003	13	6636
44	Current Science	0.22	0.271	124	Indian Academy of Sciences	India	341	3856	11.308	3	1271
45	Optical and Quantum Electronics	0.75	0.432	62	Springer	USA	334	2661	7.967	2	1056
46	Journal of Cataract and Refractive Surgery	1.21	1.367	148	Wolters Kluwer Health	USA	328	8324	25.378	7	1430
47	Astronomy & Astrophysics	1.22	1.918	305	EDP Sciences	France	322	18448	57.292	15	9319
48	Optics Express	1.24	1.233	281	Optical Society	USA	317	7074	22.315	8	1483
49	Investigative Ophthalmology & Visual Science	1.56	1.399	229	Association For Research in Vision and Ophthalmology Inc.	USA	315	6277	19.927	12	1925
50	Journal of Materials Science	0.72	0.781	187	Springer	Netherlands	314	6724	21.414	6	1216
					Total		**31109**	**614326**	**20.939**	**588**	**138315**

JCI= Journal Citation Indicator; SJR= SCImago Journal Rank; TP= Total Publications; TC= Total Citations; CPP= Citations per Paper; HCP= Highly Cited Paper; TA= Total Authors

4.7.2. Bradfords Law of Scattering

Table 4.25: Bradfords Law of Scattering

S No	No. of Journals	No. of Papers	TP	Cum. TP	S No	No. of Journals	No. of Papers	TP	Cum. TP
1	1	47	47	47	116	1	1235	1235	37417
2	1	63	63	110	117	1	1447	1447	38864
3	1	66	66	176	118	1	2042	2042	40906
4	1	71	71	247	119	1	2083	2083	42989
5	1	74	74	321	120	1	2137	2137	45126
6	1	75	75	396	121	2	57	114	45240
7	1	81	81	477	122	2	73	146	45386
8	1	82	82	559	123	2	80	160	45546
9	1	85	85	644	124	2	83	166	45712
10	1	89	89	733	125	2	84	168	45880
11	1	96	96	829	126	2	87	174	46054
12	1	99	99	928	127	2	90	180	46234
13	1	100	100	1028	128	2	93	186	46420
14	1	102	102	1130	129	2	94	188	46608
15	1	103	103	1233	130	2	95	190	46798
16	1	105	105	1338	131	2	101	202	47000
17	1	106	106	1444	132	2	109	218	47218
18	1	107	107	1551	133	2	112	224	47442
19	1	111	111	1662	134	2	129	258	47700
20	1	119	119	1781	135	2	131	262	47962
21	1	120	120	1901	136	2	144	288	48250
22	1	124	124	2025	137	2	147	294	48544
23	1	125	125	2150	138	2	169	338	48882
24	1	127	127	2277	139	2	171	342	49224
25	1	128	128	2405	140	2	190	380	49604
26	1	130	130	2535	141	2	191	382	49986
27	1	134	134	2669	142	2	195	390	50376
28	1	135	135	2804	143	2	197	394	50770
29	1	137	137	2941	144	2	226	452	51222
30	1	138	138	3079	145	2	237	474	51696
31	1	141	141	3220	146	2	311	622	52318
32	1	142	142	3362	147	2	323	646	52964
33	1	143	143	3505	148	2	340	680	53644
34	1	145	145	3650	149	2	353	706	54350
35	1	148	148	3798	150	2	762	1524	55874
36	1	153	153	3951	151	3	50	150	56024
37	1	159	159	4110	152	3	51	153	56177
38	1	160	160	4270	153	3	56	168	56345
39	1	161	161	4431	154	3	61	183	56528
40	1	170	170	4601	155	3	62	186	56714
41	1	176	176	4777	156	3	65	195	56909

S No	No. of Journals	No. of Papers	TP	Cum. TP	S No	No. of Journals	No. of Papers	TP	Cum. TP
42	1	182	182	4959	157	3	67	201	57110
43	1	183	183	5142	158	3	69	207	57317
44	1	184	184	5326	159	3	72	216	57533
45	1	189	189	5515	160	3	76	228	57761
46	1	194	194	5709	161	3	91	273	58034
47	1	198	198	5907	162	3	115	345	58379
48	1	200	200	6107	163	3	118	354	58733
49	1	205	205	6312	164	3	133	399	59132
50	1	210	210	6522	165	3	150	450	59582
51	1	211	211	6733	166	4	44	176	59758
52	1	212	212	6945	167	4	46	184	59942
53	1	218	218	7163	168	4	49	196	60138
54	1	224	224	7387	169	4	52	208	60346
55	1	229	229	7616	170	4	53	212	60558
56	1	231	231	7847	171	4	86	344	60902
57	1	235	235	8082	172	4	88	352	61254
58	1	239	239	8321	173	4	92	368	61622
59	1	247	247	8568	174	4	113	452	62074
60	1	252	252	8820	175	4	126	504	62578
61	1	259	259	9079	176	4	132	528	63106
62	1	267	267	9346	177	5	64	320	63426
63	1	270	270	9616	178	5	68	340	63766
64	1	272	272	9888	179	5	70	350	64116
65	1	280	280	10168	180	5	79	395	64511
66	1	281	281	10449	181	6	38	228	64739
67	1	286	286	10735	182	6	39	234	64973
68	1	291	291	11026	183	6	40	240	65213
69	1	307	307	11333	184	6	55	330	65543
70	1	314	314	11647	185	6	59	354	65897
71	1	319	319	11966	186	6	60	360	66257
72	1	325	325	12291	187	7	25	175	66432
73	1	327	327	12618	188	7	32	224	66656
74	1	329	329	12947	189	7	34	238	66894
75	1	334	334	13281	190	7	42	294	67188
76	1	348	348	13629	191	7	48	336	67524
77	1	358	358	13987	192	7	54	378	67902
78	1	370	370	14357	193	7	58	406	68308
79	1	378	378	14735	194	9	43	387	68695
80	1	381	381	15116	195	10	27	270	68965
81	1	390	390	15506	196	10	31	310	69275
82	1	394	394	15900	197	10	35	350	69625
83	1	406	406	16306	198	10	36	360	69985
84	1	411	411	16717	199	10	41	410	70395
85	1	418	418	17135	200	11	45	495	70890
86	1	428	428	17563	201	12	37	444	71334

S No	No. of Journals	No. of Papers	TP	Cum. TP	S No	No. of Journals	No. of Papers	TP	Cum. TP
87	1	432	432	17995	202	13	29	377	71711
88	1	439	439	18434	203	13	30	390	72101
89	1	440	440	18874	204	15	18	270	72371
90	1	446	446	19320	205	15	28	420	72791
91	1	451	451	19771	206	15	33	495	73286
92	1	453	453	20224	207	16	23	368	73654
93	1	456	456	20680	208	16	24	384	74038
94	1	463	463	21143	209	16	26	416	74454
95	1	484	484	21627	210	18	20	360	74814
96	1	531	531	22158	211	20	22	440	75254
97	1	544	544	22702	212	24	21	504	75758
98	1	565	565	23267	213	25	16	400	76158
99	1	570	570	23837	214	27	17	459	76617
100	1	579	579	24416	215	31	19	589	77206
101	1	589	589	25005	216	34	15	510	77716
102	1	596	596	25601	217	41	14	574	78290
103	1	607	607	26208	218	47	13	611	78901
104	1	647	647	26855	219	49	10	490	79391
105	1	664	664	27519	220	53	12	636	80027
106	1	711	711	28230	221	67	11	737	80764
107	1	742	742	28972	222	68	9	612	81376
108	1	768	768	29740	223	90	8	720	82096
109	1	794	794	30534	224	91	7	637	82733
110	1	867	867	31401	225	120	6	720	83453
111	1	880	880	32281	226	157	5	785	84238
112	1	901	901	33182	227	273	4	1092	85330
113	1	965	965	34147	228	378	3	1134	86464
114	1	997	997	35144	229	639	2	1278	87742
115	1	1038	1038	36182	230	1600	1	1600	89342
Total						4427		89342	

TP= Total Publications; Cum. TP= Cumulative Total Publications

4.7.3. Zone-wise Distribution of Journals

Bradford's Law of Scattering is a principle that predicts how scientific literature is distributed across different journals. According to this law, journals in any field of study can be divided into a core group of high-productivity journals, a second group of moderately productive journals, and a third group of low-productivity journals. The principle is named after Samuel C. Bradford, who first observed this pattern in 1934 (Bradford, 1937, 1953; "Sources of Information on Specific Subjects 1934," 1985).

Based on the data in Table 4.26, there are a total of 4,427 journals and 89,342 articles. To apply the $1: n: n^2$ formula, first calculate the size of the core set of journals by dividing the total number of journals by the sum of the series, which is $1 + n + n^2$. This yields a value of approximately 37, which represents the number of core journals.

Next, the formula was used to estimate the number of journals in the second and third zones. Using the value of n=176 (rounded to the nearest integer) obtained an expected number of journals in the second zone of $1 + 176 = 177$ and an expected number of journals in the third zone of $1 + 176 + 1762 = 31,057$.

The ratio between the expected and observed numbers of journals in each zone suggests that the distribution of journals follows Bradford's Law more closely (it does not conform perfectly to the) using the 1: n: n2. Both Zone 2 and Zone 3 have slightly fewer observed journals than expected, indicating that the actual distribution is more concentrated than expected under the idealized model. However, it is worth noting that the 1: n: n2 formula is also an approximation, and other factors may affect the distribution of journals in practice.

The journal and article distribution in Table 4.26 needs to follow Bradford's Law of Scattering perfectly. The overall trend of a small core set of journals containing a significant proportion of articles and increasingly peripheral sets of journals containing progressively fewer articles is observed. These findings may be useful for researchers who are interested in identifying relevant journals for their research and for librarians who need to estimate the size of bibliographic databases.

Table 4.26: Zone Wise Distribution of Journals

Zone	No. of Journals	% Journals	No. of Papers	% Papers
Zone – 1	37	0.836	29515	33.036
Zone – 2	176	3.976	30388	34.013
Zone – 3	4214	95.189	29439	32.951
Total	**4427**	**100**	**89342**	**100**

4.8. Citation Analysis

4.8.1. Highly Cited Papers

Highly Cited Papers (HCPs) are research articles that are particularly influential and impactful in each field of study. These papers are typically cited more frequently than other articles, and they often represent important contributions to the advancement of knowledge within a specific area (Grover et al., 2022; Gupta, Ahmed, et al., 2023). In the field of optics in India, Highly Cited Papers are those that have been published in high-impact journals and have received a significant number of citations from other researchers in the field. These papers may cover a wide range of topics related to optics, including optical materials, devices, and systems, as well as fundamental research in areas such as photonics, spectroscopy, and quantum optics. Identifying and analysing Highly Cited Papers in optics can provide valuable insights into the current state of research in this field in India. By studying these papers, researchers can better understand the most important and impactful work that has

been done, as well as the key trends and developments in the field. In addition, identifying HCPs can be useful for funding agencies, government organisations, and industry partners interested in supporting research in optics in India. By identifying the most influential papers and researchers in the field, these stakeholders can make more informed decisions about allocating resources and supporting future research.

In this analysis, the papers that received citations of 100 or more until 30th September 2022 are considered highly cited. As per the study concerned, a total of 89342 documents during 1992 – 2021 were found in the Web of Science core collection database. Total citations ≥ 100 were used as a filter to retrieve the HCPs, and a total of 1905 papers were found as HCPs. These 1905 HCPs involved 31269 authors, ~3000 Institutions, 91 Countries, and 546 Sources/Journals. The highest number of papers were published in collaboration (97.7%), and only 44 (2.3%) papers were contributed by single authors. Authors per paper were found to be 16.4 (n=780), 41% of papers were published in international collaboration (n=1081) 57% in intra-national collaboration. Average authors per article, average co-authors per article and the average number of articles per author suggested that most authors have collaborated with two to sixteen authors. The average number of articles per author is less than one, and the number of author appearances is greater than the total number of authors, which shows that some authors have multiple publications. Further, these 1905 HCPs were scattered in various forms; 1558 articles, 300 review articles, 42 conference proceedings, two each as letter and note, and one in editorial material. In terms of citations, the CPP of the 1905 HCPs is widely varied from 100 to 15285 per paper with an ACCP of 207.45. Among them, 1818 (95.43%) papers counted citations between 100 – 500 each, 58 (3.04%) papers counted citations between

501-1000 each, 27 papers counted citations between 1001-5000 each, and the two papers received 5413 and 15285 citations each. In this study, the citation window was not set for the number of citations for the HCPs. Citation counts are based on total citations since from 1992 to 2021. Therefore, the number of citations of highly cited articles depended on time and varied from 1 to 1280 citations per year (1992 – 2021).

Table 4.27 lists the top 50 HCPs and citations history. These 50 HCPs counted a total of 84644 (5.05% of TC). A review article by Agostinelli et al. (2003) ranked 1st with TC of 15285 and 764.25 CPP during 1992 – 2021. Peter AR et al. (2015) article ranked 2nd with a TC of 5413 and CPP of 773.29. The paper by Rai M (2009) ranked 3rd with a TC of 3858 and CPP of 275.58. The top-ranked paper is "Agostinelli S, 2003, Nucl Instrum Methods Phys Res Sect A-Accel Spectrom Dect Assoc Equip" with a TC of 15285, 764.25 CPP and a TCpY of 764.25. The paper is about the Geant4 simulation toolkit used for particle physics experiments. The 2nd ranked paper is "Ade Par, 2016, Astron Astrophys" with a TC of 5413, 773.29 CPP and a TCpY of 773.29. The paper describes the Planck mission's final results on cosmology, astrophysics, and statistical methods. The 3rd ranked paper is "Rai M, 2009, Biotechnol Adv" with a TC of 3858, 275.58 CPP and a TCpY of 275.57. The paper discusses the use of nanotechnology in agriculture, food, and the environment.

These 50 HCPs were contributed by 8031 authors (among two papers were published in single authorship, nine papers by two authors, seven by three authors, and the rest by four and more authors, respectively). Further, only two papers were published in single authorship, and the remaining papers were published in intra and international collaboration. Of the 50 HCPs, 21 papers were in the citation range

681 – 1000, 20 papers in 1000 – 2000, 5 papers in 2000 – 3000, 2 papers in 3000 – 4000, and two papers were in 5413 and 15285 citations, respectively. Of the 50 HCPs, 25 papers were funded by Indian and foreign agencies and received TC of 39725 at CPP of 1589.

Overall, Highly Cited Papers (HCPs) are a significant resource for researchers, policymakers, and other stakeholders in the field of optics in India. These papers are vital in advancing knowledge and making meaningful contributions to the broader scientific community. By studying and promoting HCPs, researchers can continue to develop their understanding of this important research area, leading to further advances and innovations. This can have a positive impact on the field of optics and its applications in various industries. Additionally, policymakers can utilize HCPs to inform evidence-based decision-making. In contrast, stakeholders can utilize these papers to gain insights into the latest research trends and identify potential collaborations or partnerships.

Table 4.27: Highly Cited Papers

Rank	Paper	DOI	TC	TCpY
1	Agostinelli S, 2003, Nucl Instrum Methods Phys Res Sect A-Accel Spectrom Dect Assoc Equip	10.1016/S0168-9002(03)01368-8	15285	764.25
2	Ade Par, 2016, Astron Astrophys	10.1051/0004-6361/201525830	5413	773.29
3	Rai M, 2009, Biotechnol Adv	10.1016/j.biotechadv.2008.09.002	3858	275.57
4	Chatrchyan S, 2008, J Instrum	10.1088/1748-0221/3/08/S08004	3343	222.87
5	Aghanim N, 2020, Astron Astrophys	10.1051/0004-6361/201833910	2890	963.33
6	Gulshan V, 2016, Jama-J Am Med Assoc	10.1001/jama.2016.17216	2797	399.57
7	Gupta VK, 2009, J Environ Manage	10.1016/j.jenvman.2008.11.017	2585	184.64
8	Yau JWY, 2012, Diabetes Care	10.2337/dc11-1909	2434	221.27
9	Ghosh SK, 2007, Chem Rev	10.1021/cr0680282	2106	131.63
10	Peng J, 2012, Nano Lett	10.1021/nl2038979	1767	160.64
11	Swarnkar A, 2016, Science	10.1126/science.aag2700	1765	252.14
12	Abbott BP, 2017, Astrophys J Lett	10.3847/2041-8213/aa91c9	1621	270.17
13	Simon R, 2000, Phys Rev Lett	10.1103/PhysRevLett.84.2726	1600	69.57
14	Eisenstein DJ, 2011, Astron J	10.1088/0004-6256/142/3/72	1526	127.17
15	Alam S, 2015, Astrophys J Suppl Ser	10.1088/0067-0049/219/1/12	1426	178.25
16	Kango S, 2013, Prog Polym Sci	10.1016/j.progpolymsci.2013.02.003	1373	137.30
17	Bhadra S, 2009, Prog Polym Sci	10.1016/j.progpolymsci.2009.04.003	1365	97.50
18	Chandran SP, 2006, Biotechnol Prog	10.1021/bp0501423	1318	77.53
19	Koekemoer AM, 2011, Astrophys J Suppl Ser	10.1088/0067-0049/197/2/36	1300	108.33
20	Harrison FA, 2013, Astrophys J	10.1088/0004-637X/770/2/103	1279	127.90
21	Flaxman SR, 2017, Lancet Glob Health	10.1016/S2214-109X(17)30393-5	1278	213.00
22	Mishra A, 2000, Chem Rev	10.1021/cr990402t	1276	55.48
23	Braga D, 1998, Chem Rev	10.1021/cr960091b	1220	48.80
24	Murphy CJ, 2002, Adv Mater	10.1002/1521-4095(20020104)14:1<80::AID-ADMA80>3.0.CO;2-%23	1164	55.43

Rank	Paper	DOI	TC	TCpY
25	Chakraborty I, 2017, Chem Rev	10.1021/acs.chemrev.6b00769	1139	189.83
26	Roy K, 2013, Nat Nanotechnol	10.1038/NNANO.2013.206	1070	107.00
27	Ramanathan V, 2001, J Geophys Res -Atmos	10.1029/2001JD900133	1058	48.09
28	Aasi J, 2015, Class Quantum Gravity	10.1088/0264-9381/32/7/074001	1042	130.25
29	Mitra S, 2007, IEEE Trans Syst Man Cybern Part C-Appl Rev	10.1109/TSMCC.2007.893280	1036	64.75
30	Bourne RRA, 2017, Lancet Glob Health	10.1016/S2214-109X(17)30293-0	980	163.33
31	Late DJ, 2013, ACS Nano	10.1021/nn400026u	978	97.80
32	Capote R, 2009, Nucl Data Sheets	10.1016/j.nds.2009.10.004	964	68.86
33	Bourne RRA, 2013, Lancet Glob Health	10.1016/S2214-109X(13)70113-X	950	95.00
34	Whitcher JP, 2001, Bull World Health Organ	NA	935	42.50
35	Unnikrishnan G, 2000, Opt Lett	10.1364/OL.25.000887	932	40.52
36	Buongiorno J, 2009, J Appl Phys	10.1063/1.3245330	927	66.21
37	Saha S, 2000, Phys Rev B	10.1103/physrevb.62.8828	891	38.74
38	Chopra KL, 2004, Prog Photovoltaics	10.1002/pip.541	847	44.58
39	Sathish M, 2005, Chem Mat	10.1021/cm052047v	821	45.61
40	Sau TK, 2010, Adv Mater	10.1002/adma.200902557	804	61.85
41	Akerboom J, 2012, J Neurosci	10.1523/JNEUROSCI.2601-12.2012	795	72.27
42	Ansari SA, 2012, Biotechnol Adv	10.1016/j.biotechadv.2011.09.005	791	71.91
43	Ajayaghosh A, 2007, Accounts Chem Res	10.1021/ar7000364	776	48.50
44	Fisher RS, 2017, Epilepsia	10.1111/epi.13671	728	121.33
45	Mane RS, 2000, Mater Chem Phys	10.1016/S0254-0584(00)00217-0	717	31.17
46	Panigrahi S, 2007, J Phys Chem C	10.1021/jp067554u	709	44.31
47	Das S, 2014, Prog Mater Sci	10.1016/j.pmatsci.2014.06.003	703	78.11
48	Maiti NC, 1998, J Phys Chem B	10.1021/jp9723372	699	27.96
49	Bharti B, 2016, Sci Rep	10.1038/srep32355	682	97.43
50	Ramakrishna SA, 2005, Rep Prog Phys	10.1088/0034-4885/68/2/R06	681	37.83

DOI= Digital Object Identifier; TC= Total Citations; TCpY= Total Citations per Year

4.8.2. Distribution of Citations

Table 4.28 presents the distribution of citations received by India's optics research, categorized into 11 citation ranges. The 'Web of Science Core Collection times cited' means the citations received for an article in other journals which are indexed and available in the Web of Science core collection. All these 89342 publications received a total of 1,676,529 citations during the study period. Among them, 81833 (91.60%) papers were cited, and 7509 (8.40%) papers remain uncited/non-cited. The second range, which includes papers with one to nine citations, has 39758 papers, representing about 53% of all papers. These papers have a total of 172335 citations, representing around 10% of the cumulative citations. The third range comprises papers with 10 to 49 citations, which accounts for 82406 papers, representing approximately 11% of all papers. These papers accumulate a total of 931523 citations, representing about 56% of the cumulative citations. The fourth range, consisting of papers with 50 to 99 citations, has 5023 papers, representing about 7% of all papers, but their citations account for approximately 20% of the cumulative citations, totalling 1269554.

Nevertheless, only 1913 (2.14%) papers were cited between 100-15285 times and treated as highly cited papers (HCPs). Among them, 1,826 HCP have citations falling within the range of 100-499, 58 Papers have citations falling within the range of 500-999, 20 Papers have citations falling within the range of 1000-1999, 5 Papers have citations falling within the range of 2000-2999, 2 Papers have citations falling within the range of 3000-3999, and 2 papers received 5413 and 15285 citations respectively.

As mentioned earlier, highly cited papers (HCP) are significant because they represent research that has received substantial attention and recognition within the

scientific community. HCPs are typically considered to be impactful and influential, with the potential to shape future research directions and perspectives in a particular field. Moreover, HCPs are often used as a metric for assessing the productivity and impact of individual researchers, institutions, or countries. This metric is known as the H-index, which considers the number of highly cited papers and the total number of citations received by an individual researcher, institution, or country.

Overall, most of India's optics research papers have received low citations, with most papers falling into the first two ranges. However, a few papers have received high citations, significantly contributing to the cumulative citation count. Papers with 100 or more citations are treated as highly cited papers, which are an important indicator of the quality and impact of research. Their analysis can provide insights into the productivity and impact of individual researchers, institutions, or countries.

Table 4.28: Distribution of Citations

S No	Citation Range	TP	Cum. TP	TC	Cum. TC
1	0	7509	7509	0	0
2	1-9	39758	47267	172335	172335
3	10-49	35139	82406	759188	931523
4	50-99	5023	87429	338031	1269554
5	100-499	1826	89255	300887	1570441
6	500-999	58	89313	38754	1609195
7	1000-1999	20	89333	26623	1635818
8	2000-2999	5	89338	12812	1648630
9	3000-3999	2	89340	7201	1655831
10	5413	1	89341	5413	1661244
11	15285	1	89342	15285	1676529
	Total	**89342**		**1676529**	

TP= Total Publications; Cum. TP= Cumulative Total Publications

4.9. Forecasting Metric Indicators

4.9.1. Time Series Analysis of Indian Optics Research Output

Table 4.29 shows the time series data for Indian Optics Research Output from 1992 to 2021. Researcher used the $y = a + bx$ formula to perform a time series analysis of the data. This formula represents a simple linear regression model, where 'y' is the dependent variable (in this case, the research output), 'x' is the independent variable (time), 'a' is the intercept (the value of 'y' when x=0), and 'b' is the slope (the rate at which 'y' changes with respect to 'x').

Using the table data, researcher can calculate the values of a and b as follows:

$$\Sigma X = 0 \qquad \Sigma Y = 89342 \qquad \Sigma x2 = 2247.5 \qquad \Sigma XY = 638290$$

$$n = 30$$

$$a = \frac{\Sigma Y}{n} \qquad a = \frac{89342}{30} \qquad a = 2978.07$$

$$b = \frac{\Sigma xy}{\Sigma x^2} \qquad b = \frac{638290}{2247.5} \qquad b = 284.147$$

Therefore, the equation for the linear trend line is:

$$y = 2978.07 + 284.147x$$

To predict the next five years, the substitute values of 'x' as 31, 32, 33, 34, and 35, respectively, into the equation and solve for 'y'.

Predictions for the next five years are as follows:

✓ Year 2022: y = 2978.07 + 284.147*31 = 10781.14;

✓ Year 2023: y = 2978.07 + 284.147*32 = 11065.28;

✓ Year 2024: y = 2978.07 + 284.147*33 = 11349.42;

✓ Year 2025: y = 2978.07 + 284.147*34 = 11633.56;

✓ Year 2026: y = 2978.07 + 284.147*35 = 11917.70

Therefore, the predicted Indian Optics Research Output for the next five years (2022-2026) is 10781.14, 11065.28, 11349.42, 11633.56, and 11917.7, respectively.

Table 4.29: Time Series Analysis of Indian Optics Research Output

Year	Y	X	X²	XY
1992	451	-14.5	210.25	-6539.50
1993	492	-13.5	182.25	-6642.00
1994	526	-12.5	156.25	-6575.00
1995	521	-11.5	132.25	-5991.50
1996	622	-10.5	110.25	-6531.00
1997	640	-9.5	90.25	-6080.00
1998	695	-8.5	72.25	-5907.50
1999	763	-7.5	56.25	-5722.50
2000	738	-6.5	42.25	-4797.00
2001	860	-5.5	30.25	-4730.00
2002	958	-4.5	20.25	-4311.00
2003	1132	-3.5	12.25	-3962.00
2004	1283	-2.5	6.25	-3207.50
2005	1416	-1.5	2.25	-2124.00
2006	1757	-0.5	0.25	-878.50
2007	2116	0.5	0.25	1058.00
2008	2513	1.5	2.25	3769.50
2009	2682	2.5	6.25	6705.00
2010	3085	3.5	12.25	10797.50
2011	3388	4.5	20.25	15246.00
2012	3718	5.5	30.25	20449.00
2013	4458	6.5	42.25	28977.00
2014	5107	7.5	56.25	38302.50
2015	5226	8.5	72.25	44421.00
2016	5862	9.5	90.25	55689.00
2017	6170	10.5	110.25	64785.00
2018	6955	11.5	132.25	79982.50
2019	7584	12.5	156.25	94800.00
2020	8241	13.5	182.25	111253.50
2021	9383	14.5	210.25	136053.50
1992-2021	**89342**	**0**	**2247.50**	**638290**

4.9.2. Time Series Analysis for Single Authored Papers

Table 4.30 shows the time series analysis for single-authored papers and in can be used to perform a linear regression analysis to model the relationship between the number of papers published and the year of publication. Again, the same $y = a + bx$ formula used perform a time series analysis for single-authored papers.

