

# In the Shadow of Mosquitoes: Analysis of Malaria Burden in India Using Citation Network

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## ABSTRACT

**Background:** Malaria, with its deep historical roots in human civilization, stands as a testament to the enduring challenges posed by infectious diseases. This paper embarks on a journey through the historical context of malaria, tracing all publications from its evolution and impact on societies worldwide. **Objectives/Purpose:** Leveraging bibliographic citation network analysis, this study explores the trajectory of malaria research in India from 1900 to 2024. **Methodology:** Drawing upon a dataset of 2045 articles sourced from the Web of Science database, the study employs VOSviewer software to analyze publication trends, citation patterns, collaborative networks, and keyword associations. **Results:** Results indicate a substantial increase in both publication volume and citations over the 124 years, reflecting evolving efforts to understand and combat malaria. A total of two thousand forty-five ( $n=2045$ ) with a citation score of 34762, h-index of 72, and contributed by 6492 authors from 89 countries. India emerges as a focal point, accounting for over 85% of publications, underscoring the country's significant burden of malaria. Collaborative networks among researchers, spanning across countries and disciplines, underscore the global effort to address this public health challenge. **Conclusion/Implications:** Specialized journals, such as the Malaria Journal, play a pivotal role in disseminating research findings and shaping discourse on malaria.

**Keywords** Anopheles, Citation Network Analysis (CNA), Malaria, *Plasmodium falciparum*, *Plasmodium vivax*.

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## INTRODUCTION

Malaria, with a historical footprint spanning centuries, stands as a testament to the resilience of infectious diseases and their enduring impact on human populations. To fully grasp the contemporary challenges posed by malaria, one must embark on a journey through its historical context, tracing the evolution of the disease and its profound consequences on societies worldwide (Carter and Mendis, 2002). Malaria's origin is shrouded in antiquity, with evidence of its presence found in ancient texts and archaeological findings (Arrow *et al.*, 2004). Early civilizations, from the Egyptians to the Greeks and Romans, documented the symptoms of what they called "marsh fever" or "ague," recognizing the cyclical nature of the disease's fevers (Dobson, 1980). The Middle Ages witnessed malaria's pervasive presence in Europe, where it was endemic in marshy regions and coastal areas. The disease, often referred to as "the ague," exacted

a heavy toll on populations, contributing to high morbidity and mortality rates (Kuhn, 2003). The Age of Exploration and colonial expansion facilitated the global spread of malaria as European powers ventured into tropical regions. Colonizers inadvertently introduced the disease to new territories, where it found fertile breeding grounds in the warm climates and abundant mosquito vectors (Bump and Aniebo, 2022). Malaria played a pivotal role in shaping the outcomes of military conflicts and the rise and fall of empires (Mertens, 2024). From the Roman Empire's struggles with malaria in Italy to the debilitating impact of the disease on European colonial ventures in Africa and Asia, malaria shaped the course of history (Mertens, 2024).

The 19<sup>th</sup> and 20<sup>th</sup> centuries witnessed significant advancements in understanding the etiology and transmission of malaria. Breakthroughs such as the discovery of the malaria parasite by Ronald Ross and the identification of the role of *Anopheles* mosquitoes as vectors paved the way for targeted interventions (Cox, 2010). The advent of quinine as a treatment for malaria in the 17<sup>th</sup> century marked a turning point in efforts to combat the disease (Achan *et al.*, 2011). The aftermath of World War II saw renewed efforts to tackle malaria worldwide. Organizations such as the World Health Organization (WHO) spearheaded initiatives to eradicate malaria through mosquito control, drug



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distribution, and the development of public health infrastructure. Despite significant progress in malaria control efforts, the disease remains a formidable global health challenge. Factors such as drug resistance, insecticide resistance, climate change, and socio-economic disparities continue to hinder efforts to eliminate malaria.

In the 21<sup>st</sup> century, the fight against malaria enters a new phase characterized by innovation, collaboration, and resilience. From the development of new antimalarial drugs (Belete, 2020) and vaccines (El-Moamly and El-Sweify, 2023) to the use of data-driven approaches for malaria surveillance and control, stakeholders are harnessing the power of science and technology to overcome longstanding challenges.

Malaria is endemic in 85 countries and territories (including French Guiana), predominantly in sub-Saharan Africa, Southeast Asia, and the Western Pacific. Sub-Saharan Africa bears the highest burden, accounting for most malaria cases and deaths globally (WHO, 2024). In Southeast Asia, India, Indonesia, and Myanmar are significant contributors to the global malaria burden. As per the Malaria Health Report (World Malaria Report, 2024), India accounted for about 65.7% of all malaria cases in the region and 1.4% of global cases, with 0.9% of the deaths. Malaria is endemic in several states across India, with varying levels of transmission intensity and epidemiological profiles. The northeastern states, including Assam, Meghalaya, and Tripura, as well as the eastern states of Odisha, Jharkhand, and Chhattisgarh, experience a high malaria burden due to favorable environmental conditions and socioeconomic vulnerabilities. States in central India, such as Madhya Pradesh and Maharashtra, also report significant malaria transmission, particularly in tribal and rural areas. Coastal regions, including parts of Andhra Pradesh, Tamil Nadu, and Gujarat, experience seasonal spikes in malaria cases during the monsoon season, driven by *Anopheles* mosquito breeding in stagnant water bodies. In urban centers like Mumbai, Delhi, and Kolkata, rapid urbanization, overcrowding, and inadequate vector control measures contribute to localized malaria outbreaks. Although Malaria cases have consistently declined from 2.09 million to 0.19 million during 2001 to 2020 but eliminating Malaria as a public health problem in India is a distant dream (NVBDCP, 2016).