Using the table data, researcher can calculate the values of a and b as follows:

$$\Sigma X = 0 \qquad \Sigma Y = 2583 \qquad \Sigma x2 = 2247.5 \qquad \Sigma XY = 10324.5$$

$$n = 30$$

$$a = \frac{\Sigma Y}{n} \qquad a = \frac{2583}{30} \qquad a = 86.1$$

$$b = \frac{\Sigma xy}{\Sigma x^2} \qquad b = \frac{10324.5}{2247.5} \qquad b = 4.59$$

Therefore, the linear regression equation for the data given is:

$$y = 86.1 + 4.59x$$

To predict the next five years, the substitute values of 'x' as 31, 32, 33, 34, and 35, respectively, into the equation and solve for 'y'.

Predictions for the next five years are as follows:

✓ Year 2022: y = 86.1 + 4.59*31 = 108.38;

✓ Year 2023: y = 86.1 + 4.59*32 = 112.97;

✓ Year 2024: y = 86.1 + 4.59*33 = 117.55;

✓ Year 2025: y = 86.1 + 4.59*34 = 122.13;

✓ Year 2026: y = 86.1 + 4.59*35 = 126.71

Therefore, according to the linear regression equation, the predicted number of single-authored papers for the next five years are 108.38, 112.97, 117.55, 122.13, and 126.71, respectively.

This equation can be used to predict the number of papers that would be published each year based on the linear trend observed in the data. However, it is important to note that this time series analysis may not be appropriate for predicting future values of Y, as there may be other factors that could influence the number of papers published each year (e.g., changes in funding, advances in technology, changes in publication practices, etc.).

Table 4.30: Time Series Analysis for Single Authored Papers

Year	Y	X	X^2	XY
1992	51	-14.5	210.25	-739.50
1993	33	-13.5	182.25	-445.50
1994	50	-12.5	156.25	-625.00
1995	35	-11.5	132.25	-402.50
1996	42	-10.5	110.25	-441.00
1997	48	-9.5	90.25	-456.00
1998	57	-8.5	72.25	-484.50
1999	70	-7.5	56.25	-525.00
2000	45	-6.5	42.25	-292.50
2001	44	-5.5	30.25	-242.00
2002	50	-4.5	20.25	-225.00
2003	51	-3.5	12.25	-178.50
2004	55	-2.5	6.25	-137.50
2005	45	-1.5	2.25	-67.50
2006	68	-0.5	0.25	-34.00
2007	60	0.5	0.25	30.00
2008	107	1.5	2.25	160.50
2009	87	2.5	6.25	217.50
2010	92	3.5	12.25	322.00
2011	101	4.5	20.25	454.50
2012	115	5.5	30.25	632.50
2013	128	6.5	42.25	832.00
2014	133	7.5	56.25	997.50
2015	119	8.5	72.25	1011.50
2016	137	9.5	90.25	1301.50
2017	132	10.5	110.25	1386.00
2018	125	11.5	132.25	1437.50
2019	149	12.5	156.25	1862.50
2020	158	13.5	182.25	2133.00
2021	196	14.5	210.25	2842.00

4.9.3. Time Series Analysis for Multi Authored Papers

Table 4.31 shows the time series analysis for multi-authored papers and in can be used to perform a linear regression analysis to model the relationship between the number of papers published and the year of publication. Again, the same $y = a + bx$ formula used to perform a time series analysis for multi-authored papers.

Using the table data, researcher can calculate the values of a and b as follows:

$$\Sigma X = 0 \qquad \Sigma Y = 86759 \qquad \Sigma x2 = 2247.5$$

$$\Sigma XY = 627965.5 \quad n = 30$$

$$a = \frac{\Sigma Y}{n} \qquad a = \frac{86759}{30} \qquad a = 2891.97$$

$$b = \frac{\Sigma xy}{\Sigma x^2} \qquad b = \frac{627965.5}{2247.5} \qquad b = 279.41$$

Therefore, the linear regression equation for the data given is:

$$y = 2891.97 + 279.41x$$

To predict the next five years, the substitute values of 'x' as 31, 32, 33, 34, and 35, respectively, into the equation and solve for 'y'.

Predictions for the next five years are as follows:

✓ Year 2022: y = 2891.97 + 279.41*31 = 11553.68;

✓ Year 2023: y = 2891.97 + 279.41*32 = 11833.09;

✓ Year 2024: y = 2891.97 + 279.41*33 = 12112.50;

✓ Year 2025: y = 2891.97 + 279.41*34 = 12391.91;

✓ Year 2026: y = 2891.97 + 279.41*35 = 12671.32

Therefore, according to the linear regression equation, the predicted number of multi-authored papers for the next five years are 11553.68, 11833.09, 12112.50, 12391.91, and 12671.32, respectively.

Table 4.31: Time Series Analysis for Multi Authored Papers

Year	Y	X	X^2	XY
1992	400	-14.5	210.25	-5800.00
1993	459	-13.5	182.25	-6196.50
1994	476	-12.5	156.25	-5950.00
1995	486	-11.5	132.25	-5589.00
1996	580	-10.5	110.25	-6090.00
1997	592	-9.5	90.25	-5624.00
1998	638	-8.5	72.25	-5423.00
1999	693	-7.5	56.25	-5197.50
2000	693	-6.5	42.25	-4504.50
2001	816	-5.5	30.25	-4488.00
2002	908	-4.5	20.25	-4086.00
2003	1081	-3.5	12.25	-3783.50
2004	1228	-2.5	6.25	-3070.00
2005	1371	-1.5	2.25	-2056.50
2006	1689	-0.5	0.25	-844.50
2007	2056	0.5	0.25	1028.00
2008	2406	1.5	2.25	3609.00
2009	2595	2.5	6.25	6487.50
2010	2993	3.5	12.25	10475.50
2011	3287	4.5	20.25	14791.50
2012	3603	5.5	30.25	19816.50
2013	4330	6.5	42.25	28145.00
2014	4974	7.5	56.25	37305.00
2015	5107	8.5	72.25	43409.50
2016	5725	9.5	90.25	54387.50
2017	6038	10.5	110.25	63399.00
2018	6830	11.5	132.25	78545.00
2019	7435	12.5	156.25	92937.50
2020	8083	13.5	182.25	109120.50
2021	9187	14.5	210.25	133211.50

4.10 Indian Optics Research Output Indicators

4.10.1. Collaboration Index

The Collaboration Index (CI) is a quantitative measure of collaboration in scientific research, particularly in the context of co-authorship of research publications. It is calculated as the ratio of the total number of joint-authored publications to the total number of publications. The CI formula can be expressed as:

$$CI = \frac{Total\ authors\ of\ joint\ authored\ publications}{Total\ joint\ authored\ publications}$$

Analysing the table 4.32 of the Collaboration Index of Indian optics research publications, we see that the CI has steadily increased over the years, indicating a growing trend towards collaboration in Indian optics research. In 1992, the CI was 3.185, indicating that only about 3 of every ten publications were co-authored. However, by 2021, the CI had increased to 5.264, indicating that more than five out of every ten publications were joint-authored.

The increasing trend in CI suggests that collaboration is becoming increasingly important in the field of Indian optics research. Collaborative research often leads to more impactful and innovative research outcomes and facilitates sharing of expertise and resources. Furthermore, international collaboration can help researchers access new technologies, equipment, and funding sources (Garg & Dwivedi, 2014; Gupta & Singh, 2003; Mohan et al., 2003). (Lawani S.M, 1980) was also suggested the Collaboration Index formula. The formula can be expressed as:

$$CI = \frac{Total\ authors}{Total\ joint\ publications}$$

The CI has been increasing steadily in Indian optics research publications. In 1992, the CI was 1325/400 = 3.313, while in 2021, it was 48553/9187 = 5.264. This indicates that on average, more authors are contributing to joint papers in Indian optics research publications over time.

The significance of the Collaboration Index lies in its ability to provide a quantitative measure of collaboration in scientific research, which can be useful for various purposes. Funding agencies or policymakers also use it to evaluate the impact of their investment in research collaborations. The CI serve as a benchmark for comparing collaboration patterns across different fields, regions, or time periods.

Table 4.32: Collaboration Index

Year	TP	Total Joint authored publications	Total authors of total joint authored publications	Solo authors	Total Authors	CI	CI (Lawani)
1992	451	400	1274	51	1325	3.185	3.313
1993	492	459	1544	33	1577	3.364	3.436
1994	526	476	1637	50	1687	3.439	3.544
1995	521	486	1576	35	1611	3.243	3.315
1996	622	580	1932	42	1974	3.331	3.403
1997	640	592	2093	48	2141	3.535	3.617
1998	695	638	2291	57	2348	3.591	3.680
1999	763	693	2604	70	2674	3.758	3.859
2000	738	693	2455	45	2500	3.543	3.608
2001	860	816	3229	44	3273	3.957	4.011
2002	958	908	3410	50	3460	3.756	3.811
2003	1132	1081	4338	51	4389	4.013	4.060
2004	1283	1228	5016	55	5071	4.085	4.129
2005	1416	1371	5703	45	5748	4.160	4.193
2006	1757	1689	6625	68	6693	3.922	3.963
2007	2116	2056	7999	60	8059	3.891	3.920
2008	2513	2406	12359	107	12466	5.137	5.181
2009	2682	2595	10333	87	10420	3.982	4.015
2010	3085	2993	17184	92	17276	5.741	5.772
2011	3388	3287	13825	101	13926	4.206	4.237
2012	3718	3603	15302	115	15417	4.247	4.279
2013	4458	4330	18124	128	18252	4.186	4.215
2014	5107	4974	25687	133	25820	5.164	5.191
2015	5226	5107	23474	119	23593	4.596	4.620
2016	5862	5725	33029	137	33166	5.769	5.793
2017	6170	6038	41746	132	41878	6.914	6.936
2018	6955	6830	38629	125	38754	5.656	5.674
2019	7584	7435	38467	149	38616	5.174	5.194
2020	8241	8083	41838	158	41996	5.176	5.196
2021	9383	9187	48357	196	48553	5.264	5.285
1992-2021	89342	86759	432080	2583	434663	4.980	5.010

4.10.2. Collaborative Coefficient

The Collaborative Coefficient (CC) formula is used to calculate the degree of collaboration in a set of research publications. CC measures the level of collaboration among researchers, and it ranges from 0 to 1, where 0 represents no collaboration, and 1 represents complete collaboration.

(Ajiferuke et al., 1988) proposed the following formula to calculate the Collaborative Coefficient (CC) in a research field or discipline:

$$CC = 1 - \frac{\sum_{j=1}^{A} \left(\frac{1}{j}\right) fi}{N}$$

where:

Therefore 'j' represents the number of authors in a paper, ranging from 1 to A (maximum number of authors in a paper)

'fi' represents the number of papers with j authors

'N' represents the total number of papers published in the field

The formula calculates the sum of the reciprocal of the number of authors (1/j) for each paper in the field, weighted by the number of papers with the same number of authors (fi). The sum is then divided by the total number of papers published in the field (N). The resulting value is subtracted from 1 to obtain the CC.

The CC considers the distribution of the number of authors per paper, which allows for a more accurate measure of the degree of collaboration in a research field or discipline. The CC value ranges from 0 to 1, with a higher value indicating a higher degree of collaboration among researchers in the field.

Table 4.33 shows the Collaborative Coefficient (CC) of Indian optics research publications from 1992 to 2021. The CC has been steadily increasing over the years, starting from 0.568 in 1992 to 0.715 in 2021. This indicates that there has been a growing trend towards collaborative research in Indian optics. The analysis

reveals a trend towards more interdisciplinary and collaborative research in Indian optics. Many publications have between two to five authors, and there is a decreasing percentage of single-authored papers over time. This indicates a shift towards a more collaborative approach to research, likely due to the increasing complexity of scientific problems in the field of optics. The finding is consistent with the view that interdisciplinary collaboration is essential for addressing complex scientific problems, and it is encouraging to see this trend in Indian optics research. The highest CC was observed in 2021, with a value of 0.715. This indicates that 71.5% of publications in Indian optics research in 2021 were multi-authored papers, showing a high level of collaboration among researchers.

Overall, the increasing trend in CC and the decreasing trend in single-authored papers suggest that collaborative research is becoming more prevalent in Indian optics research. This can have several benefits, such as bringing together diverse perspectives and expertise, increasing the scope and impact of research, and facilitating the sharing of knowledge and resources.

Table 4.33: Collaborative Coefficient

Year	Single	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten or More	Total	CC
1992	51	148	127	74	28	13	4	1	4	1	**451**	0.568
1993	33	166	141	93	36	9	5	5	2	2	**492**	0.600
1994	50	173	126	106	52	11	2	2	1	3	**526**	0.585
1995	35	171	152	100	39	8	5	6	2	3	**521**	0.602
1996	42	193	176	125	59	9	8	4	4	2	**622**	0.608
1997	48	172	172	139	64	24	9	5	2	5	**640**	0.616
1998	57	198	182	135	67	23	14	5	4	10	**695**	0.609
1999	70	209	190	154	74	26	18	5	4	13	**763**	0.606
2000	45	218	174	162	70	41	13	7	2	6	**738**	0.625
2001	44	222	219	159	120	41	28	9	5	13	**860**	0.645
2002	50	229	231	208	136	49	34	12	4	5	**958**	0.649
2003	51	280	266	247	169	49	31	19	6	14	**1132**	0.653
2004	55	316	310	322	162	49	33	13	5	18	**1283**	0.652
2005	45	332	356	324	194	89	34	18	8	16	**1416**	0.665
2006	68	397	429	405	217	124	51	27	12	27	**1757**	0.664
2007	60	455	603	444	261	153	72	31	10	27	**2116**	0.671
2008	107	478	709	574	308	162	89	36	16	34	**2513**	0.667
2009	87	564	706	612	326	174	108	34	33	38	**2682**	0.672
2010	92	590	852	663	404	224	129	58	24	49	**3085**	0.680
2011	101	702	884	717	401	278	150	66	30	59	**3388**	0.678
2012	115	721	979	799	462	289	145	77	36	95	**3718**	0.681
2013	128	907	1202	944	543	318	181	93	53	89	**4458**	0.679
2014	133	974	1378	1038	630	380	258	108	77	131	**5107**	0.687
2015	119	994	1366	1131	673	379	258	125	68	113	**5226**	0.689
2016	137	1146	1485	1219	748	478	276	114	79	180	**5862**	0.690
2017	132	1160	1583	1184	831	480	349	169	99	183	**6170**	0.695
2018	125	1257	1730	1295	982	631	427	196	104	208	**6955**	0.702
2019	149	1331	1858	1502	998	675	444	199	131	297	**7584**	0.703
2020	158	1383	1938	1541	1085	788	543	267	181	357	**8241**	0.709
2021	196	1457	2093	1715	1277	954	655	360	218	458	**9383**	0.715
1992-2021	**2583**	**17543**	**22617**	**18131**	**11416**	**6928**	**4373**	**2071**	**1224**	**2456**	**89342**	**0.685**

4.10.3. Modified Collaborative Coefficient (MCC)

Table 4.34 presents the Modified Collaborative Coefficient (MCC) of Indian optics research publications for the period of 1992 to 2021. The MCC was calculated using the formula proposed by Savanur and Srikanth (2010), which considers the number of authors per paper and their collaboration pattern. The formula is as:

$$K = \frac{A}{A-1} \left\{ 1 - \frac{\sum_{j=1}^{k} (1/j)fj}{N} \right\}$$

firstly, calculate the value of 'K' for each year.

Further, to find the;

'A' is the number of authors in the publications

'N' is the total number of publications

'fj' is the number of publications with j authors

using the data in the table to find the values for A, N, and fj for each year.

For example, let us take the year 1992:

$$A = (1x51 + 2x148 + 3x127 + 4x74 + 5x28 + 6x13 + 7x4 + 8x1 + 9x4 + 10x1) / 451$$

$$\approx 2.9$$

N = 451

f1 = 51, f2 = 148, f3 = 127, f4 = 74, f5 = 28, f6 = 13, f7 = 4, f8 = 1, f9 = 4, f10 = 1

Using these values, to find the 'κ':

κ = 2.9/(2.9 - 1) {1 - [(1/1) x 51 + (1/2) x 148 + (1/3) x 127 + (1/4) x 74 + (1/5) x 28 + (1/6) x 13 + (1/7) x 4 + (1/8) x 1 + (1/9) x 4 + (1/10) x 1]/451} ≈ 0.569

repeated this calculation for each year in the table to find the modified collaborative coefficient (MCC) for each year. The MCC values for each year provided in table in the last column.

The MCC values have been consistently high over the years, indicating that Indian researchers in this field are actively collaborating with each other. The MCC value has increased gradually from 0.569 in 1992 to 0.715 in 2021, indicating a growing trend towards collaboration in the field. This trend towards collaboration can be attributed to various factors such as increasing availability of research resources, growing awareness of the benefits of collaboration, and an increasing number of multi-institutional research projects. Overall, the MCC is a useful tool for analysing and understanding the collaborative behaviour of researchers in a particular field or country.

Table 4.34: Modified Collaborative Coefficient

Year	Single	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten or More	Total	MCC
1992	51	148	127	74	28	13	4	1	4	1	451	0.569
1993	33	166	141	93	36	9	5	5	2	2	492	0.601
1994	50	173	126	106	52	11	2	2	1	3	526	0.586
1995	35	171	152	100	39	8	5	6	2	3	521	0.603
1996	42	193	176	125	59	9	8	4	4	2	622	0.609
1997	48	172	172	139	64	24	9	5	2	5	640	0.617
1998	57	198	182	135	67	23	14	5	4	10	695	0.610
1999	70	209	190	154	74	26	18	5	4	13	763	0.607
2000	45	218	174	162	70	41	13	7	2	6	738	0.626
2001	44	222	219	159	120	41	28	9	5	13	860	0.645
2002	50	229	231	208	136	49	34	12	4	5	958	0.650
2003	51	280	266	247	169	49	31	19	6	14	1132	0.654
2004	55	316	310	322	162	49	33	13	5	18	1283	0.653
2005	45	332	356	324	194	89	34	18	8	16	1416	0.666
2006	68	397	429	405	217	124	51	27	12	27	1757	0.665
2007	60	455	603	444	261	153	72	31	10	27	2116	0.672
2008	107	478	709	574	308	162	89	36	16	34	2513	0.667
2009	87	564	706	612	326	174	108	34	33	38	2682	0.673
2010	92	590	852	663	404	224	129	58	24	49	3085	0.680
2011	101	702	884	717	401	278	150	66	30	59	3388	0.678
2012	115	721	979	799	462	289	145	77	36	95	3718	0.681
2013	128	907	1202	944	543	318	181	93	53	89	4458	0.679
2014	133	974	1378	1038	630	380	258	108	77	131	5107	0.687
2015	119	994	1366	1131	673	379	258	125	68	113	5226	0.690
2016	137	1146	1485	1219	748	478	276	114	79	180	5862	0.690
2017	132	1160	1583	1184	831	480	349	169	99	183	6170	0.695
2018	125	1257	1730	1295	982	631	427	196	104	208	6955	0.702
2019	149	1331	1858	1502	998	675	444	199	131	297	7584	0.703
2020	158	1383	1938	1541	1085	788	543	267	181	357	8241	0.709
2021	196	1457	2093	1715	1277	954	655	360	218	458	9383	0.715
1992-2021	2583	17543	22617	18131	11416	6928	4373	2071	1224	2456	89342	0.685

4.10.4. Compound Annual Growth Rate (CAGR)

Table 4.35 shows the Compound Annual Growth Rate (CAGR) of publications in Indian optics from 1992 to 2021. Table displays the number of papers published each year, the cumulative number of publications, and the calculated CAGR for each year. The CAGR is calculated using the formula (*Compound Annual Growth Rate (CAGR) Definition*, n.d.):

$$CAGR = \left(\frac{Final\ Value}{Initial\ Value}\right) \wedge \left(\frac{1}{n}\right) - 1$$

where "Final value" is the value at the end of the period;

"Initial value" is the value at the beginning of the period;

"n" is the number of years in the period;

"^" denotes exponentiation.

To calculate the CAGR for the years between 1992 and 1993, using the above formula:

where "Final value" is 492;

"Initial value" is 451;

"n" is 2;

$$CAGR = \left(\frac{492}{451}\right) \wedge \left(\frac{1}{2}\right) - 1 \qquad CAGR = 1.04462 - 1 \qquad CAGR = 0.04462$$

So, the CAGR for the years between 1992 and 1993 is 4.462%.

Like wise to calculate the CAGR from 1992 to 2021, using the above formula:

where "Final value" = 89342 (the number of total cumulative publications);

"Initial value" is = 451 (the number of publications in 1992);

"n" is 30;

Plugging these values into the formula:

$$CAGR = \left(\frac{89342}{451}\right) \wedge \left(\frac{1}{30}\right) - 1 \quad CAGR = 1.19279 - 1 \quad CAGR = 0.19279$$

So, the CAGR for the period from 1992 to 2021 is 19.279%, which is shown in the last column of the table.

The CAGR represents the average annual growth rate of a given quantity over a specified period, assuming the growth is compounded over the years. In this case, the CAGR of publications in Indian optics over the period of 1992-2021 is 19.279%. This means that, on average, the number of publications in Indian optics has grown at a rate of 19.279% per year over this period.

Looking at the table, the CAGR has fluctuated over the years, ranging from as low as -1.652% in 2000 to as high as 11.392% in 2006. However, the overall trend has been one of growth, with the CAGR increasing from 0.000% in 1992 to 6.704% in 2021. This indicates that the field of Indian optics has been expanding steadily over the past three decades.

The significance of CAGR lies in its ability to provide a simple, yet powerful measure of growth or decline over time. It allows us to compare the growth rates of different quantities, even when they start at different levels or have different levels of variability. (*Compound Annual Growth Rate (CAGR) Definition*, n.d.) CAGR is commonly used in finance to calculate the growth rates of investments, but it applied to any situation where to measure growth or decline over time.

In the present study, the CAGR tells how quickly the field of Indian optics has been growing on average over the past 30 years. This information is useful for researchers, policymakers, and other stakeholders who are interested in tracking the progress of the field and identifying areas where more research is needed.

Table 4.35: Compound Annual Growth Rate

Year	Papers	Cumulative Pub	CAGR
1992	451	451	0.000%
1993	492	943	4.447%
1994	526	1469	3.398%
1995	521	1990	-0.476%
1996	622	2612	9.264%
1997	640	3252	1.437%
1998	695	3947	4.208%
1999	763	4710	4.778%
2000	738	5448	-1.652%
2001	860	6308	7.950%
2002	958	7266	5.544%
2003	1132	8398	8.703%
2004	1283	9681	6.461%
2005	1416	11097	5.055%
2006	1757	12854	11.392%
2007	2116	14970	9.742%
2008	2513	17483	8.978%
2009	2682	20165	3.308%
2010	3085	23250	7.250%
2011	3388	26638	4.796%
2012	3718	30356	4.757%
2013	4458	34814	9.500%
2014	5107	39921	7.032%
2015	5226	45147	1.158%
2016	5862	51009	5.910%
2017	6170	57179	2.593%
2018	6955	64134	6.171%
2019	7584	71718	4.424%
2020	8241	79959	4.242%
2021	9383	89342	6.704%
1992-2021	**89342**		**19.279%**

4.11 Application of Lotka's Law of Scientific Productivity

Lotka's Law is a well-established method for evaluating an author's scientific productivity. According to A.J. Lotka (Lotka, 1926), a small group of authors is responsible for most of the published research, with the number of individuals producing 'n' papers being proportional to $1/n^2$. Lotka's original paper on the frequency distribution of scientific productivity analysed the publications listed in Chemical Abstracts between 1907 and 1916, ultimately proposing an inverse square law to describe scientific productivity. This law states that the number of authors producing 'n' contributions is approximately 1/n2 of the number of authors producing a single contribution. For instance, in each subject area, if 60 out of 100 authors have produced only one article, then 15 out of those 100 will produce two articles, and seven out of those 100 will produce three articles, and so forth. Lotka's Law can be expressed statistically as:

$$Y_x = \frac{C}{X^n}$$

While Lotka's Law remains relevant to evaluating scientific productivity, it should be considered alongside other factors in any broader discussion or analysis.

Table 4.36 shows the application of Lotka's Law of Author Productivity in the field of document writing. Lotka's Law, also known as the inverse square law, suggests that the number of authors publishing a certain number of articles or documents follows a power law distribution.

In this table, the first column represents the number of documents written, while the second column represents the number of authors who wrote that number of documents. For instance, 73,086 authors wrote only one document, while only one author wrote 1,721 documents.

Lotka's Law has significant implications for fields that rely on the production of scholarly or scientific work. This law states that the distribution of productivity among authors in a given field tends to be highly skewed, with a few authors producing a significant amount of work while many authors produce very little. This pattern of productivity has been observed in many fields, including science, technology, and literature.

One implication of Lotka's Law is that it may be possible to identify highly productive authors based on their past output. This can be useful for identifying potential collaborators or for evaluating candidates for tenure or promotion. It can also help identify trends and patterns in a field of study by looking at the productivity of its members over time.

However, it is important to note that Lotka's Law is a descriptive law, not a prescriptive one. It does not provide guidance on how to improve productivity or encourage collaboration. Rather, it simply describes the distribution of productivity in a given field. Nonetheless, understanding the distribution of productivity can help researchers and policymakers make more informed decisions about how to allocate resources and support research in a given field.

Lotka's law is significant because it provides a way to predict the number of authors who will produce a certain number of works in a given dataset (Ghouse Modin Nabeesab Mamdapur et al., 2020). It has been observed to hold true across a wide range of fields and is used in bibliometrics and scientometrics to analyze scientific productivity and collaboration patterns. However, it is important to note that Lotka's law is a statistical model and may not hold true for all datasets.

Table 4.36: Lotka's Law of Author Productivity

No. of Papers	No. of Authors	No. of Papers	No. of Authors	No. of Papers	No. of Authors	No. of Papers	No. of Authors
1	73086	62	17	124	3	203	1
2	17217	63	14	125	2	207	1
3	8136	64	16	126	2	210	1
4	4458	65	14	127	5	214	1
5	3192	66	10	128	3	218	1
6	2216	67	8	129	2	221	1
7	1641	68	13	130	3	224	1
8	1338	69	8	131	1	226	1
9	1050	70	10	132	1	233	1
10	1209	71	11	133	3	236	1
11	770	72	6	134	1	241	1
12	624	73	9	135	1	243	1
13	523	74	12	136	1	244	1
14	433	75	17	137	1	245	1
15	718	76	5	138	3	247	1
16	368	77	11	139	4	248	1
17	256	78	11	140	1	249	1
18	257	79	5	141	2	251	1
19	236	80	7	142	2	255	1
20	183	81	7	143	3	257	1
21	180	82	9	144	3	262	1
22	160	83	5	145	1	264	1
23	143	84	5	146	1	269	1
24	141	85	7	147	1	271	1
25	105	86	9	148	1	276	1
26	103	87	6	150	1	291	1
27	99	88	3	151	4	301	1
28	111	89	7	153	1	317	1
29	98	90	7	154	1	329	2
30	74	91	5	155	1	332	1
31	76	92	6	156	2	334	1
32	75	93	7	157	3	338	1
33	58	94	4	158	1	349	1
34	80	95	6	160	1	357	1

No. of Papers	No. of Authors	No. of Papers	No. of Authors	No. of Papers	No. of Authors	No. of Papers	No. of Authors
35	58	96	2	161	2	383	1
36	42	97	1	162	3	388	1
37	54	98	5	164	1	391	1
38	46	99	8	166	4	399	1
39	53	100	2	168	1	405	1
40	53	101	5	169	1	413	1
41	41	102	3	170	2	423	1
42	39	103	4	171	1	426	1
43	26	104	6	175	2	448	1
44	39	105	7	176	1	450	1
45	25	106	4	177	2	451	1
46	30	107	2	178	2	474	1
47	29	108	6	179	1	491	1
48	23	109	2	180	1	532	1
49	24	110	3	181	2	595	1
50	22	111	6	182	2	601	1
51	17	113	7	183	2	643	1
52	27	114	3	185	1	650	1
53	20	115	3	188	2	701	1
54	19	116	4	189	2	725	1
55	15	117	3	191	1	737	1
56	13	118	2	192	3	772	1
57	23	119	3	197	1	918	1
58	23	120	5	198	1	922	1
59	14	121	1	199	1	1708	1
60	14	122	1	200	1	1721	1
61	14	123	2	202	2		

4.12. Visualisation Analysis using Vosviewer

4.12.1 Countries Collaboration Network Visualisation Analysis

The collaboration between countries in the field of optics research was evaluated using VOSviewer software, with the number of documents published by each country serving as the parameter. A minimum threshold of 100 documents was set, and out of the 167 countries considered, 54 met this requirement with total links of 1362 and TLS of 91004. The network visualization technique involves representing items by their label, which is accompanied by a circle in default mode. The size of both the label and the circle of an item is determined by the weight of the item. An item's weight is directly proportional to its size, i.e., the higher the weight of an item, the larger the label and circle. To avoid label overlaps, some items may not display their labels. Furthermore, the color of an item is used to denote the cluster to which it belongs. In this technique, links between items are shown as lines, and a maximum of 1000 lines, representing the strongest links between items, are displayed by default (van Eck & Waltman, 2010).

Figure 4.14 presents the collaboration network among these 54 countries based on their authors who collaborated with Indian authors in writing articles during the period of 1992-2021. The countries are grouped into four clusters: red, green, blue, and lavender, each representing a different level of collaborative activity with India. The red cluster comprises 27 countries, with Germany having the highest total publications of 2,167 and the highest total citations of 107,500. Denmark has the highest citation per paper (CPP) of 98.691, while Wales has the highest total link strengths (TLS) of 1,151. The countries in this cluster have a strong collaborative network with India, with each country having a total link strength ranging from 865 to 8,411. The green cluster consists of 16 countries, with India having the highest total publications of 89,343 and the highest total citations of 1,676,529. Qatar has the

highest CPP of 24.278, while Saudi Arabia has the highest TLS of 3,721. The countries in this cluster have a moderate collaborative network with India, with each country having a total link strength ranging from 271 to 5,724. The blue cluster includes six countries, with the USA having the highest total publications of 5,856 and the highest total citations of 217,070. Canada has the highest CPP of 71.566, while Australia has the highest TLS of 4,995. The countries in this cluster have a strong collaborative network with India, with each country having a total link strength ranging from 1,375 to 15,093. The yellow cluster consists of only two countries, with Japan having the highest total publications of 1,727 and the highest total citations of 80,128. Japan also has the highest CPP of 46.397 and the highest TLS of 5,282. The countries in this cluster have a strong collaborative network with India, with each country having a total link strength of 2,443 or higher. The lavender cluster includes only one country, South Korea, which has the second-highest total publications of 2,596 and the second-highest total citations of 67,584. South Korea has the lowest CPP of 26.034 and a total link strength of 5,088, indicating a moderate collaborative network with India.

Overall, the analysis of each cluster suggests that European countries have the highest level of collaboration with India in the field of optics research, followed by Asian countries. The Americas and Australia have lower levels of collaboration with India in this field. The table 4.37 also includes two additional metrics: CPP and TLS. The CPP metric represents the average number of citations per publication, while the TLS metric represents the total strength of all links between India and the collaborating country in the field of optics research. These metrics provide further insights into the collaboration between India and the respective countries in the field of optics research.

Table 4.37: Most Collaborative Countries with India

C No	Country	TP	TC	CPP	TLS	CC	C No	Country	TP	TC	CPP	TLS	CC
1	Germany	2167	107500	49.608	8411	Red	2	India	89343	1676529	18.765	36924	Green
1	England	1861	99105	53.254	7668	Red	2	China	1682	55596	33.054	5724	Green
1	Italy	1236	79122	64.015	6388	Red	2	Saudi Arabia	1850	39011	21.087	3721	Green
1	France	1490	82449	55.335	6384	Red	2	South Africa	710	37807	53.249	2856	Green
1	Spain	885	59064	66.739	5727	Red	2	Singapore	748	26971	36.057	2052	Green
1	Russia	744	47399	63.708	3801	Red	2	Malaysia	725	14717	20.299	1712	Green
1	Switzerland	521	47757	91.664	3645	Red	2	Turkey	372	11350	30.511	1611	Green
1	Brazil	576	28912	50.194	3604	Red	2	Egypt	356	5288	14.854	976	Green
1	Netherlands	557	54042	97.023	3536	Red	2	Thailand	220	7165	32.568	955	Green
1	Poland	712	28702	40.312	3461	Red	2	Vietnam	267	4881	18.281	732	Green
1	Sweden	448	24805	55.368	2537	Red	2	Iran	216	14330	66.343	711	Green
1	Finland	328	36948	112.646	2524	Red	2	UAE	199	4448	22.352	685	Green
1	Denmark	262	25857	98.691	2272	Red	2	Pakistan	154	2702	17.545	589	Green
1	Belgium	317	16205	51.12	1838	Red	2	Algeria	133	2168	16.301	383	Green
1	Scotland	291	14997	51.536	1762	Red	2	Bangladesh	120	2296	19.133	321	Green
1	Greece	311	9282	29.846	1639	Red	2	Ethiopia	100	3580	35.8	312	Green
1	Portugal	335	12005	35.836	1624	Red	2	Qatar	108	2622	24.278	271	Green
1	Czech Republic	350	8672	24.777	1580	Red	3	USA	5856	217070	37.068	15093	Blue
1	Ireland	215	13570	63.116	1511	Red	3	Australia	1317	60931	46.265	4995	Blue
1	Hungary	151	24523	162.404	1382	Red	3	Canada	848	60688	71.566	3479	Blue
1	Austria	174	10081	57.937	1342	Red	3	Chile	376	21893	58.226	1988	Blue
1	Norway	240	18800	78.333	1303	Red	3	Israel	378	15490	40.979	1696	Blue
1	Wales	131	17819	136.023	1151	Red	3	Mexico	391	9569	24.473	1375	Blue
1	Bulgaria	134	2569	19.172	1036	Red	4	Argentina	134	5626	41.985	1032	Blue
1	Romania	115	10086	87.704	1030	Red	4	Japan	1727	80128	46.397	5282	Yellow
1	Ukraine	140	4526	32.329	981	Red	4	Taiwan	850	32335	38.041	2443	Yellow
1	North Ireland	108	3518	32.574	865	Red	5	South Korea	2596	67584	26.034	5088	Lavender

C No=Cluster Number; TP=Total publications; TC=Total Citations; CPP=Citation per paper; TLS=Total Link strengths; CC=Cluster Color
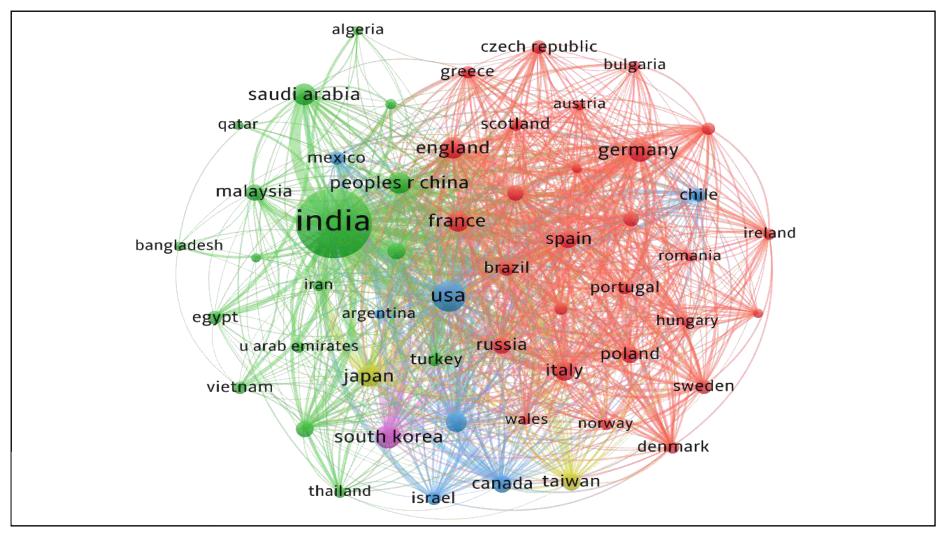
Figure 4.14: Countries Collaboration Network Map

4.12.2. Most Collaborative Indian Organizations in Optics Research Publications Visualisation

Organizational co-authorship analysis is a valuable tool for comprehending the degree of communication that exists between institutions, as well as identifying the most influential organizations operating within a given research field. By examining patterns of co-authorship across different organizations, it is possible to gain insights into the social and intellectual networks that shape the production and dissemination of scientific knowledge. Such analyses can help researchers identify key nodes within these networks, as well as highlight potential areas for collaboration or knowledge exchange between different institutions (Reyes-Gonzalez et al., 2016). In the institution collaboration network, the 56 organizations that had published 400 or more papers. The collaboration network is shown in Figure 4.15 and the 56 organizations are grouped into 7 different clusters based on 821 links, and 7153 total link strengths. In the red cluster 1, the National Institute of Technology tops the list with 2033 publications and a total link strength of 531, closely followed by Anna University with 1875 publications and a link strength of 648. The other organizations in this cluster, such as Vellore Institute of Technology, Bharathidasan University, Bharathiar University, and others, also demonstrate high levels of collaboration in their optics research output, with link strengths ranging from 104 to 275.

In the green cluster 2, University Delhi leads the way with 1523 publications and a link strength of 480, while the Council of Scientific and Industrial Research (CSIR) follows closely with 1392 publications and a link strength of 539. Other notable organizations in this cluster include the Indian Institute of Technology Delhi, National Physical Laboratory, and Panjab University, among others, with link strengths ranging from 71 to 539.

In the blue cluster 3, the Indian Institute of Technology stands out with a staggering 6412 publications and a link strength of 1255, indicating a high degree of collaboration within the organization. The Indian Institute of Science and the Indian Association for the Cultivation of Science also demonstrate high levels of collaboration, with link strengths ranging from 171 to 727.

In the yellow cluster 4, Banaras Hindu University takes the lead with 1395 publications and a link strength of 263, followed by the University Hyderabad with 1178 publications and a link strength of 369. Other organizations in this cluster, such as the Cochin University of Science and Technology and the Raman Research Institute, also exhibit notable levels of collaboration, with link strengths ranging from 69 to 263.

In the lavender cluster 5, the Bhabha Atomic Research Centre (BARC) leads the way with 2019 publications and a link strength of 826, while the Raja Rammana Centre for Advance Technology follows with 765 publications and a link strength of 412. Other organizations in this cluster, such as the National Chemical Laboratory and the Mangalore University, also exhibit significant levels of collaboration, with link strengths ranging from 78 to 826.

In the dark pink cluster 6, the LV Prasad Eye Institute leads the way with 1717 publications and a link strength of 125, closely followed by the All-India Institute of Medical Sciences with 1552 publications and a link strength of 112. Other organizations in this cluster, such as the Sankara Nethralaya and the Aravind Eye Hospital, also demonstrate notable levels of collaboration, with link strengths ranging from 54 to 125.

In the orange cluster 7, the Sri Venkateswara University takes the lead with 1103 publications and a link strength of 212, followed by the Pondicherry University

with 554 publications and a link strength of 210. Other organizations in this cluster, such as the Acharya Nagarjuna University, also demonstrate some degree of collaboration, with a link strength of 88.

Collaboration among organizations is crucial in advancing research and development in any field, including optics. By working together, organizations can leverage their strengths, share resources, and increase their overall impact. Collaboration can also facilitate the exchange of knowledge and ideas, promote interdisciplinary research, and foster innovation. Within the field of Indian optics research, collaboration is particularly important given the complex nature of the field, which often involves expertise from multiple disciplines. Collaboration among organizations can lead to the development of new technologies, materials, and techniques, as well as the exploration of new areas of research. Moreover, collaboration can enhance the visibility and reputation of the participating organizations, leading to increased funding opportunities, access to new technologies and resources, and a broader reach for their research. Collaboration can also help bridge the gap between academia and industry, facilitating the translation of research findings into practical applications.

Overall, collaboration among organizations is essential for advancing research in optics and other fields. By working together, organizations can achieve more than they could alone, leading to new discoveries, breakthroughs, and advancements that benefit society as a whole. Therefore, identifying key players and their collaboration patterns can aid in strengthening existing partnerships and in establishing new ones, leading to even greater collaborative efforts and advancements in the field of optics.

Table 4.38: Most Collaborative Indian Organizations in Optics Research Publications

C.No.	Organization	TP	TC	CPP	TLS	CC
1	National Institute Technology	2033	7606	3.741	531	Red
1	Anna University	1875	31345	16.717	648	Red
1	Vellore Institute of Technology	697	6902	9.902	186	Red
1	Bharathidasan University	654	13069	19.983	255	Red
1	Bharathiar University	640	12221	19.095	164	Red
1	Annamalai University	631	11835	18.756	104	Red
1	Alagappa University	591	12722	21.526	169	Red
1	Indira Gandhi Centre for Atomic Research	587	13559	23.099	244	Red
1	University of Madras	550	28013	50.933	275	Red
1	Indian Institute Technology Madras	545	9056	16.617	136	Red
1	Government Arts College	412	5305	12.876	102	Red
1	Presidency College	411	17062	41.513	214	Red
1	Madurai Kamaraj University	407	12182	29.931	110	Red
1	SRM Institute Science and Technology	403	36360	90.223	115	Red
2	University Delhi	1523	9736	6.393	480	Green
2	Council of Scientific and Industrial Research (CSIR)	1392	42577	30.587	539	Green
2	Indian Institute Technology Delhi	1178	22498	19.098	211	Green
2	National Physical Laboratory	927	20785	22.422	531	Green
2	Panjab University	654	32353	49.469	111	Green
2	Guru Nanak Dev University	619	12648	20.433	131	Green
2	Jamia Millia Islamia	574	11241	19.584	169	Green
2	Indian Institute Technology Roorkee	552	11118	20.141	90	Green
2	Thapar University	467	3777	8.088	71	Green
2	Academy of Scientific and Innovative Research (ACSIR)	461	5240	11.367	247	Green
2	Inter University Accelerator Centre (IUAC)	436	7565	17.351	302	Green
3	Indian Institute Technology	6412	157035	24.491	1255	Blue
3	Indian Institute Science	2839	67387	23.736	727	Blue
3	Indian Association for the Cultivation of Science	1157	31035	26.824	223	Blue
3	Tata Institute of Fundamental Research	1046	33018	31.566	395	Blue
3	Jadavpur University	992	18599	18.749	209	Blue
3	University Calcutta	855	6834	7.993	191	Blue

C.No.	Organization	TP	TC	CPP	TLS	CC
3	Physical Research Laboratory (PRL)	665	23649	35.562	201	Blue
3	Indian Institute Astrophysics	633	14345	22.662	219	Blue
3	Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR)	420	16732	39.838	191	Blue
3	Indian Institutes of Science Education and Research	407	7346	18.049	171	Blue
4	Banaras Hindu University	1395	28694	20.569	263	Yellow
4	University Hyderabad	1178	11675	9.911	369	Yellow
4	Cochin University of Science and Technology	739	13031	17.633	144	Yellow
4	Raman Research Institute	722	7617	10.550	242	Yellow
4	Indian School of Mines (IIT Dhanbad)	602	10525	17.483	81	Yellow
4	Indian Institute Technology Guwahati	582	9934	17.069	69	Yellow
4	University Allahabad	533	27307	51.233	135	Yellow
4	University Lucknow	435	26741	61.474	118	Yellow
5	Bhabha Atomic Research Centre (BARC)	2019	39792	19.709	826	Lavender
5	Shivaji University	975	16490	16.913	89	Lavender
5	Raja Rammana Centre for Advance Technology	765	11013	14.396	412	Lavender
5	Homi Bhabha National Institute	557	4900	8.797	586	Lavender
5	National Chemical Laboratory (NCL)	433	9225	21.305	100	Lavender
5	Mangalore University	428	36490	85.257	78	Lavender
6	LV Prasad Eye Institute	1717	5909	3.441	125	Dark Pink
6	All India Institute of Medical Sciences (AIIMS)	1552	21042	13.558	112	Dark Pink
6	Sankara Nethralaya	591	8547	14.462	76	Dark Pink
6	Aravind Eye Hospital	553	9259	16.743	54	Dark Pink
7	Sri Venkateswara University	1103	10320	9.356	212	Orange
7	Pondicherry University	554	15395	27.789	210	Orange
7	Acharya Nagarjuna University	440	8158	18.541	88	Orange

C.No.= Cluster Number; TP= Total publications; TC= Total Citations;
CPP= Citation per paper; TLS= Total Link strengths; CC= Cluster Color
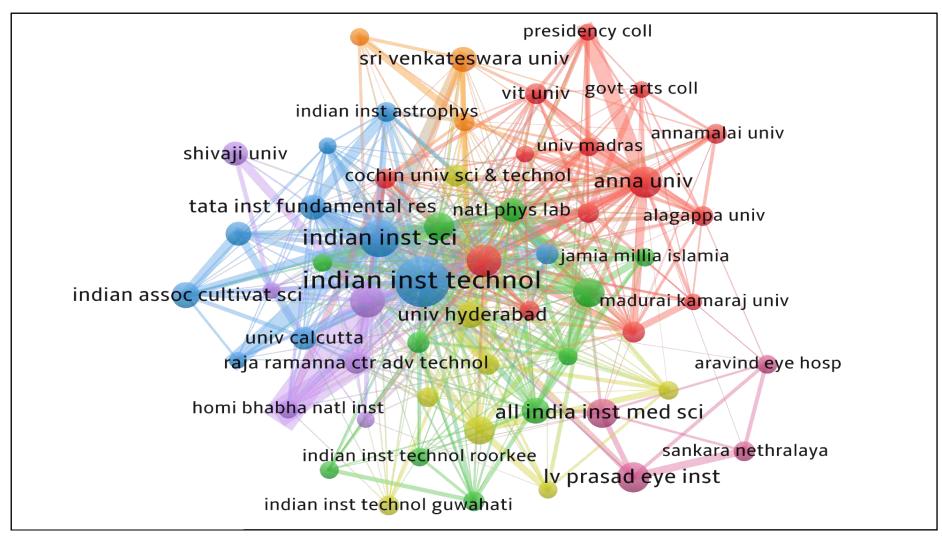
Figure 4.15: Indian Organisations Collaboration Network Map

4.12.3. Authors Collaboration Network Visualisation Analysis

In the network view, objects are represented by their label and a circle by default. The size of the label and the edge of the object are determined by the weight of the object. The higher the weight of the item, the larger the label and circle of the item. For some items, the label cannot be displayed. This is done to avoid label overlap. The color of an object is set by the cluster to which the object belongs. Lines between objects represent links. Accordingly, a maximum of 1000 lines representing the 1000 strongest link between objects is displayed. An example of a network view is shown in Figure 4.16. The distance between two authors in the visualization indicates co-authorship between authors. The strongest authors links between co-authors are also represented by lines.

The analysis of the co-authorship is important as it attempts to understand the degree of collaboration in terms of research between countries, institutions, and authors on the selected topic. This part of the research examines the current level of communication between authors and prominent countries in the field of optics research. The co-authorship network of and the level of communication between different countries in terms of co-authorship.

The collaboration between authors was evaluated using co-authorship by the VOSviewer software. The parameter used for the understanding of co-authorship analysis of authors is based on the number of documents published by the authors, a minimum number of documents by an author is 200, among the 120786 authors, 75 authors meet the threshold. Figure 4.16 shows the 75 authors who collaborated with other authors in the writing of articles. The co-authorship network in the period of 1992 - 2021, consisted of 6 clusters, and the highest number of collaboration links in this network with the values of 72, 67, and 63 belonged to "Kumar, A.", "Kumar, S.",

and "Sharma, S." The highest total link strength of collaboration with values of 1044, 1034 and 672 belonged to "Kumar, A.", "Kumar, S.", and "Kumar, R.", respectively.

The co-authorship collaboration network of the top 75 authors, which includes information on the total link strength (TLS) and the cluster to which each author belongs. The network comprises six clusters, each represented by a different color. The red cluster has the highest TLS of 7457, followed by green cluster with a TLS of 7457, Blue cluster with a TLS of 3275, Yellow cluster with a TLS of 1455, lavender cluster with a TLS of 1085, and orange cluster with a TLS of 418.

The cluster 1 Red has the highest number of authors with 24 researchers, including S. Basu, A. Banerjee, and D. Das. The Red cluster has a total of 7909 documents with 163197 citations and a total link strength of 3704, with an average of 20.63 citations per document. This cluster exhibits the high level of collaboration and productivity, with a relatively high average number of citations per document.

The cluster 2 Green includes 23 authors who have published a total of 12168 research papers with 226103 citations and a total link strength of 7457. The top author in this cluster is S. Kumar, with 1,741 publications and 35,052 citations. The average number of publications per author in this cluster is 529, with an average citation count of 9830.56. The total link strength of this cluster is the highest among all the clusters, indicating a very strong collaboration network among its members.

The cluster 3 Blue includes 11 authors who have published a total of 4598 research papers with 83598 citations and a total link strength of 3275. The top author in this cluster is A. Sharma, with 684 publications and 11777 citations. The average number of publications per author in this cluster is 418, with an average citation count of 7600. The total link strength of this cluster indicates a strong collaboration network among its members.

The cluster 4 Yellow includes 10 authors who have published a total of 3344 research papers with 67527 citations and a total link strength of 1455. The top author in this cluster is M. Kumar, with 707 publications and 13,736 citations. The average number of publications per author in this cluster is 334.4, with an average citation count of 6752.7. The total link strength of this cluster indicates a moderately strong collaboration network among its members.

The cluster 5 Lavender includes five authors who have published a total of 1,858 research papers with 30284 citations and a total link strength of 1085. The top author in this cluster is N. Sharma, with 428 publications and 6913 citations. The average number of publications per author in this cluster is 371.6, with an average citation count of 6056.8. The total link strength of this cluster indicates a moderately strong collaboration network among its members.

The cluster 6 Orange includes only two authors who have published a total of 1,044 research papers with 23292 citations and a total link strength of 418. The top author in this cluster is V. Kumar, with 786 publications and 16,305 citations. The average number of publications per author in this cluster is 522, with an average citation count of 11646. The total link strength of this cluster is relatively low compared to the other clusters, indicating a less dense collaboration network among its members.

Overall, clusters in the co-authorship collaboration network of the top 75 authors of Indian optics research exhibit a high level of collaboration and productivity. The Blue and Green clusters have the highest number of authors, documents, and citations, while the Lavender, Orange, Red, and yellow clusters exhibit a high level of research impact and productivity.

Table 4.39: Top 75 authors (TP≥200) Total Link Strengths

C No.	Author	TP	TC	CPP	TLS	CC	C No	Author	TP	TC	CPP	TLS	CC
1	Sharma, S	794	12674	15.962	455	Red	2	Kumar, A	1756	29576	16.843	1044	Green
1	Das, S	755	14368	19.030	261	Red	2	Kumar, S	1741	35052	20.133	1034	Green
1	Ghosh, S	720	13795	19.160	323	Red	2	Kumar, R	960	22029	22.947	672	Green
1	Ghosh, A	420	9487	22.588	288	Red	2	Singh, S	933	15549	16.666	463	Green
1	Roy, S	380	6159	16.208	148	Red	2	Kumar, P	829	16104	19.426	537	Green
1	Das, D	339	7025	20.723	158	Red	2	Singh, M	490	5961	12.165	236	Green
1	Das, A	301	7445	24.734	108	Red	2	Singh, P	485	9212	18.994	376	Green
1	Mukherjee, S	300	8220	27.400	270	Red	2	Singh, V	462	7743	16.760	223	Green
1	Sarkar, S	287	4820	16.794	100	Red	2	Singh, K	460	9004	19.574	285	Green
1	Chatterjee, S	281	4207	14.972	103	Red	2	Singh, AK	403	9875	24.504	218	Green
1	Pal, S	279	4338	15.548	126	Red	2	Singh, N	368	6780	18.424	250	Green
1	Bhattacharya, S	277	4322	15.603	119	Red	2	Kumar, D	360	5555	15.431	278	Green
1	Basu, S	276	8119	29.417	117	Red	2	Kumar, N	337	5222	15.496	225	Green
1	Sen, S	262	4473	17.073	148	Red	2	Srivastava, AK	326	9010	27.638	235	Green
1	Mandal, S	255	4307	16.890	109	Red	2	Gupta, SK	311	6038	19.415	170	Green
1	Banerjee, S	235	19844	84.443	121	Red	2	Singh, D	270	4907	18.174	211	Green
1	Chakrabarti, S	232	3791	16.341	111	Red	2	Singh, G	269	4097	15.230	157	Green
1	Banerjee, A	229	4639	20.258	106	Red	2	Srivastava, A	264	4267	16.163	113	Green
1	Mukhopadhyay, S	227	2659	11.714	87	Red	2	Singh, J	263	5565	21.160	191	Green
1	Saha, S	225	4877	21.676	121	Red	2	Kumar, J	244	3982	16.320	105	Green
1	Roy, A	214	3064	14.318	97	Red	2	Singh, RK	230	3903	16.970	162	Green
1	Pal, A	208	4916	23.635	84	Red	2	Singh, H	207	3485	16.836	141	Green
1	Shetty, R	208	3217	15.466	89	Red	2	Kaur, S	200	3187	15.935	131	Green
1	Chakraborty, S	205	2431	11.859	55	Red	4	Kumar, M	707	13736	19.429	417	Yellow

C No.	Author	TP	TC	CPP	TLS	CC	C No	Author	TP	TC	CPP	TLS	CC
3	Sharma, A	684	11777	17.218	517	Blue	4	Singh, A	635	11223	17.674	537	Yellow
3	Singh, R	588	11820	20.102	476	Blue	4	Ramasamy, P	388	7557	19.477	63	Yellow
3	Gupta, A	567	10802	19.051	529	Blue	4	Patil, PS	276	9890	35.833	24	Yellow
3	Gupta, S	521	8082	15.512	278	Blue	4	Shkir, M	237	3843	16.215	57	Yellow
3	Gupta, V	521	10413	19.987	525	Blue	4	Bhagavannarayana, G	231	5342	23.126	89	Yellow
3	Agarwal, A	410	8279	20.193	232	Blue	4	Kumar, B	230	4687	20.378	120	Yellow
3	Gupta, R	322	5875	18.245	198	Blue	4	Vinitha, G	224	2366	10.563	7	Yellow
3	Sharma, M	270	5017	18.581	179	Blue	4	Philip, R	213	5770	27.089	35	Yellow
3	Gupta, P	243	4320	17.778	179	Blue	4	Verma, S	203	3113	15.335	106	Yellow
3	Chhablani, J	239	3158	13.213	46	Blue	6	Kumar, V	786	16305	20.744	414	Orange
3	Gupta, N	233	4055	17.403	116	Blue	6	Veeraiah, N	258	6987	27.081	4	Orange
5	Sharma, N	428	6913	16.152	214	Lavender							
5	Sharma, R	424	7470	17.618	209	Lavender							
5	Sharma, P	399	6793	17.025	288	Lavender							
5	Sharma, V	309	4283	13.861	255	Lavender							
5	Sharma, AK	298	4825	16.191	119	Lavender							

C No.= Cluster Number; TP= Total publications; TC= Total Citations; CPP= Citation per paper; TLS= Total Link strengths; CC= Cluster Color
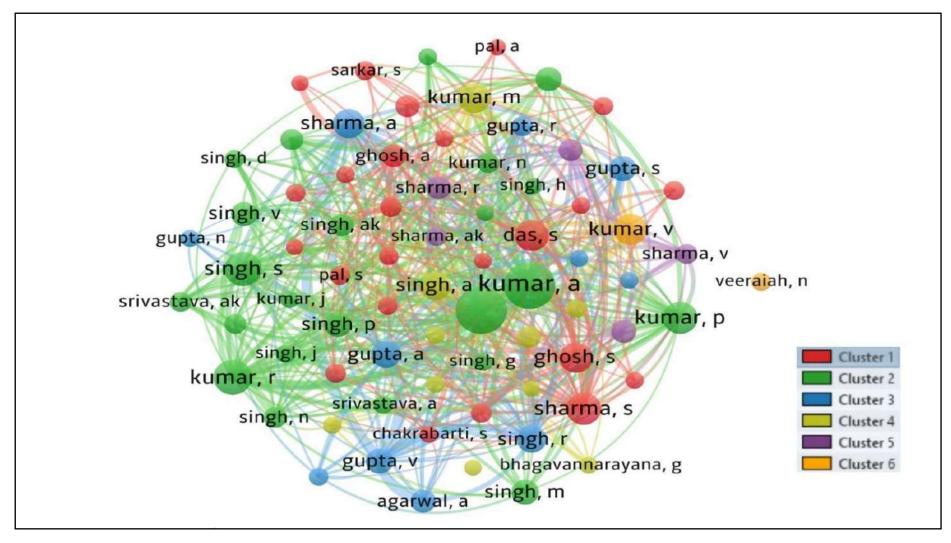
Figure 4.16: Indian Authors Collaboration Network Map

4.12.4. Keyword Co-Occurrence Network Visualisation Analysis

Keyword network analysis, including co-occurrence analysis, is a critical component of bibliometric research. This method allows for the identification and visualization of research trends and hot topics within various academic fields by examining the relationships and frequency of occurrence between keywords. Through this analysis, it is possible to gain insights into the broader scientific landscape and support ongoing research efforts. Additionally, co-occurrence analysis enables a clear understanding of the internal composition relationships and structure within a particular academic domain, revealing the research frontiers of the discipline. As a result, keywords co-occurrence analysis has become a common research method in Scientometrics, offering valuable context and guidance for future studies (Grover et al., 2022; Gupta, Kappi, et al., 2023; Li et al., 2016; Shi et al., 2019).

A total of 112426 keywords were extracted from 89342 Indian optics research publications. However, to better understand the relationship among the documents, a selection condition was set in VOSviewer to identify keywords that appeared more than 200 times in the publications. As a result, 70 author keywords were successfully identified by the software, which were used to create a co-occurrence network with 1729 links and 24505 total link strengths, as shown in Figure 4.17. Each node in the network represents a keyword, and the size of the node corresponds to the frequency of the keyword in the publications. The links connecting the nodes represent the relationship between the keywords.

To analyse the keywords in more detail, they were categorized into different clusters based on their similarities, with each cluster represented by a different color, including red, green, blue, yellow, lavender, and brown. Table 4.40 provides information on the most frequently occurring author keywords in Indian optics

research publications, and their corresponding cluster color and total link strength. The total link strength for each cluster reflects the strength of the interrelation between the keywords within the same cluster.

Cluster 1 (Red) is dominated by keywords related to photoluminescence, nanoparticles, and luminescence. These are important areas of research in materials science and nanotechnology. The top keyword in this cluster is photoluminescence, with 2366 occurrences and a total link strength of 2091, indicating a strong correlation with other keywords in the cluster. Other notable keywords in this cluster include ZNO, band gap, photocatalysis, and fluorescence.

Cluster 2 (Green) focuses on experimental techniques, i.e. X-ray diffraction (XRD), Fourier-Transform Infrared spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and Raman spectroscopy. The top keyword in this cluster is XRD, with 1352 occurrences and a total link strength of 1929. Other keywords in this cluster with high link strengths include FTIR, SEM, and optical absorption.

Cluster 3 (Blue) centers on crystallography and materials characterization. Top keywords in this cluster X-ray diffraction (2270 occurrences, 3607 total link strength) and crystal growth (1045 occurrences, 1620 total link strength). Other keywords in this cluster include microstructure, dielectric properties, and thermal analysis.

Cluster 4 (Yellow) encompasses a wide range of topics, including optical properties, thin films, and chemical synthesis. The top keyword in this cluster is optical properties, with 3959 occurrences and a total link strength of 5462. Other keywords in this cluster with high link strengths include thin films, electrical properties, and chemical synthesis.

Cluster 5 (Lavender) is focused on computational techniques and nonlinear optics. The top keyword in this cluster is DFT (Density Functional Theory), with 780 occurrences and a total link strength of 436. Other keywords in this cluster include nonlinear optics, z-scan, and optical limiting.

Cluster 6 (Brown) is the smallest cluster, consisting of only two keywords: glaucoma and Optical Coherence Tomography (OCT). Both keywords are related to biomedical optics, with glaucoma referring to a common eye disease and OCT being an imaging technique used to diagnose it. The link strengths for both keywords are relatively low, with glaucoma having a total link strength of 19 and OCT having a total link strength of 14.

Overall, the table provides valuable insights into the trends and patterns in Indian optics research, highlighting the key areas of focus and relationships between different keywords. The Total Link Strengths provide additional context, indicating the strength of the correlations between different keywords within each cluster.

Table 4.40: Most Occurred Author Keywords

C No.	Keyword	Occ.	TLS	CC	C No.	Keyword	Occ.	TLS	CC
1	Photoluminescence	2366	2091	Red	2	XRD	1352	1929	Green
1	Nanoparticles	1093	1142	Red	2	FTIR	751	1015	Green
1	Luminescence	958	1178	Red	2	Sem	637	1078	Green
1	ZNO	642	760	Red	2	Raman Spectroscopy	609	757	Green
1	Band Gap	587	608	Red	2	Optical Absorption	584	533	Green
1	Photocatalysis	555	333	Red	2	TEM	387	602	Green
1	Fluorescence	552	250	Red	2	Optical	358	334	Green
1	Thin Film	520	524	Red	2	Glasses	344	431	Green
1	Optical Band Gap	515	507	Red	2	XPS	305	414	Green
1	Sol-Gel	476	538	Red	2	Raman	276	392	Green
1	Refractive Index	418	258	Red	2	AFM	261	394	Green
1	Density Functional Theory	410	235	Red	2	Electrical Conductivity	261	287	Green
1	Nanocomposites	376	342	Red	2	EPR	259	312	Green
1	Surface Plasmon Resonance	359	248	Red	3	X-Ray Diffraction	2270	3607	Blue
1	Zinc Oxide	352	400	Red	3	Crystal Growth	1045	1620	Blue
1	Sensor	338	216	Red	3	Microstructure	679	503	Blue
1	Quantum Dots	320	224	Red	3	Crystal Structure	569	901	Blue
1	Doping	316	381	Red	3	Optical Materials	559	1040	Blue
1	Morphology	313	224	Red	3	Dielectric Properties	527	766	Blue
1	Nanocomposite	309	230	Red	3	Mechanical Properties	499	520	Blue
1	Semiconductor	302	398	Red	3	Characterization	397	439	Blue
1	Defects	291	382	Red	3	Growth From Solutions	342	502	Blue
1	Absorption	281	228	Red	3	Organic Compounds	314	606	Blue
1	Polarization	275	28	Red	3	Nonlinear Optical Materials	267	403	Blue
1	Silver Nanoparticles	273	166	Red	3	Thermal Analysis	257	357	Blue
1	Graphene	261	144	Red	4	Optical Properties	3959	5462	Yellow
1	Photocatalytic Activity	255	195	Red	4	Thin Films	1631	2283	Yellow
1	Annealing	253	339	Red	4	Electrical Properties	637	1185	Yellow
5	DFT	780	436	Lavender	4	Nanostructures	635	1089	Yellow
5	Nonlinear Optics	458	366	Lavender	4	Chemical Synthesis	581	1277	Yellow
5	Z-Scan	429	476	Lavender	4	Semiconductors	570	950	Yellow
5	NLO	367	353	Lavender	4	Spray Pyrolysis	428	539	Yellow
5	Optical Limiting	308	345	Lavender	4	Electron Microscopy	399	708	Yellow
6	Glaucoma	378	19	Brown	4	Structural Properties	398	602	Yellow
6	Optical Coherence Tomography	311	14	Brown	4	Magnetic Properties	388	595	Yellow

C No= Cluster Number; Occ.= Occurrences; TLS= Total Link strengths; CC= Cluster Color
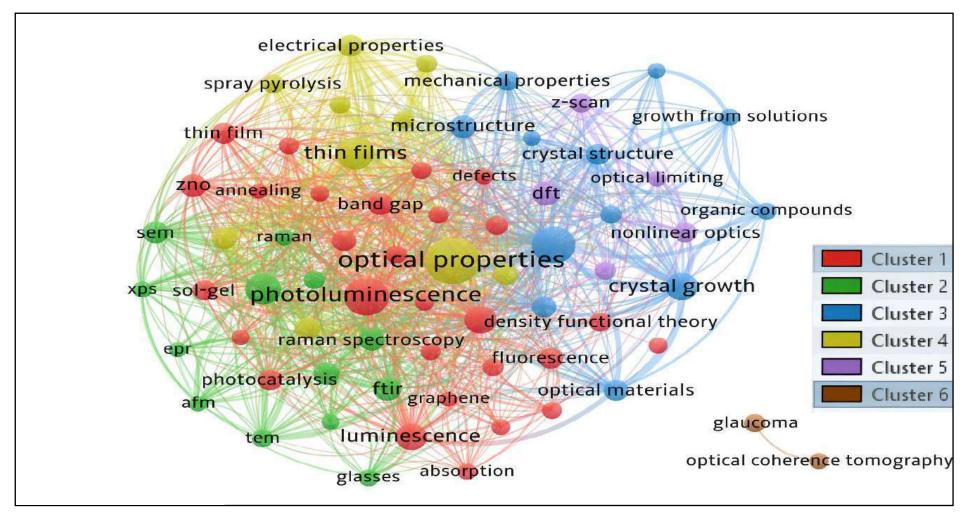
Figure 4.17: Most Occurred Author Keywords Network Map

4.13. Conclusion

This chapter analysed the research output on Indian optics with a variety of scientometrics measures and statistical tools. Further social network analysis was also created to reveal social, theoretical and scholarly organization of Indian optics research during 1992-2021. The results were obtainable in tables, charts, figures along with the interpretations. The next chapter converse and examine the findings and suggestions.

The current chapter is dedicated to presenting an analysis of the research output in the field of Indian optics. In doing so, several scientometric measures and statistical tools were employed to provide a comprehensive understanding of the research landscape. Furthermore, a social network analysis was conducted to reveal the social, theoretical, and scholarly organization of Indian optics research over the last three decades. The findings of this study are presented in various forms, including tables, charts, and figures, and are interpreted to provide meaningful insights. The scientometric measures used in this study include publication and citation counts, impact factor, and h-index. Additionally, various statistical tools such as regression analysis, clustering, and principal component analysis were utilized to provide a comprehensive view of Indian optics research.

The social network analysis conducted in this study provides valuable information about the collaboration and communication patterns within the Indian optics research community. This analysis revealed the key players in the field, as well as the research topics and themes that have received the most attention in recent years. The next chapter will delve deeper into the findings presented in this chapter, examining the implications of the results, and suggesting avenues for future research. It is hoped that the insights gained from this study will contribute to the advancement of the field of Indian optics and inform future research endeavours.

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CHAPTER – V

FINDINGS, SUGGESTIONS, SUGGESTIONS FOR FUTURE STUDY AND CONCLUSION

5.1. Introduction

Chapter V presents the comprehensive findings derived from the extensive research conducted on the Growth and Collaboration Trends in the Field of Indian Optics. This chapter aims to provide a detailed analysis of the data collected and the observations made during the research process. The findings will be presented in a logical and structured manner, highlighting the key results and their implications. Additionally, this chapter will offer valuable suggestions and recommendations based on the findings, which can potentially contribute to the practical application or enhancement of the subject matter. Moreover, it will outline possible avenues for future research, identifying areas that require further exploration or investigation. Finally, the chapter will conclude by summarizing the main findings and their significance, reinforcing the thesis's overall objective, and showcasing the value of the study's contributions.

5.2. Summary of the Retrieved Data on Indian Optics Research

- The dataset covers Indian Optics Research from 1992 to 2021.

- A total of 89,342 documents were collected and analysed in this dataset.

- The documents exhibit an annual growth rate of 3.68% during the study period.

- On average, the age of the documents in the dataset is 8.34 years.

- On average, each document receives 18.79 citations from other works.

- The dataset contains 73,601 instances of Keywords Plus, showcasing diverse topics.

- Authors contributed 112,426 keywords to dataset to contextualize their work.

- A significant number of 120,786 authors have contributed to Indian Optics Research.

- Among the documents, 1,504 are single-authored, indicating individual contributions.

- Collaboration is common, with an average of 4.90 co-authors per document, and 25.57% of collaborations extend internationally.

5.3. Basic Metrics Indicators

5.3.1. Optics Research Performance

- **Gradual Growth of Indian Optics Research:** Over the years 1992 to 2021, India contributed an increasing number of publications in optics research. The number of Indian publications rose from 451 in 1992 to 9383 in 2021, indicating substantial growth.

- **Global Comparison:** The global optics research output also showed growth during the same period. Worldwide publications increased from 23957 in 1992 to 115269 in 2021, signifying a prominent expansion of the field internationally.

- **India's Share of Global Research:** India's contribution to global optics research demonstrated steady growth in terms of its share. The proportion of Indian publications in the global total gradually increased from 1.883% in 1992 to 8.140% in 2021, showcasing a rising impact on the global stage.

- **Citation Impact:** The citations received by Indian optics research provided insight into its influence. The citations for Indian publications increased from 7388 in 1992 to 34508 in 2021, indicating growing recognition within the academic community.

- **Exceptional Growth Rate:** Indian optics research exhibited a notable growth rate over the study period. India's publication output increased by 1877.61%, from 451 publications in 1992 to 9383 publications in 2021, underscoring the vibrant growth trajectory.

- **Relative Global Position:** The comparative analysis of India's research output elucidated its relative standing. India's share of global optics research surged from 1.883% in 1992 to 8.140% in 2021, indicating a substantial ascent in global rankings.

- **Focus on Collaboration:** The collaborative nature of Indian optics research was evident in the increasing trend of publications. Collaborative efforts led to a rise in the number of Indian publications from 451 in 1992 to 9383 in 2021, highlighting collaborative initiatives in the field.

- **Contributions to Knowledge Pool:** The cumulative optics research output over the entire period was substantial. India's cumulative publication count reached 89342 during 1992-2021, contributing significantly to the global pool of knowledge in the optics domain.

- **Steady Annual Increase:** The annual publication counts portrayed a steady growth pattern. Indian optics research consistently witnessed an increase in publications, with each year contributing a larger number of papers to the global discourse.

- **Research Impact:** The cumulative citations received by Indian optics research indicated its impact on the scholarly community. Over the study period, Indian publications garnered a total of 1676529 citations, reflecting the scholarly significance and influence of the research conducted in the country.

5.3.2. Year-wise Activity Index of Indian Optics Publications

- The Activity Index (AI), which is the ratio of Indian optics publications to global optics publications, has increased from 37.556% in 1992 to 162.394% in 2021.

- The year with the highest AI was 2021, with an AI of 162.394%.

- The year with the lowest AI was 1992, with an AI of 37.556%.

- The average AI over the period 1992-2021 was 81.446%.

- The number of Indian optics publications has grown at an average annual rate of 8.6% over the period 1992-2021.

- The AI has grown at an average annual rate of 8.9% over the period 1992-2021.

5.3.3. Year-wise India's Optics research performance with various parameters

- The number of Highly Cited Papers (HCPs) has increased from 10 (64.5%) in 1992 to 1905 (83.4%) in 2021. The number of HCPs has increased significantly over the past three decades. This is a positive sign, as it suggests that Indian optics research is becoming increasingly influential.

- The total number of authors of Indian optics research publications has increased from 394 in 1992 to 81833 in 2021.

- The percentage of non-cited papers (NCP) has decreased from 35.5% in 1992 to 16.6% in 2021.

- The number of funded papers has increased from 2 (0.4%) in 1992 to 5476 (46.3%) in 2021.

- The average number of authors per paper has increased from 8.7 to 9.4.

- The number of funded papers has also increased significantly. This suggests that there is growing support for optics research in India.

- The average number of citations per paper has increased slightly. This suggests that the quality of Indian optics research is improving.

5.3.4. Relative Growth Rate (RGR) and Doubling Time (DT)

- The RGR ranges from 0.738 in 1993 to 0.111 in 2021.

- The DT ranges from 0.806 in 2001 to 2.236 in 2019.

- The mean RGR ranges from 0.440 in 1996 to 0.111 in 2021.

- The mean DT ranges from 1.830 in 1996 to 1.237 in 2019.

- The RGR decreases over time, as shown by the decreasing trend from 0.738 in 1993 to 0.109 in 2020.

- The DT increases over time, as shown by the increasing trend from 0.806 in 2001 to 2.236 in 2019.

- The highest RGR was in 1993 with 0.738, while the lowest was in 2020 with 0.109.

- The highest DT was in 2019 with 2.236, while lowest was in 2001 with 0.806.

- The mean RGR was highest in 1996 with 0.440, while the lowest was in 2021 with 0.111.

- The mean DT was highest in 1996 with 1.830, while the lowest was in 2019 with 1.237.

5.3.5. Annual Ratio of Growth (ARoG) and Annual Growth Rate (AGR)

- The ARoG is a measure expressing how the number of publications in a given year relates to the previous year, indicating whether there was an increase or decrease.

- AGR reflects the proportional change in the number of publications from one year to the next, signifying the rate of growth or decline.

- In 1992, the dataset starts with 451 publications as the initial value, and the corresponding growth and growth rate values are 0 and 0, respectively.

- From 1993 to 1999, there is a consistent positive growth trend in both the ARoG and the AGR, with ratios ranging from 1.091 to 1.098, indicating a gradual increase in publications.

- Notably, 2000 experiences a slight decline in both the ARoG and the AGR, with a ratio of 0.967 and a growth rate of 0.033, possibly suggesting a dip in publication output.

- 2006 stands out as a year of significant growth, with an ARoG of 1.241 and an AGR of 0.241, indicating a substantial increase in publications.

- In 2013, there is another notable spike in growth, with an ARoG of 1.199 and an AGR of 0.199, suggesting a substantial expansion in publications.

- The years 2014 to 2021 continue to witness a positive growth trend, with annual ratios of growth ranging from 1.023 to 1.139, underscoring consistent growth in publications during this period.

5.3.6. Types of Documents Preferred for Communication

- Articles and their Total Citations consistently dominate the landscape of optics research communication, suggesting their central role in scholarly discourse.

- The proportion of articles within the overall document landscape has notably risen from 3.2% in 1992 to 4.7% in 2021, concomitantly reflecting both the increasing emphasis on this communicative form and the consistent growth of Articles from 379 in 1992 to a substantial 8466 in 2021, underlining the escalating dissemination of crucial research findings and encapsulating the evolving scholarly discourse.

- Conference Papers (n=2634) and their corresponding Total Citations (CPTC=40543), although in lower numerical abundance compared to articles, exhibit discernible fluctuations across the chronological spectrum, underscoring

the noteworthy role of conference communications. Notably, the proportion of conference papers has witnessed a decline from 4.2% in 1992 to 3.5% in 2021, implying evolving dynamics within this communicative avenue.

- Editorial Materials (n=707) and Total Citations (EMTC=1714) exhibit a relatively steady presence, suggesting their consistent contribution to the optics research domain.

- Concurrently, Review Articles (n=2807) and their Total Citations (RATC= 157256), while relatively fewer in count compared to articles, enrich the diversity of the communication landscape in optics research. Despite their lower numerical representation, they contribute significantly to the scholarly dialogue. Remarkably, the proportion of reviews has exhibited a consistent stability, hovering around 0.2% across the timeline.

- The various document types including Review Articles, Letters, and Meeting Abstracts highlights the multifaceted nature of scholarly communication within the optics domain.

- Book Chapters (n=34) contribute to the scholarly dialogue in optics, reflecting a collaborative approach to disseminating specialized knowledge.

5.3.7. Language wise distribution of Optics Publications

- English is the dominant language for research publications, accounting for 99.989% of the total. This is followed by Chinese (0.002%), Russian (0.002%), Estonian (0.001%), French (0.001%), German (0.001%), Hungarian (0.001%), Polish (0.001%), Portuguese (0.001%), and Turkish (0.001%).

- The remaining 10 languages together account for only 0.011% of the total research publications. This suggests that English is the lingua franca of research

communication, and that it is essential for researchers to be proficient in English if they want to publish their work in top journals.

- There is a significant variation in the number of research publications in different languages. For example, English has over 89,000 publications, while Estonian only has 1 publication. This suggests that there are some languages that are more popular for research communication than others.

- The number of research publications in English has been steadily increasing over time. This suggests that English is becoming an increasingly important language for research communication.

- The language-wise distribution of publications may have implications for the accessibility and dissemination of research findings to non-English speaking audiences.

5.3.8. Research Area-wise Distribution of Papers

- Materials Science leads as the most popular research area in India, with 26,597 publications and 559,971 citations.

- Physics follows closely as the second most popular research area, boasting 26,558 publications and 574,608 citations.

- Materials Science and Physics are the leading research areas, each contributing around 29.77% of the TP, showcasing their substantial influence on scholarly output.

- Chemistry secures the third position with 19,620 (21.96%) publications and 525,286 citations.

- Optics stands as the fourth most popular research area, presenting 12,857(14.39%) publications and 172,464 citations.

- Engineering ranks fifth in popularity, contributing 10,265 (11.49%) publications and 148,726 citations.

- Ophthalmology holds 8.29% of the total publications, underscoring its relevance in scholarly communication.

- The research area with the highest citation per paper is Science and Technology other topics, with an impressive 25.426 citations per paper.

- In contrast, the research area of Meteorology and Atmospheric Sciences boasts the lowest citation per paper, with 29.572 citations per paper.

5.3.9. Keywords Analysis

- The top 10 keywords account for 22.3% of all keywords used in Indian optics publications.

- 'Optical Properties' emerge as the most frequent keyword, occurring 9683 times, reflecting its central role in Indian optics publications. 'Nanoparticles' hold a prominent place, appearing 5718 times, underscoring their significance in optical research. 'Photoluminescence' is a prevalent keyword with 5126 occurrences, indicating its relevance in the field.

- 'Thin-Films' are commonly addressed, featuring 3500 times, highlighting their prevalence in optical studies. 'Temperature' is a recurring theme, occurring 3241 times, suggesting its impact on optical investigations. Luminescence garners 2890 occurrences, emphasizing its significance within optical research topics. Absorption holds sway, appearing 2688 times, indicating its vital role in optical studies. Films are frequently discussed, featuring 2394 times, showcasing their relevance in optical investigations. X-Ray Diffraction (XRD) emerges frequently, with 2270 occurrences, underlining its importance in optical material analysis.

- The most frequently occurring keyword is "Optical Properties" (9683 occurrences), followed by "Nanoparticles" (5718 occurrences) and "Photoluminescence" (5126 occurrences). These keywords collectively underscore the foundational concepts in optical research.

- The keywords "Optical Properties" and "Nanoparticles" are closely related, as they are both used to describe the properties of materials at the nanoscale. This highlights the significance of nanomaterials in optical studies and their unique characteristics.

- The keyword "Photoluminescence" refers to the emission of light by a material when it is excited by light or another form of radiation. This points to the exploration of light-matter interactions in optical investigations.

- The keywords "Thin Films" (3500 occurrences) and "Films" (2394 occurrences) are also frequently occurring keywords, suggesting that thin films are an important research area in optics. Their usage implies a focus on material properties in reduced dimensions.

- The keywords "Temperature" (3241 occurrences) and "Deposition" (1783 occurrences) are also frequently occurring keywords, suggesting that the study of the effects of temperature and deposition methods on optical properties is an important research area. This signifies the exploration of external influences on optical behavior.

- The keywords "Luminescence" (2890 occurrences) and "Absorption" (2688 occurrences) are also frequently occurring keywords, suggesting that the study of light emission and absorption by materials is an important research area. These keywords emphasize the investigation of light-matter interactions and energy transfer.

- The keywords "Films" and "Thin Films" are often used interchangeably in the literature, but they have slightly different meanings. A film is a thin layer of material, while a thin film is a film that is typically less than 100 nanometers thick. This distinction highlights precision in terminologies used in optical research.

5.4. Author Metrics

5.4.1. Authorship pattern

- **Authorship Diversity:** The majority of publications (70.9%) have two or three authors, followed by single-authored publications (18.2%) and four-authored publications (6.4%).

- **Increasing Collaboration**: The number of publications with five or more authors has steadily increased over the years, growing from 13 in 1992 to 458 in 2021.

- **Year-wise Variation:** Notable year-wise variations in authorship pattern exist. Single-authored publications were more prominent in the early years (1992-2000), while publications with five or more authors dominated in recent years (2017-2021).

- **Cross-Country Comparison:** Authorship patterns vary across countries. Publications from China and the United States tend to have more authors than those from India.

- **Steady Publication Growth:** The data reveals a consistent growth in the number of publications over the years, reflecting the escalating interest and engagement in optics research within India.

- **Collaborative Focus:** Collaboration is prevalent, with the majority of publications involving multiple authors. Around 19.64% have two authors, 25.30% have three authors, and 20.29% have four authors.

- **Shift to Interdisciplinary Collaboration:** Notably, recent years witness a shift towards higher collaboration levels. In 2021, around 73.28% of publications involve four or more authors, indicating a trend towards interdisciplinary and collaborative research.

- **Emergence of Extensive Collaboration:** The emergence of publications with ten or more authors is notable, constituting around 2.75% of total publications in 2021. This points to research teams addressing intricate optical phenomena.

- **Impact of Technological Advances:** Complex optical research, often involving advanced technologies and methodologies, likely contributes to the observed increase in author counts.

- **Interdisciplinary Potential:** The consistent rise in multi-author publications underscores the potential for interdisciplinary research, where experts from diverse fields collaborate to address intricate optical challenges.

5.4.2. Degree of Collaboration

- The DC in Indian optics publications has increased steadily over the years, from 0.887 in 1992 to 0.979 in 2021.

- The DC is higher for publications with more authors.

- The DC also varies by the year of publication, with the highest DC in 2021.

- Collaboration has been evident since the early years of Indian optics research.

- Indian optics research has maintained a strong collaborative ethos over three decades.

- High collaboration implies cross-disciplinary synergy, enhancing the complexity of optical research.

- The increase in DC is a positive trend for the field of optics in India. Collaborative research leads to more innovative and impactful results.

- The increasing availability of funding for collaborative research is also a positive trend. This will help to support the growth of collaborative research in the field of optics in India.

- The variation in DC by the year of publication suggests that the trend towards collaborative research is accelerating. This is likely due to a number of factors, such as the increasing complexity of optical research, the need for interdisciplinary collaboration, and the availability of funding for collaborative research.

5.4.3. Size of Research Team

- **Solo Research:** 2.891% of total publications are solo-authored papers, highlighting individual contributions.

- **Collaborative Duets:** 19.636% of papers are authored by duets, showcasing prevalent collaboration.

- **Very Small Teams:** Teams of 3 to 4 authors contribute significantly with 45.609% of publications, reflecting balanced collaboration.

- **Small Teams:** 29.882% of publications come from teams of 5 to 10 authors, indicating broader collaboration.

- **Medium Teams:** Teams of 11 to 25 authors contribute 1.436% of publications, showcasing larger-scale collaboration.

- **Large Teams:** Teams with 26 or more authors contribute 0.546% of publications, indicating impactful specialized efforts.

- **Collaboration Dominance:** Very small and small teams contribute 75.491% of total publications, emphasizing collaborative efforts.

- **Citation Per Paper Variation:** Larger teams tend to have higher CPP, with large teams having a CPP of 135.004.

- **Balanced Distribution:** The distribution of team sizes highlights a balanced and adaptable collaboration approach.

- **Research Dynamics:** Team sizes vary based on project complexity, reflecting researcher adaptability.

- **Collaborative Impact:** Collaboration across team sizes contributes significantly to total citations, enhancing research visibility.

- The range of team sizes suggests a mature research ecosystem with diverse collaboration models.

- **Holistic Approach:** Various team sizes reflect a holistic research approach catering to diverse project scopes and objectives.

5.4.4. Most Productive/Prolific Authors

- The top 50 most productive authors have published a total of 11775 papers, accounting for 13.2% of all papers published in Indian optics.

- The most productive author is Kumar A from IIT, Kanpur, with 1741 publications.

- The author with the highest CPP is Das, S. from Indian Institute of Technology System, with a CPP of 23.454.

- The author with the highest h-index is Srivastava AK from Deen Dayal Upadhyaya Gorakhpur University, with an h-index of 51.

- The authors from IITs, NITs, and other Central Universities are the most productive.

- The authors from medical institutions are also well-represented in the top 50.

- The authors from state universities and private institutions are also making significant contributions to Indian optics research.

- The top 50 most productive authors are all from India. This suggests that Indian researchers are making significant contributions to the field of optics.

- The most productive authors are also the most cited authors. This suggests that their research is of high quality and is having a significant impact on the field.

- The authors with the highest CPP are also the most cited authors. This suggests that their research is highly cited because it is of high quality and is making a significant impact on the field.

- The authors with the highest h-index are the most established and influential researchers in the field.

- The authors from IITs, NITs, and other Central Universities are the most productive because these institutions have strong research infrastructure and support.

- The authors from medical institutions are also well-represented in the top 50 because optics is a multidisciplinary field and is used in many medical applications.

- The authors from state universities and private institutions are also making significant contributions to Indian optics research. This suggests that the research ecosystem in India is becoming more diverse and inclusive.

5.4.5. Most Impactful Authors

- The top 50 most impactful authors in Indian optics are all highly cited, with an average h-index of 47.

- Most cited author is Kumar S, with h-index of 71 and a total of 35650 citations.

- The second most cited author is Kumar A, with an h-index of 68 and a total of 34729 citations.

- Third most cited author Patil PS, with h-index of 59 and total of 10802 citations.

- The top 50 authors are all from India, with the majority from the Indian Institutes of Technology (IITs).

- The top 50 authors have published a total of 12352 papers, which have received a total of 292399 citations.

- The average CPP for top 50 authors is 23.58, which is significantly higher than the average CPP for all Indian optics authors (14.95).

- The top 50 authors have made significant contributions to the field of optics, and their work has had a major impact on the field.

- The high h-indexes of the top 50 authors indicate that they are highly productive and have made significant contributions to the field.

- The large number of citations received by the top 50 authors' work indicates that their work is highly influential.

- The fact that the top 50 authors are all from India suggests that India is major hub for research in optics.

- The high CPP for the top 50 authors indicates that their work is of high quality and is being cited frequently.

- The significant contributions made by the top 50 authors have helped to advance the field of optics and have made it a more competitive field.

5.4.6. Most Collaborative Authors

- Kumar A and Kumar S lead the list with high collaboration impact, evidenced by their substantial TP (1756 and 1741), TC (29576 and 35052), and elevated CPP (16.843 and 20.133) values, along with notable TLS (1044 and 1034) scores.

- Kumar R and Kumar P demonstrate high collaboration impact, possibly indicative of interdisciplinary collaboration leading to increased citations. They have

significant TP (960 and 829), TC (22029 and 16104), and CPP (22.947 and 19.426) values, along with considerable TLS (672 and 537) scores.

- Singh A and Gupta A exhibit significant number of total citations, reflecting the recognition and visibility of their collaborative research. They show strong TP (635 and 567) and TC (11223 and 10802) values, along with notable CPP (17.674 and 19.051) scores and substantial TLS (537 and 529) scores.

- Gupta V and Sharma A showcase substantial collaboration, leading to high TP (521 and 684) and TC (10413 and 11777) counts. Their notable CPP (19.987 and 17.218) values and substantial TLS (525 and 517) scores reflect their impactful collaborative efforts.

- Singh R and Singh S showcase strong collaboration impact, as evident from their high CPP values (20.102 and 16.666), indicating effective collaborative research leading to higher impact. Their substantial TP (588 and 933) and TC (11820 and 15549) values are supported by substantial TLS (476 and 463) scores.

- Sharma S and Kumar M exhibit a strong balance between collaboration and individual research output. Their significant TP (794 and 707) and TC (12674 and 13736) values, along with balanced CPP (15.962 and 19.429) and moderate TLS (455 and 417) scores, underscore their well-rounded collaborative contributions.

- Ghosh S and Ghosh A strike balance between collaboration impact and citations, suggesting their collaborative work's influence. With considerable TP (720 and 420) and TC (13795 and 9487) values, along with robust CPP (19.160 and 22.588) and notable TLS (323 and 288) scores, their collaborative research makes a significant impact.

- Authors like Mukherjee S and Das S demonstrate substantial collaboration impact despite their relatively lower publication counts, indicating the influence of their

collaborative work on the research landscape. Their noteworthy TLS values (270 and 261) demonstrate their growing collaborative networks.

- High collaborative impact from authors like Singh V and Singh AK suggests the dynamic nature of collaboration within different research contexts. Their substantial TLS (223 and 218) scores showcase their effective collaborative efforts.

- Authors like Sharma N and Singh D exhibit effective collaboration, contributing to impactful research despite specializing in different areas. Their considerable TLS values (214 and 211) highlight the collaborative dynamics in diverse fields of study.

- Authors like Kaur S and Saha S reflect collaborative efforts across institutions, contributing to higher collaboration impact. Their notable TLS values (131 and 121) underscore the significance of inter-institutional collaboration.

- Authors like Bhattacharya S and Kumar B demonstrate effective collaboration leading to notable citation impact. Their considerable TLS values (119 and 120) reflect the collaborative networks that contribute to their research influence.

5.4.7. Co-authorship Index (CAI)

- The CAI for single-author papers has decreased from 391.133 in 1992 to 66.314 in 2020.

- The CAI for three or more author papers has increased from 259.543 in 1992 to 382.669 in 2021.

- The average CAI for Indian optics research publications has increased over time, from 225.32 in 1992 to 377.643 in 2021.

- The CAI for two-author publications has remained relatively stable over time, ranging from 167.123 in 1992 to 99.561 in 2016.

- The increase in CAI is likely due to the increasing complexity of optics research, which requires more collaboration between researchers.

- The number of single-author publications has decreased over time, while the number of two-author and three or more author publications has increased.

- The CAI for publications from IITs and NITs is generally higher than CAI for publications from other institutions.

- The CAI for publications from medical colleges and research institutes is generally lower than the CAI for publications from universities and IITs/NITs.

- The CAI for publications in high-impact journals is generally higher than CAI for publications in other journals.

- The year 2020 is an outlier, with a lower CAI for all three categories of papers. This may be due to the COVID-19 pandemic, which may have disrupted research collaborations.

5.5. Geo-Metrics

5.5.1. Most Collaborative Countries

- India ranks first in terms of TP in Optics research, with a significant number of 89,342 papers.

- The United States is the most collaborative country in optics research, with a total of 5,996 publications and 224,967 citations.

- South Korea is the second most collaborative country, with a total of 2,620 publications and 72,377 citations.

- Germany is the third most collaborative country, with a total of 2,219 publications and 113,141 citations.

- England is the fourth most collaborative country, with a total of 1,892 publications and 104,179 citations.

- Saudi Arabia is the fifth most collaborative country, with a total of 1,850 publications and 38,071 citations.

- The average ACPP for the United States is 37.520, which is significantly higher than the average ACPP for all countries (12.328).

- The average ACPP for South Korea is 27.625, which is also significantly higher than the average ACPP for all countries.

- The top 5 most collaborative countries after omitting India are all developed countries with strong research infrastructures.

- There is a positive correlation between the number of publications and the number of citations, suggesting that more collaborative countries tend to produce more high-quality research.

- European countries like Germany, England, France, Italy, Spain, and Switzerland are prominent contributors to optics research, with substantial publication numbers and notable citation counts.

5.6. Institutions and Publisher Metrics

5.6.1. Most Productive Organisations

- The Indian Institute of Technology (IIT) System is the most productive organization in optics research in India, with a total of 13,478 publications (15.086%), 272,656 citations (18.765%), and a CPP of 20.230.

- The Council of Scientific and Industrial Research (CSIR), India is the second most productive organization, with 6,485 publications (7.259%), 171,663 citations (12.647%), and a CPP of 26.471.

- The Department of Science and Technology (DST), India is the third most productive organization, with 4,970 publications (5.563%), 120,632 citations (9.982%), and a CPP of 24.272.

- The National Institute of Technology (NIT) System is the fourth most productive organization, with 4,780 publications (5.350%), 72,213 citations (5.823%), and a CPP of 15.107.

- Anna University, Chennai is the fifth most productive organization, with 3,597 publications (4.026%), 60,194 citations (4.842%), and a CPP of 16.735.

- The top 10 most productive organizations account for 54.27% of the total publications, 67.84% of the total citations, and 57.99% of the average CPP in optics research in India.

- The IIT system accounts for the largest share of publications, citations, and CPP, which suggests that it is the leading organization in optics research in India.

- CSIR and DST are also major players in optics research in India, with a significant share of publications and citations.

5.6.2. Most Productive Publishers

- Elsevier is most productive publisher in optics research, with a total of 30,466 publications (34.100%), 717,483 citations (23.550%), and a CPP of 23.550.

- Springer is the second most productive publisher, with 10,159 publications (11.371%), 111,109 citations (10.937%), and a CPP of 10.937.

- Wiley is the third most productive publisher, with 4,167 publications (4.664%), 74,469 citations (17.871%), and a CPP of 18.104.

- Taylor & Francis is the fourth most productive publisher, with 4,081 publications (4.568%), 44,391 citations (10.877%), and a CPP of 11.025.

- IOP Publishing Ltd is the fifth most productive publisher, with 3,551 publications (3.975%), 69,396 citations (19.543%), and a CPP of 19.543.

- The top 10 most productive publishers account for 71.17% of the total publications (75.68%), 68.97% of the total citations (74.40%), and 63.67% of the average CPP (67.23%) in optics research.

- Elsevier has the highest CPP, with 23.550 citations per paper. This is 1.24 times higher than the average CPP for all publishers.

- Springer has the second highest CPP, with 10.937 citations per paper. This is 0.82 times higher than the average CPP for all publishers.

- Taylor & Francis has the third highest CPP, with 10.877 citations per paper. This is 0.81 times higher than the average CPP for all publishers.

- The average CPP for the top 10 most productive publishers is 16.446 citations per paper. This is 1.41 times higher than the average CPP for all publishers.

5.6.3. Global Funding Agencies

- The National Science Foundation (NSF) is the most prolific funding agency in optics research, with a total of 982 publications (1.099%) and 18,219 citations (5.88%).

- The European Commission is the second most prolific funding agency, with 838 publications (0.938%) and 15,731 citations (5.07%).

- UK Research Innovation is the third most prolific funding agency, with 734 publications (0.822%) and 13,257 citations (4.23%).

- The National Aeronautics Space Administration (NASA) is the fourth most prolific funding agency, with 595 publications (0.666%) and 10,982 citations (3.47%).

- The United States Department of Health and Human Services (HHS) is fifth most prolific funding agency, with 525 publications (0.588%), 10,381 citations (3.31%).

- The top 10 most prolific funding agencies account for 48.44% of the total publications and 34.50% of the total citations in optics research.

- The NSF has the highest CPP, with 18.219 citations per paper.

- UK Research Innovation has third highest CPP, with 13.257 citations per paper.

- The average CPP for the top 10 most prolific funding agencies is 12.370 citations per paper.

- The top 10 most prolific funding agencies are all from developed countries, with a strong presence from the United States, Europe, and Asia.

- The top 10 most prolific funding agencies are all well-established organizations with a long history of supporting research in optics.

- The top 10 most prolific funding agencies are all active in supporting both basic and applied research in optics.

5.6.4. Indian Funding Agencies

- **Leading Contributor:** The Department of Science and Technology (DST), India is the most prolific funding agency in optics research in India, with a total of 10,780 publications (12.066%).

- **Diverse Support:** Various funding agencies, including the University Grants Commission (8.359%) and Council of Scientific Industrial Research (7.563%), play crucial roles in supporting research.

- **Sector Focus:** Funding agencies like the Department of Atomic Energy (1.648%), Defence Research Development Organisation (0.947%), and Department of Biotechnology (0.894%) allocate resources to different sectors.

- **Educational and Healthcare Impact:** The Ministry of Human Resource Development (0.842%) and Indian Council of Medical Research (0.391%) contribute significantly to education and healthcare research.

- **Space and Technology:** Entities such as the Department of Space (0.178%) and Indian Space Research Organization (0.106%) prioritize space and technology research.

- **Niche Initiatives:** The Department of Science Technology Nano Mission (0.152%) focuses on nano-scale research projects.

- **Educational Institutes:** Renowned institutions like the University of Delhi (0.168%) and Indian Institutes of Technology (IITs) contribute funding for research.

- **State-Level Participation:** State-level organizations like Kerala State Council for Science, Technology, Environment (0.056%) support regional research efforts.

- **Encouraging New Researchers:** Initiatives like the Department of Science Technology Inspire Fellowship (0.056%) provide support for young researchers.

- **Cross-Disciplinary Support:** Ministries such as Ministry of Electronics and Information Technology (0.148%) and Ministry of New and Renewable Energy (0.139%) contribute to multidisciplinary research.

- **Collaborative Ventures:** India Alliance (0.048%) emphasizes collaborative research efforts.

5.7. Journal Metric Indicators

5.7.1. Most Productive Sources

- The top 5 most productive journals in terms of total publications are: Optik (n=1805), Journal of Materials Science-Materials in Electronics (n=1751), Indian Journal of Ophthalmology (1732), Journal of Alloys and Compounds (1296) and Spectrochimica Acta Part A-Molecular and Biomolecular Spectroscopy (n=1184)

- The top 5 most productive journals in terms of total citations are: Optics Letters (TC=12203), Applied Physics Letters (TC=10438), Journal of Physical Chemistry C (TC=18870), Journal of Luminescence (TC=15636) and Journal of Crystal Growth (14193)

- The top 5 journals with the highest CPP are: Applied Surface Science (32.547 CPP), Applied Physics A-Materials Science & Processing (10.664 CPP), Materials Research Express (7.363 CPP), Journal of Physics and Chemistry of Solids (23.061 CPP) and Journal of Physics D-Applied Physics (24.844 CPP)

- The journal with the most HCP is Optics Letters (13)

- The journal with the most total authors is Optics Express (1483) Journals like "Optik" from Elsevier (JCI 2021: 0.89) and "Journal of Alloys and Compounds" (JCI 2021: 1.19) are highly influential in terms of Journal Citation Indicator.

- The total number of publications in the top 50 journals is 31,109, and the total number of citations is 614,326. This means that the average journal in the top 50 has 19.84 citations per paper.

- The top 50 journals account for 34.82% of the total publications and 36.64% of the total citations. This means that a small number of journals are responsible for the majority of the research output and citations in optics.

5.7.2. Zone Wise Distribution of Journals

- Zone 3 has the most number of journals (4214) and the most number of papers (29439), accounting for 95.189% and 32.951% of the total number of journals and papers, respectively.

- Zone 2 has the second most number of journals (176) and the second most number of papers (30388), accounting for 3.976% and 34.013% of the total number of journals and papers, respectively.

- Zone 1 has the least number of journals (37) and the least number of papers (29515), accounting for 0.836% and 33.036% of the total number of journals and papers, respectively.

- There is a clear skewness in the distribution of journals and papers, with Zone 3 dominating the distribution.

- This skewness is likely due to the fact that Zone 3 contains the most prestigious journals, which tend to publish more papers.

- The findings of this study are consistent with the Bradford's law of scattering, which states that the number of journals with a given number of papers decreases as the number of papers increases.

5.8. Citation Analysis

5.8.1. Highly Cited Papers

- The paper with the highest TC is 'Agostinelli S, 2003, Nucl Instrum Methods Phys Res Sect A-Accel Spectrom Dect Assoc Equip', with 15,285 citations. This makes it most influential paper in Indian optics research.

- Various papers in the list have received significant attention from the research community, as evidenced by their high TCpY values. These papers cover diverse

areas of research, including astronomy, biotechnology, physics, materials science, and environmental management.

- The citation counts of these papers demonstrate their impact and influence their respective fields, indicating their contribution to advancing knowledge and research. Some papers are published in prestigious journals such as Nature, Science, The Lancet, and Chemical Reviews, further highlighting their significance.

- The highly cited papers reflect the multidisciplinary nature of Indian optics research, involving various domains and applications. Authors of these papers have made substantial contributions to their respective fields and have gained recognition for their work in the scientific community.

- The findings emphasize the importance of these highly cited papers in shaping the landscape of Indian optics research, serving as valuable references for further studies and advancements.

5.8.2. Distribution of Citations

- The majority of papers (75.09%) received zero citations, indicating that a significant portion of the research output did not garner immediate attention or recognition.

- **Dominance of Lower Citations:** The majority of publications 39758 (53.2%) received citations in the range of 1 to 9, emphasizing that a significant portion of research garnered moderate attention.

- **Impactful Publications:** 1826 (14.7%) publications obtained citations in the range of 100 to 499, indicating a substantial number of impactful contributions that gained recognition in the academic community.

- **Long-Tail Distribution:** The distribution of citations follows a long-tail pattern, wherein a few highly cited papers contribute significantly to the cumulative citation count, while the majority of publications have relatively lower citation counts.

- **Cumulative Influence:** The cumulative impact of citations increases as the citation ranges progress, highlighting the combined recognition garnered by research outputs across various impact levels.

- **Cumulative Total Publications:** The Cumulative Total Publications column provides a growing perspective on the overall scholarly output as citation ranges advance, giving insight into the accumulated scholarly activity.

5.9. Forecasting Metric Indicators

5.9.1. Time Series Analysis of Research Output, Single Authored Papers, and Multi Authored Papers

- The number of Indian optics research papers published has increased over time, from 451 in 1992 to 9383 in 2021.

- The average number of Indian optics research papers published per year has increased from 25.9 to 41.8.

- The peak year for Indian optics research output was 2021, with 9383 papers published.

- The years 2008, 2010, 2011, 2013, 2014, and 2017 also saw a high number of Indian optics research papers published.

- The quadratic trend line fits the data well, suggesting that the growth of Indian optics research output is accelerating.

- The predictions for the next five years are as follows: Year 2022: 10781.14, Year 2023: 11065.28, Year 2024: 11349.42, Year 2025: 11633.56 and Year 2026: 11917.70.

- The number of multi-authored optics research papers published in India has increased over time, from 400 in 1992 to 9187 in 2021.

- The peak year for multi-authored optics research output was 2021, with 9187 papers published.

- The predictions for the next five years are as follows: Year 2022: 11553.68, Year 2023: 11833.09, Year 2024: 12112.50, Year 2025: 12391.91 and Year 2026: 12671.32.

5.10. Indian Optics Research Output Indicators

5.10.1. Collaborative Index (CI), Collaborative Coefficient (CC), Modified Collaborative Coefficient (MCC), and Compound Annual Growth Rate (CAGR)

- The collaboration in Indian optics research has increased over time, as measured by the CI, Lawani CI, CC, and MCC.

- The peak year for collaboration was 2021, with all four measures reaching their highest values that year.

- The years 2008, 2010, 2011, 2013, 2014, 2017, 2018, 2019, 2020, and 2021 also saw high levels of collaboration.

- The years 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, and 2001 saw the lowest levels of collaboration.

- The average CI, Lawani CI, CC, and MCC for the period 1992-2021 are 4.980, 5.010, 0.685, and 0.685, respectively.

- The CAGR of the number of Indian optics research publications from 1992 to 2021 is 19.279%.

- The CAGR has been increasing over time, with the highest growth rate in the period 2018-2021 (6.704%).

- The number of Indian optics research publications has increased from 451 in 1992 to 89342 in 2021.

- The peak year for the number of publications was 2021, with 9383 publications.

- The years 2018, 2019, 2020, and 2021 also saw a high number of publications.

- The years 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, and 2001 saw the lowest number of publications.

5.11. Collaboration Visualisation Network of Countries, Institutions, Authors and Keywords

- Germany, England, Italy, France, Spain, and Russia are the most collaborative countries with India in optics research, forming the red cluster with strong collaborative networks.

- The blue cluster includes the USA, Australia, Canada, Chile, Israel, Mexico, and Argentina, indicating a strong collaborative network with India.

- The National Institute of Technology, Anna University, and Vellore Institute of Technology are the most collaborative Indian organizations in optics research, forming the red cluster with a strong collaborative network.

- University Delhi, the Council of Scientific and Industrial Research (CSIR), and the Indian Institute of Technology Delhi are among the top collaborative organizations, forming the green cluster with a moderate collaborative network.

- Indian Institute of Technology and the Indian Institute of Science are the leading organizations in optics research, forming the blue cluster with a strong collaborative network.

- Sharma, S, Kumar, A, and Kumar, S are the top three authors with the highest total link strengths in Indian optics research publications.

- The red cluster comprises authors with a high number of total publications and moderate to high citation per paper values, indicating their significant contributions to the field.

- The green cluster consists of authors with a high number of total publications and citations, indicating their strong impact in optics research.

- The keyword "Photoluminescence" was the most occurred author keyword in Indian optics research publications, indicating its significant presence in the field.

- The red cluster represents keywords that are frequently mentioned and has a moderate to high total link strength, suggesting their importance in Indian optics research.

- The green cluster includes keywords related to various analytical techniques such as XRD, FTIR, SEM, and Raman Spectroscopy, highlighting their relevance in Indian optics research.

5.12 Suggestions

Based on Optics research in India, here are several suggestions to enhance the growth and impact of this field.

- *Foster Research Collaboration:* Encouraging and promoting collaboration among researchers should be a priority. Collaborative research has been shown to have a positive impact on the quality and visibility of publications. Institutions and funding agencies can facilitate collaborative initiatives, such as joint research

projects, workshops, and conferences, to foster interdisciplinary collaboration and knowledge exchange.

- **_Enhance Funding Support:_** Increasing funding support for optics research enable researchers to undertake more ambitious and high-impact projects. Funding agencies, such as the Department of Science and Technology (DST), University Grants Commission (UGC), and Council of Scientific and Industrial Research (CSIR), should consider allocating dedicated funds for optics research and providing competitive grants to support innovative research ideas.

- **_Promote Interdisciplinary Approaches:_** Optics research often intersects with various disciplines such as materials science, physics, and chemistry. Encouraging interdisciplinary collaborations and promoting cross-disciplinary research lead to breakthroughs and advancements. Institutions should establish interdisciplinary research centers or programs that bring together researchers from different disciplines to address complex research problems.

- **_Strengthen Research Infrastructure:_** Investing in state-of-the-art research infrastructure, including advanced laboratories, testing facilities, and equipment, is crucial for conducting cutting-edge optics research. Institutions should prioritize infrastructure development and upgrade existing facilities to attract and retain talented researchers and provide them with the necessary tools to conduct world-class research.

- **_Support Early-Career Researchers:_** Recognizing the importance of nurturing young talent, institutions and funding agencies should provide dedicated support and mentorship programs for early-career researchers in optics. Initiatives such as research fellowships, grants for early-career scientists, and career development

workshops can help in fostering the growth of young researchers and enable them to make significant contributions to the field.

- ***Promote International Collaborations:*** Strengthening international collaborations can facilitate knowledge exchange, access to advanced research facilities, and joint research projects. Institutions should actively seek partnerships with renowned international institutions and participate in international conferences and workshops to foster collaboration and enhance the global visibility of Indian optics research.

- ***Emphasize Science Communication:*** Efforts should be made to enhance science communication and outreach activities to bridge the gap between researchers and the general public. Researchers should be encouraged to engage in public lectures, science exhibitions, media interactions to disseminate their findings and create awareness about importance of optics research in addressing societal challenges.

By implementing these suggestions, India can further consolidate its position in optics research and contribute to advancements in this field. A collaborative and supportive ecosystem, combined with enhanced funding, infrastructure, and interdisciplinary approaches, will create a conducive environment for researchers to thrive and make impactful contributions to the field of optics.

5.13 Suggestion for Further Study

Based on the findings of the study on optics research in India, several suggestions for further study and research proposed. These suggestions aim to address the gaps, explore new avenues, and contribute to the advancement of optics research in India.

- ***Longitudinal Analysis:*** Conducting a longitudinal analysis of optics research in India provides a deeper understanding of the growth patterns, trends, and shifts

in research output, citations, and collaboration over time. This analysis helps identify the factors influencing the rise and decline of research activity, enabling researchers to make informed predictions and projections for the future.

- *Impact Assessment:* Performing a comprehensive impact assessment of Indian optics research helps evaluate the influence and significance of research output in terms of citations, collaboration networks, and international collaborations. Assessing the impact of research assists in identifying the most impactful research areas, influential authors, and productive institutions, thereby guiding resource allocation and strategic planning.

- *Interdisciplinary Approaches:* Exploring the interdisciplinary aspects of optics research open up new avenues for innovation and knowledge creation. Investigating the intersections between optics and other fields such as materials science, physics, chemistry, and engineering lead to novel applications, technological advancements, and scientific breakthroughs. This interdisciplinary approach foster collaboration across disciplines and promote holistic problem-solving.

- *Research Quality Assessment:* Conducting a comprehensive assessment of research quality in Indian optics publications help identify areas for improvement, enhance the rigor and reliability of research findings, and ensure adherence to international standards and best practices. This assessment includes factors such as experimental design, methodology, data analysis, and reporting practices, ultimately enhancing the credibility and impact of Indian optics research.

- *International Collaborations:* Encouraging and facilitating international collaborations in optics research provide opportunities for knowledge exchange, cross-cultural learning, and shared resources. Strengthening ties with reputed

international institutions, participating in collaborative research projects, and promoting joint publications enhance the global visibility and impact of Indian optics research, while also fostering a global research ecosystem.

By undertaking further studies in these areas, researchers contribute to the continuous growth and development of optics research in India, facilitate knowledge transfer, and drive technological advancements in this field. These suggestions aim to inspire future research endeavors and foster a vibrant research community focused on advancing optics research in India.

5.14 Conclusion

The study on optics research in India has provided a comprehensive analysis of the trends, patterns, and contributions in this field. The findings reveal a significant growth in research output, with India's share of global research output in optics steadily increasing over the years. This indicates the country's growing prominence and contribution to the field. The study confirms the exponential growth pattern in optics research, highlighting the rapid expansion of knowledge in this domain. The analysis of the year-wise activity index reveals a surge in the number of articles and total citations until 2014, followed by a recent decline in total citations despite the increase in articles. This suggests the need for further investigation into the factors influencing citation impact. Collaboration has emerged as a key feature in Indian optics research, with a notable increase in multi-authored papers and a higher degree of collaboration over time. Prolific authors like Kumar A and Kumar S have demonstrated extensive collaboration and significant impact, as reflected in their high citation counts and total link strengths. The study also provides insights into the preferred document types, language distribution, and influential publishers in Indian optics research. The findings can inform policymakers, funding agencies, and

researchers in making informed decisions regarding research collaborations, funding allocations, and publication strategies. Continued emphasis on collaboration, interdisciplinary research, and investment in key research areas will contribute to the further growth and impact of Indian optics research. Overall, this study provides a comprehensive understanding of the Indian optics research landscape and sets the stage for future research and advancements in this field.

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APPENDIX – I

RESEARCHER LIST OF PUBLICATIONS

1. Kappi, M., & Biradar, B. S. (2023). Quantifying the influence of Indian optics research: An index based on three citation indicators. Iberoamerican Journal of Science Measurement and Communication, 3(1). https://doi.org/10.47909 /ijsmc.39

2. Gupta, B. M., Kappi, M., Walke, R., & Biradar, B. S. (2022). Quantum Optics: A Scientometric Assessment of India's Publications during 1996-2021. *Journal of Data Science, Informetrics, and Citation Studies*, *1*(1), 12–21.

3. Kappi, Mallikarjun, & Biradar, B. S. (2022). A Comparative Bibliometric Analysis and Visualization of Indian and South Korean Library and Information Science Research Publications During 2001–2020. *International Journal of Knowledge Content Development & Technology*.

4. Kappi, Mallikarjun, & Biradar, B.S. (2022). Scientometric analysis and visualisation of global information literacy from higher education perspective. *COLLNET Journal of Scientometrics and Information Management*, *16*(1), 125–143.

5. Kappi, Mallikarjun, & Biradar, B. S. (2022). Comparative Analysis of the Research Publications Output, Publication Excellence, and Collaboration Patterns of Indian CSIR-Chemical Sciences Laboratories during last decade. *Journal of Indian Library Association*, *57*(4), 165–181.

6. Kappi, Mallikarjun, & Biradar, B. S. (2022). Twenty-six years of research performance of the Journal of Optics: a bibliometric analysis and future path. *Journal of Optics*, 1–13.

7. Kappi, Mallikarjun, Biradar, B. S., & S, Madhu. (2021). Evaluation of the Indian Top 10 Pharma Education Institutions Research Output listed by National Institutional Ranking Framework (NIRF) 2020: A Scientometric Study. *International Journal of Pharmacy and Pharmaceutical Sciences*, *13*(7), 1–10.

8. Kappi, Mallikarjun, Chaman Sab, M., & Biradar, B. S. (2021). Measuring Research Productivity of 'Universities with Centre with Potential for Excellence in Particular Area (CPEPA) status' in Karnataka State. *DESIDOC Journal of Library & Information Technology*, *41*(5), 358–367.

9. Kappi, Mallikarjun, Sab M, C., Biradar, B. S., & Bagalkoti, V. T. (2021). Bibliometric Study of World COVID-19 Publication Output. *Shanlax International Journal of Arts, Science and Humanities*, *8*(3), 86–95.

10. Kappi, Mallikarjun, & Biradar, B. S. (2020). Bibliometric Analysis of Indian Optics Research: Identifying Knowledge Domain. *Library Philosophy and Practice (e-journal)*.

11. Kappi, Mallikarjun, & Biradar, B. S. (2020). Overview of trends in Indian Optics Research (2008–2018). *Library Philosophy and Practice (e-journal)*.

12. Kappi, Mallikarjun, Biradar, B. S., & Sab M, C. (2020). Current Science: Bibliometric Visualization based on SCOPUS Database. *Kelpro Bulletin*, *24*(2), 11–30.

13. Kappi, Mallikarjun, Biradar, B. S., & Sab M, C. (2020). Measuring and assessing research productivity of Physics Scientist Dr RG Sonkawade. *Library Philosophy and Practice (e-journal)*.

14. Kappi, Mallikarjun, M, Chaman Sab, & Biradar, B. S. (2020). *Measuring Research Productivity of Centre with Potential for Excellence in Particular Area*
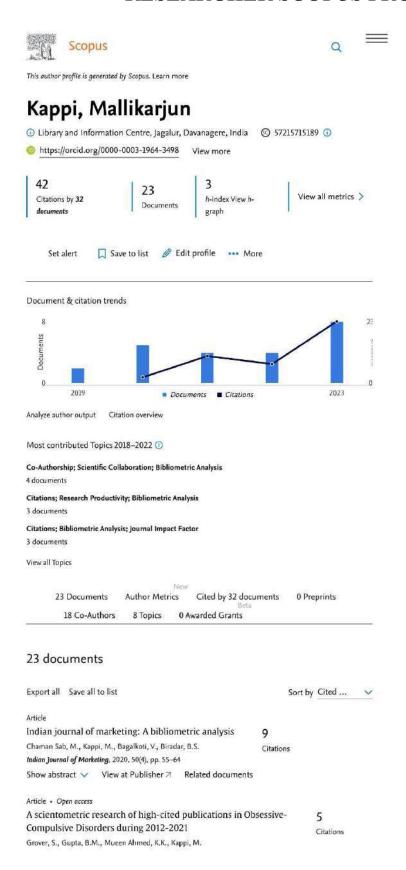
(CPEPA) status in Karnataka state. 43–58. https://doi.org/10.6025/stm/ 2020/2/43-58.

15. Kappi, Mallikarjun, Sab, C., Biradar, B. S., & Bagalkoti, V. T. (2020). Scientometrics Dimensions of World BitCoin Research: A Study Based on Scopus Database. *International Journal of Information Dissemination and Technology*, *10*(2), 82–87.

16. Sab, M. C., Kappi, M., Bagalkoti, V., & Biradar, B. S. (2020). Indian Journal of Marketing: a bibliometric analysis. *Indian Journal of Marketing*, *50*(4), 55–65.

17. Kappi, Mallikarjun, & Biradar, B. S. (2019). Bibliometric Analysis of the Research Output of Kuvempu University's Publication in ISI Web of Science during 1990–2019. *Library Philosophy and Practice (e-journal)*.

Book Chapters

1. Kappi, M., S., M., Biradar, B. S., & Kannappanavar, B. U. (2022, July 27). The Quantitative and Qualitative Assessment of Re-Search Conducted Using Computational Intelligence for the Diagnosis or Treatment of COVID-19. *Advances in Computing Communications and Informatics*. Bentham Science Publishers. http://doi.org/10.2174/9789815040401122030010

2. Kappi, Mallikarjun, Chaman, S. M., Biradar, B. S., & Bagalkoti, V. T. (2022). Coronavirus: a scientometric study of worldwide research publications. *Data Science for COVID-19* (pp. 433–448). Elsevier.

APPENDIX – II

RESEARCHER SCOPUS PROFILE

Scopus

Q

Kappi, Mallikarjun

Library and Information Centre, Jagalur, Davanagere, India   57215715189

https://orcid.org/0000-0003-1964-3498   View more

42 Citations by **32 documents**	**23** Documents	**3** h-index View h-graph	View all metrics >

Set alert   Save to list   Edit profile   ••• More

Document & citation trends

Analyze author output   Citation overview

Most contributed Topics 2018–2022

Co-Authorship; Scientific Collaboration; Bibliometric Analysis
4 documents

Citations; Research Productivity; Bibliometric Analysis
3 documents

Citations; Bibliometric Analysis; Journal Impact Factor
3 documents

View all Topics

23 Documents	Author Metrics	New Cited by 32 documents	0 Preprints
18 Co-Authors	8 Topics	Beta 0 Awarded Grants	

23 documents

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Article
Indian journal of marketing: A bibliometric analysis   9
Chaman Sab, M., Kappi, M., Bagalkoti, V., Biradar, B.S.   Citations
Indian Journal of Marketing, 2020, 50(4), pp. 55–64
Show abstract ∨   View at Publisher ↗   Related documents

Article • Open access
**A scientometric research of high-cited publications in Obsessive-   5
Compulsive Disorders during 2012-2021**   Citations
Grover, S., Gupta, B.M., Mueen Ahmed, K.K., Kappi, M.

301

Iberoamerican Journal of Science Measurement and Communication, 2022, 2(3)

Show abstract ∨   View at Publisher ↗   Related documents

Article

Overview of trends in Indian Optics Research (2008 – 2018)   4

Kappi, M., Biradar, B.S.   Citations

Library Philosophy and Practice, 2020, 20

Show abstract ∨   Related documents

Article • *Open access*

Quantifying the influence of Indian optics research: An index based   3
on three citation indicators   Citations

Kappi, M., Biradar, B.S.

Iberoamerican Journal of Science Measurement and Communication, 2023, 3(1)

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Article

A scientometric analysis of India's publications in arthroplasty in the   3
last two decades from the SCOPUS database   Citations

Vaishya, R., Gupta, B.M., Kappi, M., Vaish, A.

Journal of Clinical Orthopaedics and Trauma, 2022, 34, 102041

Show abstract ∨   View at Publisher ↗   Related documents

Article

Scientometric analysis of Indian Orthopaedic Research in the last two   3
decades   Citations

Vaishya, R., Gupta, B.M., Kappi, M., Vaish, A.

International Orthopaedics, 2022, 46(11), pp. 2471–2481

Show abstract ∨   View at Publisher ↗   Related documents

Article

Prominence and impact of the 'indian journal of finance' during 2013   3
– 2019 using scientometric methods   Citations

Kappi, M., Chaman Sab, M., Kumaraswamy, B.H., Bagalkoti, V.T.

Indian Journal of Finance, 2021, 15(9), pp. 41–56

Show abstract ∨   View at Publisher ↗   Related documents

Article

Bibliometric Analysis of Indian Optics Research: Identifying   3
Knowledge Domain   Citations

Kappi, M., Biradar, B.S.

Library Philosophy and Practice, 2020, 2020

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Article • *Open access*

International Orthopaedics journal: A bibliometric analysis during   2
1977-2022   Citations

Vaishya, R., Gupta, B.M., Kappi, M., Vaish, A.

Iberoamerican Journal of Science Measurement and Communication, 2023, 3(1)

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Covid-19 research in Bangladesh: A scientometric analysis during   1
2020-23   Citations

Gupta, B.M., Kappi, M., Walke, R., Bansal, M.

Iberoamerican Journal of Science Measurement and Communication, 2023, 3(1)

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302

Article

Twenty-six years of research performance of the Journal of Optics: a bibliometric analysis and future path

Kappi, M., Biradar, B.S.

Journal of Optics (India), 2023, 52(1), pp. 77–89

Show abstract ∨   View at Publisher ↗   Related documents

1
Citations

Book Chapter

Coronavirus: A scientometric study of worldwide research publications

Kappi, M., Chaman, S.M., Biradar, B.S., Bagalkoti, V.T.

Data Science for COVID-19: Volume 2: Societal and Medical Perspectives, 2021, pp. 433–448

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1
Citations

Article

Scientometric Visualisation of Fifteen Years of Indian Engineering Research Output

Jaali, S., Bagalkoti, V.T., Chaman Sab, M., Kappi, M.

Library Philosophy and Practice, 2021, 2021, pp. 1–26

Show abstract ∨   Related documents

1
Citations

Article

Visualisation of Asthma Research Output in India during 2010-2019

Mallikarjun, B., KAPPI, M.

Library Philosophy and Practice, 2020, 2020, pp. 1–15

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1
Citations

Article

Bibliometric Analysis of the Research Output of Kuvempu University's Publication in ISI Web of Science during 1990 - 2019

Kappi, M., Biradar, D.B.S.

Library Philosophy and Practice, 2019, 2019, pp. 1–13

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1
Citations

Article

Overview of trends in indian optics research (2008-2018)

Kappi, M., Biradar, B.S.

Library Philosophy and Practice, 2019, 2019, pp. 2–18

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1
Citations

Article • Open access

United Arab Emirates (UAE): A scientometric assessment of Covid-19 publications

Gupta, B.M., Dhawan, S.M., Kappi, M.

Iberoamerican Journal of Science Measurement and Communication, 2023, 3(2)

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Citations

Article • Open access

Covid-19 associated coagulopathy (CAC): Global research output, 2020-2022

Gupta, B.M., Kappi, M.M., Walke, R., Bansal, M., Mandal, A.

Iberoamerican Journal of Science Measurement and Communication, 2023, 3(2)

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Citations

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Fracture research from India between 1989 to 2022: A scientometric study

Vaishya, R., Gupta, B.M., Kappi, M., Vaish, A.

Iberoamerican Journal of Science Measurement and Communication, 2023, 3(1)

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Citations

Research on Non-alcoholic Fatty Liver Disease From Indian Subcontinent: A Bibliometric Analysis of Publications During 2001–2022

0 Citations

Vaishya, R., Gupta, B.M., Kappi, M.M., ...Kuchay, M.S., Vaish, A.

Journal of Clinical and Experimental Hepatology, 2023

Show abstract ∨   View at Publisher ↗   Related documents

Ethnopharmacology Research: A Scientometric Assessment of Indian Publications During 2011 to 2020

0 Citations

Chaman Sab, M., Kappi, M., Mueen Ahmed, K.K.

Journal of Pharmacology and Pharmacotherapeutics, 2022, 13(1), pp. 48–58

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Measuring research productivity of 'universities with centre with potential for excellence in particular area (Cpepa) status' in karnataka state

0 Citations

Kappi, M., Chaman Sab, M., Biradar, B.S.

DESIDOC Journal of Library and Information Technology, 2021, 41(5), pp. 358–367

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Measuring and assessing research productivity of Physics Scientist Dr R. G. Sonkawade

0 Citations

Kappi, M., Biradar, B.S., Sab, C.

Library Philosophy and Practice, 2020, 2020

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Documents	Average citations	FWCI

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Co-author   27%   ∨

Corresponding author   40%   ∨

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304

APPENDIX – III

RESEARCHER WEB OF SCIENCE PROFILE

Web of Science™

Web of Science CV
Prepared on August 28t

Mallikarjun Kappi

https://www.webofscience.com/wos/author/rid/G-5012-2019
Web of Science ResearcherID: G-5012-2019
ORCiD: 0000-0003-1964-3498

Publication Metrics

For manuscripts published from date range August 2010 - August 2

1	4
H-index	Sum of Times Cited
42	10
Total Publications	Web of Science Core Collection Pub

For all time

1	4
H-index	Sum of Times Cited
42	10

Publishing Summary

For manuscripts published from date range August 2010 - Augus

(4) Library Philosophy and Practice (...

(3) Library Philosophy

(2) DESIDOC Journal of Library & Inf...

(2) International Jourr

(2) Iberoamerican Journal of Scienc...

(1) Second Internatio

(1) Indian Journal of Marketing

(1) International Jourr

(1) Shanlax International Journal of ...

(1) International Jourr

(1) Journal of Drug Delivery and The...

(1) Kelpro Bulletin

(1) Pharmacognosy Research

(1) Indian Journal of F

(1) Pharmacognosy Magazine

(1) International Jourr

(1) International Journal of Pharmac...

(1) The Journal of Opt

(1) Journal of Pharmacology and Ph...

(1) Library Herald

(1) International Journal of Clinical a...

(1) International Orth

(1) Collnet Journal of Scientometrics...

(1) Dubai Medical Jou

(1) Journal of Clinical Orthopaedics ...

(1) Apollo Medicine

(1) Journal of Young Pharmacists

Publications

For manuscripts published from date range August 2010 - Augus

Twenty-six years of research performance of the Journal of Optics: bibliometric analysis and future path
Authors (2): Kappi, Mallikarjun; Biradar, B. S.
Published: Mar 2023 in The Journal of Optics
DOI: 10.1007/S12596-022-00849-5
Web of Science accession number: WOS:000776336600001

Fracture research from India between 1989 to 2022: A scientomet
Authors (4): Raju Vaishya; Brij Mohan Gupta ... Abhishek Vaish
Published: Jan 2023 in Iberoamerican Journal of Science Measurer Communication
DOI: 10.47909/IJSMC.35

High-cited publications from the indian orthopedic research in the decades
Authors (5): Abhishek Vaish; Raju Vaishya ... Shuchi Kohli
Published: 2023 in Apollo Medicine
DOI: 10.4103/AM.AM_162_22

Scientometric Assessment of Global Research Output about Monk during 1970-2022
Authors (4): Gupta, Brij Mohan; Kappi, Mallikarjun ... Gupta, Atul
Published: 2023 in Dubai Medical Journal
DOI: 10.1159/000529705
Web of Science accession number: WOS:000963252400001

Scientometric analysis of Indian Orthopaedic Research in the last decades
Authors (4): Vaishya, Raju; Gupta, Brij Mohan ... Vaish, Abhishek
Published: Nov 2022 in International Orthopaedics
DOI: 10.1007/S00264-022-05523-W
Web of Science accession number: WOS:000830256600001

A scientometric analysis of India's publications in arthroplasty in t
decades from the SCOPUS database

Scientometric Mapping of Mucormycosis Research in Relation to t
COVID-19 Pandemic

Authors (3): Devi Dayal; Brij Mohan Gupta; Mallikarjun Kappi

Published: Apr 2022 in International Journal of Medicine and Publi

DOI: 10.5530/IJMEDPH.2022.2.11

Ethnopharmacology Research: A Scientometric Assessment of Ind
Publications During 2011 to 2020

Authors (3): Sab, M. Chaman; Kappi, Mallikarjun; Ahmed, K. K. Mu

Published: Mar 2022 in Journal of Pharmacology and Pharmacoth

DOI: 10.1177/0976500X221082839

Web of Science accession number: WOS:000987282200006

Scientometric analysis and visualisation of global information lite
higher education perspective

Authors (2): Kappi, Mallikarjun; Biradar, B. S.

Published: Jan 2022 in Collnet Journal of Scientometrics and Infor
Management

DOI: 10.1080/09737766.2021.2017763

Web of Science accession number: WOS:000830873200009

Comparative Mapping of World and Indian Nanocellulose Researc
during the last Decade: A Scientometric Study

Authors (4): Kappi, Mallikarjun; Chavali, Murthy ... Ahmed, K. K. Mu

Published: Jan 2022 in International Journal of Pharmaceutical Inv

DOI: 10.5530/IJPI.2022.1.18

Web of Science accession number: WOS:000768519300018

Quantum Optics: A Scientometric Assessment of India's Publicatio
1996-2021

Published: 2022

DOI: 10.5530/JCITATION.1.1.3

Bibliometric Visualisation of Research Performance of Post COVID
Mucormycosis: Where Do We Stand?

EVALUATION OF THE INDIAN TOP 10 PHARMA EDUCATION INSTITUT
RESEARCH OUTPUT LISTED BY NATIONAL INSTITUTIONAL RANKING
FRAMEWORK (NIRF) 2020: A SCIENTOMETRIC STUDY
Authors (3): MALLIKARJUN KAPPI; MADHU S.; BALABHIM SANKRAPP
Published: Jul 2021 in International Journal of Pharmacy and Pharr
Sciences
DOI: 10.22159/IJPPS.2021V13I7.41709

Scientometric Analysis of Pharmacognosy Magazine: A Decade of
Publishing
Authors (3): Sab, M. Chaman; Kappi, Mallikarjun; Ahmed, K. K. Mue
Published: Jul 2021 in Pharmacognosy Magazine
DOI: 10.4103/PM.PM_221_21
Web of Science accession number: WOS:000755312500001

Global Research Productivity on Calotropic sps. Over the Last Deca
(2011-2020): A Bibliometric Evaluation
Authors (3): Sab, Chaman M.; Kappi, Mallikarjun; Ahmed, K. K. Mue
Published: Jul 2021 in Pharmacognosy Research
DOI: 10.5530/PRES.13.3.2
Web of Science accession number: WOS:000756918800002

Bibliometric Study of World COVID-19 Publication Output
Authors (4): Mallikarjun Kappi; M Chaman Sab ... Vitthal T. Bagalko
Published: Jan 2021 in Shanlax International Journal of Arts, Scien
Humanities
DOI: 10.34293/SIJASH.V8I3.3489

Scientometric Visualisation of Fifteen Years of Indian Engineering
Output
Authors (4): Jaali, S.; Bagalkoti, V.T. ... Kappi, M.
Published: 2021 in Library Philosophy and Practice

Covid-19 and Cancer: A Scientometric Assessment of India's Publ[i]
During 2020–21
Authors (3): Mallikarjun Kappi; B.M. Gupta; Jagdish Sharma
Published: 2021 in Library Herald
DOI: 10.5958/0976-2469.2021.00048.8

Measuring Research Productivity of Centre with Potential for Excel[l]
Particular Area (CPEPA) status in Karnataka state
Authors (3): Mallikarjun Kappi; Chaman Sab M; Balabhim Sankrap
Published: Dec 2020 in Second International Conference on Scien[ce]
Technology Metrics
DOI: 10.6025/STM/2020/2/43-58

Indian Journal of Marketing : A Bibliometric Analysis
Authors (4): M. Chaman Sab; Mallikarjun Kappi ... B. S. Biradar
Published: Apr 2020 in Indian Journal of Marketing
DOI: 10.17010/IJOM/2020/V50/I4/151574

Bibliometric Analysis of Indian Optics Research: Identifying Knowl[e]
Domain
Published: 2020 in Library Philosophy and Practice (e-journal)

Overview of trends in Indian Optics Research (2008--2018)
Published: 2020 in Library Philosophy and Practice (e-journal)

Visualisation of Asthma Research Output in India during 2010-201[
Published: 2020

Current Science: Bibliometric Visualization based on SCOPUS Dat[a
Published: 2020 in Kelpro Bulletin

Overview of trends in indian optics research (2008-2018)
Authors (2): Kappi, M.; Biradar, B.S.
Published: 2019 in Library Philosophy and Practice

Bibliometric Analysis of the Research Output of Kuvempu Unive
Publication in ISI Web of Science during 1990—2019
Published: 2019 in Library Philosophy and Practice (e-journal)

Managing Modern Libraries: Challenges for Academic Libraries
Century
Published: Nov 2018 in International Journal of Emerging Techn
Innovative Research

Knowledge Management in Academic Libraries in Changing En
Overview
Published: 2018

Changing Role of Library and Information Professionals in Digit
Published: 2010

Verified reviews

1 REVIEWS OF 1 MANUSCRIPTS
For manuscripts published from date range August 2010 - Augu

-

Reviewed for Journal of Information Science

APPENDIX – IV

RESEARCHER GOOGLE SCHOLAR PROFILE

Mallikarjun Kappi

Other names ▸

Research Scholar, Kuvempu University and Librarian, Government First Grade College, Hospet

Library and Information Science
Scientometrics
Bibliometrics
Knowledge Management

	All	Since 2018
Citations	129	126
h-index	6	6
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0 articles   4 articles

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TITLE	CITED BY	YEAR
Indian Journal of Marketing: a bibliometric analysis MC Sab, M Kappi, V Bagalkoti, BS Biradar Indian Journal of Marketing 50 (4), 55-65	16	2020
Data Science for COVID-19: Volume 2: Societal and Medical Perspectives U Kose, D Gupta, VHC de Albuquerque, A Khanna Academic Press	10	2021
Overview of trends in Indian Optics Research (2008–2018) M Kappi, BS Biradar Library Philosophy and Practice (e-journal)	9	2020
Bibliometric Study of World COVID-19 Publication Output M Kappi, C Sab M, BS Biradar, VT Bagalkoti Shanlax International Journal of Arts, Science and Humanities 8 (3), 86-95	8	2021
Bibliometric Analysis of Indian Optics Research: Identifying Knowledge Domain M Kappi, BS Biradar Library Philosophy and Practice (e-journal)	7	2020
A scientometric research of high-cited publications in Obsessive-Compulsive Disorders during 2012-2021 S Grover, BM Gupta, KKM Ahmed, M Kappi	6 *	2022
Scientometrics Dimensions of World BitCoin Research: A Study Based On Scopus Database M Kappi, C Sab, BS Biradar, VT Bagalkoti International Journal of Information Dissemination and Technology 10 (2), 82-87	6 *	2020
Scientometric analysis of Indian orthopaedic research in the last two decades R Vaishya, BM Gupta, M Kappi, A Vaish International Orthopaedics 46 (11), 2471-2481	5	2022
Bibliometric visualisation of research performance of post COVID-19 and mucormycosis: where do we stand? K Mallikarjun, B Mallikarjun, T Vidyashree Journal of Drug Delivery and Therapeutics 11 (6), 31-39	5	2021
Visualisation of Asthma Research Output in India during 2010-2019 M B, M Kappi https://digitalcommons.unl.edu/libphilprac	5 *	2020
Managing Modern Libraries: Challenges for Academic Libraries in the 21st Century M Kappi, C S	5	2018

TITLE	CITED BY	YEAR
International Journal of Emerging Technologies and Innovative Research 5 (11 …		
International Orthopaedics journal: A bibliometric analysis during 1977-2022 R Vaishya, BM Gupta, M Kappi, A Vaish Iberoamerican Journal of Science Measurement and Communication 3 (1)	4	2023
Twenty-six years of research performance of the Journal of Optics: a bibliometric analysis and future path M Kappi, BS Biradar Journal of Optics 52 (1), 77-89	4	2023
Current Science: Bibliometric Visualization based on SCOPUS Database M Kappi, BS Biradar, C Sab M Kelpro Bulletin 24 (2), 11-30	4	2020
Bibliometric Analysis of the Research Output of Kuvempu University's Publication in ISI Web of Science during 1990–2019 M Kappi, BS Biradar Library Philosophy and Practice (e-journal)	4	2019
Quantifying the influence of Indian optics research: An index based on three citation indicators M Kappi, BS Biradar Iberoamerican Journal of Science Measurement and Communication 3 (1)	3	2023
A scientometric analysis of India's publications in arthroplasty in the last two decades from the SCOPUS database R Vaishya, BM Gupta, M Kappi, A Vaish Journal of Clinical Orthopaedics and Trauma 34, 102041	3	2022
Prominence and Impact of the 'Indian Journal of Finance' During 2013 – 2019 Using Scientometric Methods M Kappi, CS M, K BH, VT Bagalkoti Indian Journal of Finance 15 (9), 41-56	3	2021
Covid-19 research in Bangladesh: A scientometric analysis during 2020-23 BM Gupta, M Kappi, R Walke, M Bansal Iberoamerican Journal of Science Measurement and Communication 3 (1)	2	2023
Scientometric analysis and visualisation of global information literacy from higher education perspective M Kappi, BS Biradar COLLNET Journal of Scientometrics and Information Management 16 (1), 125-143	2	2022
Ethnopharmacology Research: A Scientometric Assessment of Indian Publications During 2011 to 2020 M Chaman Sab, M Kappi, KKM Ahmed Journal of Pharmacology and Pharmacotherapeutics. https://doi. org/10.1177 …	2	2022
Scientometric mapping of mucormycosis research in relation to the COVID-19 pandemic D Dayal, BM Gupta, M Kappi International Journal of Medicine and Public Health 12 (2)	2	2022
Measuring Research Productivity of 'Universities with Centre with Potential for Excellence in Particular Area (CPEPA) status' in Karnataka State M Kappi, BS Biradar	2	2021

313

TITLE	CITED BY	YEAR
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GROWTH AND COLLABORATION TRENDS
IN THE FIELD OF INDIAN OPTICS RESEARCH:
A SCIENTOMETRIC ANALYSIS

**Thesis Submitted to the Faculty of Science and Technology,
Kuvempu University for the Award of the Degree of**

DOCTOR OF PHILOSOPHY
IN
LIBRARY AND INFORMATION SCIENCE

Submitted by

MALLIKARJUNA KAPPI
Research Scholar

Guide

Dr. B.S. BIRADAR
**Professor
Department of P.G. Studies and Research in
Library and Information Science**

DEPARTMENT OF P.G. STUDIES AND RESEARCH
IN LIBRARY AND INFORMATION SCIENCE,
KUVEMPU UNIVERSITY, JNANA SAHYADRI,
SHANKARAGHATTA-577451,
SHIVAMOGGA, KARNATAKA

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CHAPTER – V

FINDINGS, SUGGESTIONS, SUGGESTIONS FOR FUTURE STUDY AND CONCLUSION

5.1. Introduction

Chapter V presents the comprehensive findings derived from the extensive research conducted on the Growth and Collaboration Trends in the Field of Indian Optics. This chapter aims to provide a detailed analysis of the data collected and the observations made during the research process. The findings will be presented in a logical and structured manner, highlighting the key results and their implications. Additionally, this chapter will offer valuable suggestions and recommendations based on the findings, which can potentially contribute to the practical application or enhancement of the subject matter. Moreover, it will outline possible avenues for future research, identifying areas that require further exploration or investigation. Finally, the chapter will conclude by summarizing the main findings and their significance, reinforcing the thesis's overall objective, and showcasing the value of the study's contributions.

5.2. Summary of the Retrieved Data on Indian Optics Research

- The dataset covers Indian Optics Research from 1992 to 2021.

- A total of 89,342 documents were collected and analysed in this dataset.

- The documents exhibit an annual growth rate of 3.68% during the study period.

- On average, the age of the documents in the dataset is 8.34 years.

- On average, each document receives 18.79 citations from other works.

- The dataset contains 73,601 instances of Keywords Plus, showcasing diverse topics.

- Authors contributed 112,426 keywords to dataset to contextualize their work.

- A significant number of 120,786 authors have contributed to Indian Optics Research.

- Among the documents, 1,504 are single-authored, indicating individual contributions.

- Collaboration is common, with an average of 4.90 co-authors per document, and 25.57% of collaborations extend internationally.

5.3. Basic Metrics Indicators

5.3.1. Optics Research Performance

- **Gradual Growth of Indian Optics Research:** Over the years 1992 to 2021, India contributed an increasing number of publications in optics research. The number of Indian publications rose from 451 in 1992 to 9383 in 2021, indicating substantial growth.

- **Global Comparison:** The global optics research output also showed growth during the same period. Worldwide publications increased from 23957 in 1992 to 115269 in 2021, signifying a prominent expansion of the field internationally.

- **India's Share of Global Research:** India's contribution to global optics research demonstrated steady growth in terms of its share. The proportion of Indian publications in the global total gradually increased from 1.883% in 1992 to 8.140% in 2021, showcasing a rising impact on the global stage.

- **Citation Impact:** The citations received by Indian optics research provided insight into its influence. The citations for Indian publications increased from 7388 in 1992 to 34508 in 2021, indicating growing recognition within the academic community.

- **Exceptional Growth Rate:** Indian optics research exhibited a notable growth rate over the study period. India's publication output increased by 1877.61%, from 451 publications in 1992 to 9383 publications in 2021, underscoring the vibrant growth trajectory.

- **Relative Global Position:** The comparative analysis of India's research output elucidated its relative standing. India's share of global optics research surged from 1.883% in 1992 to 8.140% in 2021, indicating a substantial ascent in global rankings.

- **Focus on Collaboration:** The collaborative nature of Indian optics research was evident in the increasing trend of publications. Collaborative efforts led to a rise in the number of Indian publications from 451 in 1992 to 9383 in 2021, highlighting collaborative initiatives in the field.

- **Contributions to Knowledge Pool:** The cumulative optics research output over the entire period was substantial. India's cumulative publication count reached 89342 during 1992-2021, contributing significantly to the global pool of knowledge in the optics domain.

- **Steady Annual Increase:** The annual publication counts portrayed a steady growth pattern. Indian optics research consistently witnessed an increase in publications, with each year contributing a larger number of papers to the global discourse.

- **Research Impact:** The cumulative citations received by Indian optics research indicated its impact on the scholarly community. Over the study period, Indian publications garnered a total of 1676529 citations, reflecting the scholarly significance and influence of the research conducted in the country.

5.3.2. Year-wise Activity Index of Indian Optics Publications

- The Activity Index (AI), which is the ratio of Indian optics publications to global optics publications, has increased from 37.556% in 1992 to 162.394% in 2021.

- The year with the highest AI was 2021, with an AI of 162.394%.

- The year with the lowest AI was 1992, with an AI of 37.556%.

- The average AI over the period 1992-2021 was 81.446%.

- The number of Indian optics publications has grown at an average annual rate of 8.6% over the period 1992-2021.

- The AI has grown at an average annual rate of 8.9% over the period 1992-2021.

5.3.3. Year-wise India's Optics research performance with various parameters

- The number of Highly Cited Papers (HCPs) has increased from 10 (64.5%) in 1992 to 1905 (83.4%) in 2021. The number of HCPs has increased significantly over the past three decades. This is a positive sign, as it suggests that Indian optics research is becoming increasingly influential.

- The total number of authors of Indian optics research publications has increased from 394 in 1992 to 81833 in 2021.

- The percentage of non-cited papers (NCP) has decreased from 35.5% in 1992 to 16.6% in 2021.

- The number of funded papers has increased from 2 (0.4%) in 1992 to 5476 (46.3%) in 2021.

- The average number of authors per paper has increased from 8.7 to 9.4.

- The number of funded papers has also increased significantly. This suggests that there is growing support for optics research in India.

- The average number of citations per paper has increased slightly. This suggests that the quality of Indian optics research is improving.

5.3.4. Relative Growth Rate (RGR) and Doubling Time (DT)

- The RGR ranges from 0.738 in 1993 to 0.111 in 2021.

- The DT ranges from 0.806 in 2001 to 2.236 in 2019.

- The mean RGR ranges from 0.440 in 1996 to 0.111 in 2021.

- The mean DT ranges from 1.830 in 1996 to 1.237 in 2019.

- The RGR decreases over time, as shown by the decreasing trend from 0.738 in 1993 to 0.109 in 2020.

- The DT increases over time, as shown by the increasing trend from 0.806 in 2001 to 2.236 in 2019.

- The highest RGR was in 1993 with 0.738, while the lowest was in 2020 with 0.109.

- The highest DT was in 2019 with 2.236, while lowest was in 2001 with 0.806.

- The mean RGR was highest in 1996 with 0.440, while the lowest was in 2021 with 0.111.

- The mean DT was highest in 1996 with 1.830, while the lowest was in 2019 with 1.237.

5.3.5. Annual Ratio of Growth (ARoG) and Annual Growth Rate (AGR)

- The ARoG is a measure expressing how the number of publications in a given year relates to the previous year, indicating whether there was an increase or decrease.

- AGR reflects the proportional change in the number of publications from one year to the next, signifying the rate of growth or decline.

- In 1992, the dataset starts with 451 publications as the initial value, and the corresponding growth and growth rate values are 0 and 0, respectively.

- From 1993 to 1999, there is a consistent positive growth trend in both the ARoG and the AGR, with ratios ranging from 1.091 to 1.098, indicating a gradual increase in publications.

- Notably, 2000 experiences a slight decline in both the ARoG and the AGR, with a ratio of 0.967 and a growth rate of 0.033, possibly suggesting a dip in publication output.

- 2006 stands out as a year of significant growth, with an ARoG of 1.241 and an AGR of 0.241, indicating a substantial increase in publications.

- In 2013, there is another notable spike in growth, with an ARoG of 1.199 and an AGR of 0.199, suggesting a substantial expansion in publications.

- The years 2014 to 2021 continue to witness a positive growth trend, with annual ratios of growth ranging from 1.023 to 1.139, underscoring consistent growth in publications during this period.

5.3.6. Types of Documents Preferred for Communication

- Articles and their Total Citations consistently dominate the landscape of optics research communication, suggesting their central role in scholarly discourse.

- The proportion of articles within the overall document landscape has notably risen from 3.2% in 1992 to 4.7% in 2021, concomitantly reflecting both the increasing emphasis on this communicative form and the consistent growth of Articles from 379 in 1992 to a substantial 8466 in 2021, underlining the escalating dissemination of crucial research findings and encapsulating the evolving scholarly discourse.

- Conference Papers (n=2634) and their corresponding Total Citations (CPTC=40543), although in lower numerical abundance compared to articles, exhibit discernible fluctuations across the chronological spectrum, underscoring

the noteworthy role of conference communications. Notably, the proportion of conference papers has witnessed a decline from 4.2% in 1992 to 3.5% in 2021, implying evolving dynamics within this communicative avenue.

- Editorial Materials (n=707) and Total Citations (EMTC=1714) exhibit a relatively steady presence, suggesting their consistent contribution to the optics research domain.

- Concurrently, Review Articles (n=2807) and their Total Citations (RATC= 157256), while relatively fewer in count compared to articles, enrich the diversity of the communication landscape in optics research. Despite their lower numerical representation, they contribute significantly to the scholarly dialogue. Remarkably, the proportion of reviews has exhibited a consistent stability, hovering around 0.2% across the timeline.

- The various document types including Review Articles, Letters, and Meeting Abstracts highlights the multifaceted nature of scholarly communication within the optics domain.

- Book Chapters (n=34) contribute to the scholarly dialogue in optics, reflecting a collaborative approach to disseminating specialized knowledge.

5.3.7. Language wise distribution of Optics Publications

- English is the dominant language for research publications, accounting for 99.989% of the total. This is followed by Chinese (0.002%), Russian (0.002%), Estonian (0.001%), French (0.001%), German (0.001%), Hungarian (0.001%), Polish (0.001%), Portuguese (0.001%), and Turkish (0.001%).

- The remaining 10 languages together account for only 0.011% of the total research publications. This suggests that English is the lingua franca of research

communication, and that it is essential for researchers to be proficient in English if they want to publish their work in top journals.

- There is a significant variation in the number of research publications in different languages. For example, English has over 89,000 publications, while Estonian only has 1 publication. This suggests that there are some languages that are more popular for research communication than others.

- The number of research publications in English has been steadily increasing over time. This suggests that English is becoming an increasingly important language for research communication.

- The language-wise distribution of publications may have implications for the accessibility and dissemination of research findings to non-English speaking audiences.

5.3.8. Research Area-wise Distribution of Papers

- Materials Science leads as the most popular research area in India, with 26,597 publications and 559,971 citations.

- Physics follows closely as the second most popular research area, boasting 26,558 publications and 574,608 citations.

- Materials Science and Physics are the leading research areas, each contributing around 29.77% of the TP, showcasing their substantial influence on scholarly output.

- Chemistry secures the third position with 19,620 (21.96%) publications and 525,286 citations.

- Optics stands as the fourth most popular research area, presenting 12,857(14.39%) publications and 172,464 citations.

- Engineering ranks fifth in popularity, contributing 10,265 (11.49%) publications and 148,726 citations.

- Ophthalmology holds 8.29% of the total publications, underscoring its relevance in scholarly communication.

- The research area with the highest citation per paper is Science and Technology other topics, with an impressive 25.426 citations per paper.

- In contrast, the research area of Meteorology and Atmospheric Sciences boasts the lowest citation per paper, with 29.572 citations per paper.

5.3.9. Keywords Analysis

- The top 10 keywords account for 22.3% of all keywords used in Indian optics publications.

- 'Optical Properties' emerge as the most frequent keyword, occurring 9683 times, reflecting its central role in Indian optics publications. 'Nanoparticles' hold a prominent place, appearing 5718 times, underscoring their significance in optical research. 'Photoluminescence' is a prevalent keyword with 5126 occurrences, indicating its relevance in the field.

- 'Thin-Films' are commonly addressed, featuring 3500 times, highlighting their prevalence in optical studies. 'Temperature' is a recurring theme, occurring 3241 times, suggesting its impact on optical investigations. Luminescence garners 2890 occurrences, emphasizing its significance within optical research topics. Absorption holds sway, appearing 2688 times, indicating its vital role in optical studies. Films are frequently discussed, featuring 2394 times, showcasing their relevance in optical investigations. X-Ray Diffraction (XRD) emerges frequently, with 2270 occurrences, underlining its importance in optical material analysis.

- The most frequently occurring keyword is "Optical Properties" (9683 occurrences), followed by "Nanoparticles" (5718 occurrences) and "Photoluminescence" (5126 occurrences). These keywords collectively underscore the foundational concepts in optical research.

- The keywords "Optical Properties" and "Nanoparticles" are closely related, as they are both used to describe the properties of materials at the nanoscale. This highlights the significance of nanomaterials in optical studies and their unique characteristics.

- The keyword "Photoluminescence" refers to the emission of light by a material when it is excited by light or another form of radiation. This points to the exploration of light-matter interactions in optical investigations.

- The keywords "Thin Films" (3500 occurrences) and "Films" (2394 occurrences) are also frequently occurring keywords, suggesting that thin films are an important research area in optics. Their usage implies a focus on material properties in reduced dimensions.

- The keywords "Temperature" (3241 occurrences) and "Deposition" (1783 occurrences) are also frequently occurring keywords, suggesting that the study of the effects of temperature and deposition methods on optical properties is an important research area. This signifies the exploration of external influences on optical behavior.

- The keywords "Luminescence" (2890 occurrences) and "Absorption" (2688 occurrences) are also frequently occurring keywords, suggesting that the study of light emission and absorption by materials is an important research area. These keywords emphasize the investigation of light-matter interactions and energy transfer.

- The keywords "Films" and "Thin Films" are often used interchangeably in the literature, but they have slightly different meanings. A film is a thin layer of material, while a thin film is a film that is typically less than 100 nanometers thick. This distinction highlights precision in terminologies used in optical research.

5.4. Author Metrics

5.4.1. Authorship pattern

- **Authorship Diversity:** The majority of publications (70.9%) have two or three authors, followed by single-authored publications (18.2%) and four-authored publications (6.4%).

- **Increasing Collaboration**: The number of publications with five or more authors has steadily increased over the years, growing from 13 in 1992 to 458 in 2021.

- **Year-wise Variation:** Notable year-wise variations in authorship pattern exist. Single-authored publications were more prominent in the early years (1992-2000), while publications with five or more authors dominated in recent years (2017-2021).

- **Cross-Country Comparison:** Authorship patterns vary across countries. Publications from China and the United States tend to have more authors than those from India.

- **Steady Publication Growth:** The data reveals a consistent growth in the number of publications over the years, reflecting the escalating interest and engagement in optics research within India.

- **Collaborative Focus:** Collaboration is prevalent, with the majority of publications involving multiple authors. Around 19.64% have two authors, 25.30% have three authors, and 20.29% have four authors.

- **Shift to Interdisciplinary Collaboration:** Notably, recent years witness a shift towards higher collaboration levels. In 2021, around 73.28% of publications involve four or more authors, indicating a trend towards interdisciplinary and collaborative research.

- **Emergence of Extensive Collaboration:** The emergence of publications with ten or more authors is notable, constituting around 2.75% of total publications in 2021. This points to research teams addressing intricate optical phenomena.

- **Impact of Technological Advances:** Complex optical research, often involving advanced technologies and methodologies, likely contributes to the observed increase in author counts.

- **Interdisciplinary Potential:** The consistent rise in multi-author publications underscores the potential for interdisciplinary research, where experts from diverse fields collaborate to address intricate optical challenges.

5.4.2. Degree of Collaboration

- The DC in Indian optics publications has increased steadily over the years, from 0.887 in 1992 to 0.979 in 2021.

- The DC is higher for publications with more authors.

- The DC also varies by the year of publication, with the highest DC in 2021.

- Collaboration has been evident since the early years of Indian optics research.

- Indian optics research has maintained a strong collaborative ethos over three decades.

- High collaboration implies cross-disciplinary synergy, enhancing the complexity of optical research.

- The increase in DC is a positive trend for the field of optics in India. Collaborative research leads to more innovative and impactful results.

- The increasing availability of funding for collaborative research is also a positive trend. This will help to support the growth of collaborative research in the field of optics in India.

- The variation in DC by the year of publication suggests that the trend towards collaborative research is accelerating. This is likely due to a number of factors, such as the increasing complexity of optical research, the need for interdisciplinary collaboration, and the availability of funding for collaborative research.

5.4.3. Size of Research Team

- **Solo Research:** 2.891% of total publications are solo-authored papers, highlighting individual contributions.

- **Collaborative Duets:** 19.636% of papers are authored by duets, showcasing prevalent collaboration.

- **Very Small Teams:** Teams of 3 to 4 authors contribute significantly with 45.609% of publications, reflecting balanced collaboration.

- **Small Teams:** 29.882% of publications come from teams of 5 to 10 authors, indicating broader collaboration.

- **Medium Teams:** Teams of 11 to 25 authors contribute 1.436% of publications, showcasing larger-scale collaboration.

- **Large Teams:** Teams with 26 or more authors contribute 0.546% of publications, indicating impactful specialized efforts.

- **Collaboration Dominance:** Very small and small teams contribute 75.491% of total publications, emphasizing collaborative efforts.

- **Citation Per Paper Variation:** Larger teams tend to have higher CPP, with large teams having a CPP of 135.004.

- **Balanced Distribution:** The distribution of team sizes highlights a balanced and adaptable collaboration approach.

- **Research Dynamics:** Team sizes vary based on project complexity, reflecting researcher adaptability.

- **Collaborative Impact:** Collaboration across team sizes contributes significantly to total citations, enhancing research visibility.

- The range of team sizes suggests a mature research ecosystem with diverse collaboration models.

- **Holistic Approach:** Various team sizes reflect a holistic research approach catering to diverse project scopes and objectives.

5.4.4. Most Productive/Prolific Authors

- The top 50 most productive authors have published a total of 11775 papers, accounting for 13.2% of all papers published in Indian optics.

- The most productive author is Kumar A from IIT, Kanpur, with 1741 publications.

- The author with the highest CPP is Das, S. from Indian Institute of Technology System, with a CPP of 23.454.

- The author with the highest h-index is Srivastava AK from Deen Dayal Upadhyaya Gorakhpur University, with an h-index of 51.

- The authors from IITs, NITs, and other Central Universities are the most productive.

- The authors from medical institutions are also well-represented in the top 50.

- The authors from state universities and private institutions are also making significant contributions to Indian optics research.

- The top 50 most productive authors are all from India. This suggests that Indian researchers are making significant contributions to the field of optics.

- The most productive authors are also the most cited authors. This suggests that their research is of high quality and is having a significant impact on the field.

- The authors with the highest CPP are also the most cited authors. This suggests that their research is highly cited because it is of high quality and is making a significant impact on the field.

- The authors with the highest h-index are the most established and influential researchers in the field.

- The authors from IITs, NITs, and other Central Universities are the most productive because these institutions have strong research infrastructure and support.

- The authors from medical institutions are also well-represented in the top 50 because optics is a multidisciplinary field and is used in many medical applications.

- The authors from state universities and private institutions are also making significant contributions to Indian optics research. This suggests that the research ecosystem in India is becoming more diverse and inclusive.

5.4.5. Most Impactful Authors

- The top 50 most impactful authors in Indian optics are all highly cited, with an average h-index of 47.

- Most cited author is Kumar S, with h-index of 71 and a total of 35650 citations.

- The second most cited author is Kumar A, with an h-index of 68 and a total of 34729 citations.

- Third most cited author Patil PS, with h-index of 59 and total of 10802 citations.

- The top 50 authors are all from India, with the majority from the Indian Institutes of Technology (IITs).

- The top 50 authors have published a total of 12352 papers, which have received a total of 292399 citations.

- The average CPP for top 50 authors is 23.58, which is significantly higher than the average CPP for all Indian optics authors (14.95).

- The top 50 authors have made significant contributions to the field of optics, and their work has had a major impact on the field.

- The high h-indexes of the top 50 authors indicate that they are highly productive and have made significant contributions to the field.

- The large number of citations received by the top 50 authors' work indicates that their work is highly influential.

- The fact that the top 50 authors are all from India suggests that India is major hub for research in optics.

- The high CPP for the top 50 authors indicates that their work is of high quality and is being cited frequently.

- The significant contributions made by the top 50 authors have helped to advance the field of optics and have made it a more competitive field.

5.4.6. Most Collaborative Authors

- Kumar A and Kumar S lead the list with high collaboration impact, evidenced by their substantial TP (1756 and 1741), TC (29576 and 35052), and elevated CPP (16.843 and 20.133) values, along with notable TLS (1044 and 1034) scores.

- Kumar R and Kumar P demonstrate high collaboration impact, possibly indicative of interdisciplinary collaboration leading to increased citations. They have

significant TP (960 and 829), TC (22029 and 16104), and CPP (22.947 and 19.426) values, along with considerable TLS (672 and 537) scores.

- Singh A and Gupta A exhibit significant number of total citations, reflecting the recognition and visibility of their collaborative research. They show strong TP (635 and 567) and TC (11223 and 10802) values, along with notable CPP (17.674 and 19.051) scores and substantial TLS (537 and 529) scores.

- Gupta V and Sharma A showcase substantial collaboration, leading to high TP (521 and 684) and TC (10413 and 11777) counts. Their notable CPP (19.987 and 17.218) values and substantial TLS (525 and 517) scores reflect their impactful collaborative efforts.

- Singh R and Singh S showcase strong collaboration impact, as evident from their high CPP values (20.102 and 16.666), indicating effective collaborative research leading to higher impact. Their substantial TP (588 and 933) and TC (11820 and 15549) values are supported by substantial TLS (476 and 463) scores.

- Sharma S and Kumar M exhibit a strong balance between collaboration and individual research output. Their significant TP (794 and 707) and TC (12674 and 13736) values, along with balanced CPP (15.962 and 19.429) and moderate TLS (455 and 417) scores, underscore their well-rounded collaborative contributions.

- Ghosh S and Ghosh A strike balance between collaboration impact and citations, suggesting their collaborative work's influence. With considerable TP (720 and 420) and TC (13795 and 9487) values, along with robust CPP (19.160 and 22.588) and notable TLS (323 and 288) scores, their collaborative research makes a significant impact.

- Authors like Mukherjee S and Das S demonstrate substantial collaboration impact despite their relatively lower publication counts, indicating the influence of their

collaborative work on the research landscape. Their noteworthy TLS values (270 and 261) demonstrate their growing collaborative networks.

- High collaborative impact from authors like Singh V and Singh AK suggests the dynamic nature of collaboration within different research contexts. Their substantial TLS (223 and 218) scores showcase their effective collaborative efforts.

- Authors like Sharma N and Singh D exhibit effective collaboration, contributing to impactful research despite specializing in different areas. Their considerable TLS values (214 and 211) highlight the collaborative dynamics in diverse fields of study.

- Authors like Kaur S and Saha S reflect collaborative efforts across institutions, contributing to higher collaboration impact. Their notable TLS values (131 and 121) underscore the significance of inter-institutional collaboration.

- Authors like Bhattacharya S and Kumar B demonstrate effective collaboration leading to notable citation impact. Their considerable TLS values (119 and 120) reflect the collaborative networks that contribute to their research influence.

5.4.7. Co-authorship Index (CAI)

- The CAI for single-author papers has decreased from 391.133 in 1992 to 66.314 in 2020.

- The CAI for three or more author papers has increased from 259.543 in 1992 to 382.669 in 2021.

- The average CAI for Indian optics research publications has increased over time, from 225.32 in 1992 to 377.643 in 2021.

- The CAI for two-author publications has remained relatively stable over time, ranging from 167.123 in 1992 to 99.561 in 2016.

- The increase in CAI is likely due to the increasing complexity of optics research, which requires more collaboration between researchers.

- The number of single-author publications has decreased over time, while the number of two-author and three or more author publications has increased.

- The CAI for publications from IITs and NITs is generally higher than CAI for publications from other institutions.

- The CAI for publications from medical colleges and research institutes is generally lower than the CAI for publications from universities and IITs/NITs.

- The CAI for publications in high-impact journals is generally higher than CAI for publications in other journals.

- The year 2020 is an outlier, with a lower CAI for all three categories of papers. This may be due to the COVID-19 pandemic, which may have disrupted research collaborations.

5.5. Geo-Metrics

5.5.1. Most Collaborative Countries

- India ranks first in terms of TP in Optics research, with a significant number of 89,342 papers.

- The United States is the most collaborative country in optics research, with a total of 5,996 publications and 224,967 citations.

- South Korea is the second most collaborative country, with a total of 2,620 publications and 72,377 citations.

- Germany is the third most collaborative country, with a total of 2,219 publications and 113,141 citations.

- England is the fourth most collaborative country, with a total of 1,892 publications and 104,179 citations.

- Saudi Arabia is the fifth most collaborative country, with a total of 1,850 publications and 38,071 citations.

- The average ACPP for the United States is 37.520, which is significantly higher than the average ACPP for all countries (12.328).

- The average ACPP for South Korea is 27.625, which is also significantly higher than the average ACPP for all countries.

- The top 5 most collaborative countries after omitting India are all developed countries with strong research infrastructures.

- There is a positive correlation between the number of publications and the number of citations, suggesting that more collaborative countries tend to produce more high-quality research.

- European countries like Germany, England, France, Italy, Spain, and Switzerland are prominent contributors to optics research, with substantial publication numbers and notable citation counts.

5.6. Institutions and Publisher Metrics

5.6.1. Most Productive Organisations

- The Indian Institute of Technology (IIT) System is the most productive organization in optics research in India, with a total of 13,478 publications (15.086%), 272,656 citations (18.765%), and a CPP of 20.230.

- The Council of Scientific and Industrial Research (CSIR), India is the second most productive organization, with 6,485 publications (7.259%), 171,663 citations (12.647%), and a CPP of 26.471.

- The Department of Science and Technology (DST), India is the third most productive organization, with 4,970 publications (5.563%), 120,632 citations (9.982%), and a CPP of 24.272.

- The National Institute of Technology (NIT) System is the fourth most productive organization, with 4,780 publications (5.350%), 72,213 citations (5.823%), and a CPP of 15.107.

- Anna University, Chennai is the fifth most productive organization, with 3,597 publications (4.026%), 60,194 citations (4.842%), and a CPP of 16.735.

- The top 10 most productive organizations account for 54.27% of the total publications, 67.84% of the total citations, and 57.99% of the average CPP in optics research in India.

- The IIT system accounts for the largest share of publications, citations, and CPP, which suggests that it is the leading organization in optics research in India.

- CSIR and DST are also major players in optics research in India, with a significant share of publications and citations.

5.6.2. Most Productive Publishers

- Elsevier is most productive publisher in optics research, with a total of 30,466 publications (34.100%), 717,483 citations (23.550%), and a CPP of 23.550.

- Springer is the second most productive publisher, with 10,159 publications (11.371%), 111,109 citations (10.937%), and a CPP of 10.937.

- Wiley is the third most productive publisher, with 4,167 publications (4.664%), 74,469 citations (17.871%), and a CPP of 18.104.

- Taylor & Francis is the fourth most productive publisher, with 4,081 publications (4.568%), 44,391 citations (10.877%), and a CPP of 11.025.

- IOP Publishing Ltd is the fifth most productive publisher, with 3,551 publications (3.975%), 69,396 citations (19.543%), and a CPP of 19.543.

- The top 10 most productive publishers account for 71.17% of the total publications (75.68%), 68.97% of the total citations (74.40%), and 63.67% of the average CPP (67.23%) in optics research.

- Elsevier has the highest CPP, with 23.550 citations per paper. This is 1.24 times higher than the average CPP for all publishers.

- Springer has the second highest CPP, with 10.937 citations per paper. This is 0.82 times higher than the average CPP for all publishers.

- Taylor & Francis has the third highest CPP, with 10.877 citations per paper. This is 0.81 times higher than the average CPP for all publishers.

- The average CPP for the top 10 most productive publishers is 16.446 citations per paper. This is 1.41 times higher than the average CPP for all publishers.

5.6.3. Global Funding Agencies

- The National Science Foundation (NSF) is the most prolific funding agency in optics research, with a total of 982 publications (1.099%) and 18,219 citations (5.88%).

- The European Commission is the second most prolific funding agency, with 838 publications (0.938%) and 15,731 citations (5.07%).

- UK Research Innovation is the third most prolific funding agency, with 734 publications (0.822%) and 13,257 citations (4.23%).

- The National Aeronautics Space Administration (NASA) is the fourth most prolific funding agency, with 595 publications (0.666%) and 10,982 citations (3.47%).

- The United States Department of Health and Human Services (HHS) is fifth most prolific funding agency, with 525 publications (0.588%), 10,381 citations (3.31%).

- The top 10 most prolific funding agencies account for 48.44% of the total publications and 34.50% of the total citations in optics research.

- The NSF has the highest CPP, with 18.219 citations per paper.

- UK Research Innovation has third highest CPP, with 13.257 citations per paper.

- The average CPP for the top 10 most prolific funding agencies is 12.370 citations per paper.

- The top 10 most prolific funding agencies are all from developed countries, with a strong presence from the United States, Europe, and Asia.

- The top 10 most prolific funding agencies are all well-established organizations with a long history of supporting research in optics.

- The top 10 most prolific funding agencies are all active in supporting both basic and applied research in optics.

5.6.4. Indian Funding Agencies

- **Leading Contributor:** The Department of Science and Technology (DST), India is the most prolific funding agency in optics research in India, with a total of 10,780 publications (12.066%).

- **Diverse Support:** Various funding agencies, including the University Grants Commission (8.359%) and Council of Scientific Industrial Research (7.563%), play crucial roles in supporting research.

- **Sector Focus:** Funding agencies like the Department of Atomic Energy (1.648%), Defence Research Development Organisation (0.947%), and Department of Biotechnology (0.894%) allocate resources to different sectors.

- **Educational and Healthcare Impact:** The Ministry of Human Resource Development (0.842%) and Indian Council of Medical Research (0.391%) contribute significantly to education and healthcare research.

- **Space and Technology:** Entities such as the Department of Space (0.178%) and Indian Space Research Organization (0.106%) prioritize space and technology research.

- **Niche Initiatives:** The Department of Science Technology Nano Mission (0.152%) focuses on nano-scale research projects.

- **Educational Institutes:** Renowned institutions like the University of Delhi (0.168%) and Indian Institutes of Technology (IITs) contribute funding for research.

- **State-Level Participation:** State-level organizations like Kerala State Council for Science, Technology, Environment (0.056%) support regional research efforts.

- **Encouraging New Researchers:** Initiatives like the Department of Science Technology Inspire Fellowship (0.056%) provide support for young researchers.

- **Cross-Disciplinary Support:** Ministries such as Ministry of Electronics and Information Technology (0.148%) and Ministry of New and Renewable Energy (0.139%) contribute to multidisciplinary research.

- **Collaborative Ventures:** India Alliance (0.048%) emphasizes collaborative research efforts.

5.7. Journal Metric Indicators

5.7.1. Most Productive Sources

- The top 5 most productive journals in terms of total publications are: Optik (n=1805), Journal of Materials Science-Materials in Electronics (n=1751), Indian Journal of Ophthalmology (1732), Journal of Alloys and Compounds (1296) and Spectrochimica Acta Part A-Molecular and Biomolecular Spectroscopy (n=1184)

- The top 5 most productive journals in terms of total citations are: Optics Letters (TC=12203), Applied Physics Letters (TC=10438), Journal of Physical Chemistry C (TC=18870), Journal of Luminescence (TC=15636) and Journal of Crystal Growth (14193)

- The top 5 journals with the highest CPP are: Applied Surface Science (32.547 CPP), Applied Physics A-Materials Science & Processing (10.664 CPP), Materials Research Express (7.363 CPP), Journal of Physics and Chemistry of Solids (23.061 CPP) and Journal of Physics D-Applied Physics (24.844 CPP)

- The journal with the most HCP is Optics Letters (13)

- The journal with the most total authors is Optics Express (1483) Journals like "Optik" from Elsevier (JCI 2021: 0.89) and "Journal of Alloys and Compounds" (JCI 2021: 1.19) are highly influential in terms of Journal Citation Indicator.

- The total number of publications in the top 50 journals is 31,109, and the total number of citations is 614,326. This means that the average journal in the top 50 has 19.84 citations per paper.

- The top 50 journals account for 34.82% of the total publications and 36.64% of the total citations. This means that a small number of journals are responsible for the majority of the research output and citations in optics.

5.7.2. Zone Wise Distribution of Journals

- Zone 3 has the most number of journals (4214) and the most number of papers (29439), accounting for 95.189% and 32.951% of the total number of journals and papers, respectively.

- Zone 2 has the second most number of journals (176) and the second most number of papers (30388), accounting for 3.976% and 34.013% of the total number of journals and papers, respectively.

- Zone 1 has the least number of journals (37) and the least number of papers (29515), accounting for 0.836% and 33.036% of the total number of journals and papers, respectively.

- There is a clear skewness in the distribution of journals and papers, with Zone 3 dominating the distribution.

- This skewness is likely due to the fact that Zone 3 contains the most prestigious journals, which tend to publish more papers.

- The findings of this study are consistent with the Bradford's law of scattering, which states that the number of journals with a given number of papers decreases as the number of papers increases.

5.8. Citation Analysis

5.8.1. Highly Cited Papers

- The paper with the highest TC is 'Agostinelli S, 2003, Nucl Instrum Methods Phys Res Sect A-Accel Spectrom Dect Assoc Equip', with 15,285 citations. This makes it most influential paper in Indian optics research.

- Various papers in the list have received significant attention from the research community, as evidenced by their high TCpY values. These papers cover diverse

areas of research, including astronomy, biotechnology, physics, materials science, and environmental management.

- The citation counts of these papers demonstrate their impact and influence their respective fields, indicating their contribution to advancing knowledge and research. Some papers are published in prestigious journals such as Nature, Science, The Lancet, and Chemical Reviews, further highlighting their significance.

- The highly cited papers reflect the multidisciplinary nature of Indian optics research, involving various domains and applications. Authors of these papers have made substantial contributions to their respective fields and have gained recognition for their work in the scientific community.

- The findings emphasize the importance of these highly cited papers in shaping the landscape of Indian optics research, serving as valuable references for further studies and advancements.

5.8.2. Distribution of Citations

- The majority of papers (75.09%) received zero citations, indicating that a significant portion of the research output did not garner immediate attention or recognition.

- **Dominance of Lower Citations:** The majority of publications 39758 (53.2%) received citations in the range of 1 to 9, emphasizing that a significant portion of research garnered moderate attention.

- **Impactful Publications:** 1826 (14.7%) publications obtained citations in the range of 100 to 499, indicating a substantial number of impactful contributions that gained recognition in the academic community.

- **Long-Tail Distribution:** The distribution of citations follows a long-tail pattern, wherein a few highly cited papers contribute significantly to the cumulative citation count, while the majority of publications have relatively lower citation counts.

- **Cumulative Influence:** The cumulative impact of citations increases as the citation ranges progress, highlighting the combined recognition garnered by research outputs across various impact levels.

- **Cumulative Total Publications:** The Cumulative Total Publications column provides a growing perspective on the overall scholarly output as citation ranges advance, giving insight into the accumulated scholarly activity.

5.9. Forecasting Metric Indicators

5.9.1. Time Series Analysis of Research Output, Single Authored Papers, and Multi Authored Papers

- The number of Indian optics research papers published has increased over time, from 451 in 1992 to 9383 in 2021.

- The average number of Indian optics research papers published per year has increased from 25.9 to 41.8.

- The peak year for Indian optics research output was 2021, with 9383 papers published.

- The years 2008, 2010, 2011, 2013, 2014, and 2017 also saw a high number of Indian optics research papers published.

- The quadratic trend line fits the data well, suggesting that the growth of Indian optics research output is accelerating.

- The predictions for the next five years are as follows: Year 2022: 10781.14, Year 2023: 11065.28, Year 2024: 11349.42, Year 2025: 11633.56 and Year 2026: 11917.70.

- The number of multi-authored optics research papers published in India has increased over time, from 400 in 1992 to 9187 in 2021.

- The peak year for multi-authored optics research output was 2021, with 9187 papers published.

- The predictions for the next five years are as follows: Year 2022: 11553.68, Year 2023: 11833.09, Year 2024: 12112.50, Year 2025: 12391.91 and Year 2026: 12671.32.

5.10. Indian Optics Research Output Indicators

5.10.1. Collaborative Index (CI), Collaborative Coefficient (CC), Modified Collaborative Coefficient (MCC), and Compound Annual Growth Rate (CAGR)

- The collaboration in Indian optics research has increased over time, as measured by the CI, Lawani CI, CC, and MCC.

- The peak year for collaboration was 2021, with all four measures reaching their highest values that year.

- The years 2008, 2010, 2011, 2013, 2014, 2017, 2018, 2019, 2020, and 2021 also saw high levels of collaboration.

- The years 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, and 2001 saw the lowest levels of collaboration.

- The average CI, Lawani CI, CC, and MCC for the period 1992-2021 are 4.980, 5.010, 0.685, and 0.685, respectively.

- The CAGR of the number of Indian optics research publications from 1992 to 2021 is 19.279%.

- The CAGR has been increasing over time, with the highest growth rate in the period 2018-2021 (6.704%).

- The number of Indian optics research publications has increased from 451 in 1992 to 89342 in 2021.

- The peak year for the number of publications was 2021, with 9383 publications.

- The years 2018, 2019, 2020, and 2021 also saw a high number of publications.

- The years 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, and 2001 saw the lowest number of publications.

5.11. Collaboration Visualisation Network of Countries, Institutions, Authors and Keywords

- Germany, England, Italy, France, Spain, and Russia are the most collaborative countries with India in optics research, forming the red cluster with strong collaborative networks.

- The blue cluster includes the USA, Australia, Canada, Chile, Israel, Mexico, and Argentina, indicating a strong collaborative network with India.

- The National Institute of Technology, Anna University, and Vellore Institute of Technology are the most collaborative Indian organizations in optics research, forming the red cluster with a strong collaborative network.

- University Delhi, the Council of Scientific and Industrial Research (CSIR), and the Indian Institute of Technology Delhi are among the top collaborative organizations, forming the green cluster with a moderate collaborative network.

- Indian Institute of Technology and the Indian Institute of Science are the leading organizations in optics research, forming the blue cluster with a strong collaborative network.

- Sharma, S, Kumar, A, and Kumar, S are the top three authors with the highest total link strengths in Indian optics research publications.

- The red cluster comprises authors with a high number of total publications and moderate to high citation per paper values, indicating their significant contributions to the field.

- The green cluster consists of authors with a high number of total publications and citations, indicating their strong impact in optics research.

- The keyword "Photoluminescence" was the most occurred author keyword in Indian optics research publications, indicating its significant presence in the field.

- The red cluster represents keywords that are frequently mentioned and has a moderate to high total link strength, suggesting their importance in Indian optics research.

- The green cluster includes keywords related to various analytical techniques such as XRD, FTIR, SEM, and Raman Spectroscopy, highlighting their relevance in Indian optics research.

5.12 Suggestions

Based on Optics research in India, here are several suggestions to enhance the growth and impact of this field.

- *Foster Research Collaboration:* Encouraging and promoting collaboration among researchers should be a priority. Collaborative research has been shown to have a positive impact on the quality and visibility of publications. Institutions and funding agencies can facilitate collaborative initiatives, such as joint research

projects, workshops, and conferences, to foster interdisciplinary collaboration and knowledge exchange.

- *Enhance Funding Support:* Increasing funding support for optics research enable researchers to undertake more ambitious and high-impact projects. Funding agencies, such as the Department of Science and Technology (DST), University Grants Commission (UGC), and Council of Scientific and Industrial Research (CSIR), should consider allocating dedicated funds for optics research and providing competitive grants to support innovative research ideas.

- *Promote Interdisciplinary Approaches:* Optics research often intersects with various disciplines such as materials science, physics, and chemistry. Encouraging interdisciplinary collaborations and promoting cross-disciplinary research lead to breakthroughs and advancements. Institutions should establish interdisciplinary research centers or programs that bring together researchers from different disciplines to address complex research problems.

- *Strengthen Research Infrastructure:* Investing in state-of-the-art research infrastructure, including advanced laboratories, testing facilities, and equipment, is crucial for conducting cutting-edge optics research. Institutions should prioritize infrastructure development and upgrade existing facilities to attract and retain talented researchers and provide them with the necessary tools to conduct world-class research.

- *Support Early-Career Researchers:* Recognizing the importance of nurturing young talent, institutions and funding agencies should provide dedicated support and mentorship programs for early-career researchers in optics. Initiatives such as research fellowships, grants for early-career scientists, and career development

workshops can help in fostering the growth of young researchers and enable them to make significant contributions to the field.

- ***Promote International Collaborations:*** Strengthening international collaborations can facilitate knowledge exchange, access to advanced research facilities, and joint research projects. Institutions should actively seek partnerships with renowned international institutions and participate in international conferences and workshops to foster collaboration and enhance the global visibility of Indian optics research.

- ***Emphasize Science Communication:*** Efforts should be made to enhance science communication and outreach activities to bridge the gap between researchers and the general public. Researchers should be encouraged to engage in public lectures, science exhibitions, media interactions to disseminate their findings and create awareness about importance of optics research in addressing societal challenges.

By implementing these suggestions, India can further consolidate its position in optics research and contribute to advancements in this field. A collaborative and supportive ecosystem, combined with enhanced funding, infrastructure, and interdisciplinary approaches, will create a conducive environment for researchers to thrive and make impactful contributions to the field of optics.

5.13 Suggestion for Further Study

Based on the findings of the study on optics research in India, several suggestions for further study and research proposed. These suggestions aim to address the gaps, explore new avenues, and contribute to the advancement of optics research in India.

- ***Longitudinal Analysis:*** Conducting a longitudinal analysis of optics research in India provides a deeper understanding of the growth patterns, trends, and shifts

in research output, citations, and collaboration over time. This analysis helps identify the factors influencing the rise and decline of research activity, enabling researchers to make informed predictions and projections for the future.

- *Impact Assessment:* Performing a comprehensive impact assessment of Indian optics research helps evaluate the influence and significance of research output in terms of citations, collaboration networks, and international collaborations. Assessing the impact of research assists in identifying the most impactful research areas, influential authors, and productive institutions, thereby guiding resource allocation and strategic planning.

- *Interdisciplinary Approaches:* Exploring the interdisciplinary aspects of optics research open up new avenues for innovation and knowledge creation. Investigating the intersections between optics and other fields such as materials science, physics, chemistry, and engineering lead to novel applications, technological advancements, and scientific breakthroughs. This interdisciplinary approach foster collaboration across disciplines and promote holistic problem-solving.

- *Research Quality Assessment:* Conducting a comprehensive assessment of research quality in Indian optics publications help identify areas for improvement, enhance the rigor and reliability of research findings, and ensure adherence to international standards and best practices. This assessment includes factors such as experimental design, methodology, data analysis, and reporting practices, ultimately enhancing the credibility and impact of Indian optics research.

- *International Collaborations:* Encouraging and facilitating international collaborations in optics research provide opportunities for knowledge exchange, cross-cultural learning, and shared resources. Strengthening ties with reputed

international institutions, participating in collaborative research projects, and promoting joint publications enhance the global visibility and impact of Indian optics research, while also fostering a global research ecosystem.

By undertaking further studies in these areas, researchers contribute to the continuous growth and development of optics research in India, facilitate knowledge transfer, and drive technological advancements in this field. These suggestions aim to inspire future research endeavors and foster a vibrant research community focused on advancing optics research in India.

5.14 Conclusion

The study on optics research in India has provided a comprehensive analysis of the trends, patterns, and contributions in this field. The findings reveal a significant growth in research output, with India's share of global research output in optics steadily increasing over the years. This indicates the country's growing prominence and contribution to the field. The study confirms the exponential growth pattern in optics research, highlighting the rapid expansion of knowledge in this domain. The analysis of the year-wise activity index reveals a surge in the number of articles and total citations until 2014, followed by a recent decline in total citations despite the increase in articles. This suggests the need for further investigation into the factors influencing citation impact. Collaboration has emerged as a key feature in Indian optics research, with a notable increase in multi-authored papers and a higher degree of collaboration over time. Prolific authors like Kumar A and Kumar S have demonstrated extensive collaboration and significant impact, as reflected in their high citation counts and total link strengths. The study also provides insights into the preferred document types, language distribution, and influential publishers in Indian optics research. The findings can inform policymakers, funding agencies, and

researchers in making informed decisions regarding research collaborations, funding allocations, and publication strategies. Continued emphasis on collaboration, interdisciplinary research, and investment in key research areas will contribute to the further growth and impact of Indian optics research. Overall, this study provides a comprehensive understanding of the Indian optics research landscape and sets the stage for future research and advancements in this field.