Malaria is transmitted through the bite of an infected female *Anopheles* (An.) mosquitoes, which inject *Plasmodium* parasites into the bloodstream. These mosquitoes play a crucial role in the transmission cycle of malaria parasites (*Plasmodium* species) to humans (Figure 1). The parasites then multiply within the host's liver and red blood cells, leading to the characteristic symptoms of fever, chills, sweating, fatigue, and, in severe cases, organ failure and, in some cases, fetal disease if not treated promptly. Because of diverse geo-ecological factors and multi-ethnicity, the epidemiology of malaria is very complex in India (Dash et al., 2008; Kumar et al., 2007; Sindhanian et al., 2020).

The emergence of drug-resistant strains of malaria parasites, particularly *Plasmodium falciparum* (Shah et al., 2011), and the increasing prevalence of insecticide resistance among malaria vectors pose a significant challenge to malaria control efforts (Quiñones et al., 2015). Further, changing climate patterns, including temperature fluctuations and altered rainfall patterns (Kripa et al., 2024), as well as environmental changes such as deforestation, urbanization, and land-use alterations, affect vector breeding habitats and human-mosquito interactions, complicating malaria control efforts in India (Steiger et al., 2016). Many countries have spearheaded efforts to eliminate malaria and are approaching the milestone of zero indigenous malaria cases. Twenty-five countries achieved this target in 2000, maintaining 3 consecutive years of zero indigenous malaria cases; 15 of these were also certified malaria-free by the World Health Organisation (2024). Among Southeast Asian countries, Sri Lanka was certified malaria-free in 2016 and remains so to date. India has also committed to eliminating malaria as a public health problem by 2030, in line with global efforts to achieve this goal across countries (NVBDCP, 2016).

Work to eliminate malaria as a health problem is underway in most countries worldwide, from highly endemic to non-endemic areas, generating substantial scientific literature of interest. To trace the historical trajectory of these research publications on malaria in India, examining trends in prevalence, incidence, mortality, and control efforts over time. This study conducted a bibliographic analysis of the malaria burden in India to advance our understanding of the disease, identify opportunities for intervention, and inform evidence-based policies and programs to reduce malaria morbidity and mortality in the country. The study examines all publications from 1900 to 2024. The analysis was conducted across all relevant publications on the topic, and data were retrieved from the Web of Science portal and analysed using the Citation Network. The publications were quantified based on their numbers, citations, co-citations, cited references, collaborations among researchers, highly cited articles, publications in top journals, and countries (Sindhanian et al., 2024; Sharma et al., 2025).

## METHODOLOGY

The publication data was retrieved extensively from the Web of Science (WoS) database using the desired keywords (Figure 2). A total of 2975 articles were found in the search on various aspects of malaria, including prevalence, vectors, parasites, distribution, epidemiology, history, and the elimination of the disease. The Web of Science search was restructured using Boolean operators and keywords such as “must include” and “should include” to obtain the desired results. The WoS maximizes output by searching additional databases, such as reference libraries in the social sciences and humanities, and proceedings indexes. After manual screening, articles not relevant to the basic theme of malaria were

removed ( $n=819$ ) and the remaining 2156 articles were exported to the master list. Further analysis helps in removing the 111 article including corrections ( $n=24$ ), notes ( $n=19$ ), letter ( $n=18$ ), Meeting abstract (12), publication with expression of concerns ( $n=10$ ), Book chapter (9), Early access articles (8), Book reviews (7), retracted publications ( $n=2$ ), and reprints ( $n=2$ ) were removed. Finally, data for 2045 articles were exported for further analysis. The data were curated and analysed with VOSviewer software version 1.6.20 (Van and Waltman, 2007). To correlate publication trends, citations, and co-citations with references, author collaborations across countries, Universities, and departments. Top journals with the greatest number of publications and the highest number of citations were also analyzed. The data analysis conducted using Citation Network provides a broad view of the bibliographic network in the study area.

### Network data analysis

The VOSviewer software was employed for the analysis, as it enables visualization and examination of citation networks within scientific publications. It facilitates the extraction and analysis of citation data from thousands of publications directly retrieved from the Web of Science database. Consequently, a citation network consists of a large set of interconnected publications and their citation links. Highly referenced publications were quantitatively assessed using the citation score attribute, which accounts not only for internal connections within the Web of Science database but also for external citations. The relationship among publications was estimated using the following equation (Van and Waltman, 2007):

$$V(c_1, \dots, c_n) = \sum_{i < j} \delta(c_i, c_j) (s_{ij} - \gamma)$$

Here,  $n$  denotes the total number of publications included in the citation network visualization. Each publication is represented as a node within the network, while  $C_i$  and  $C_j$  indicate the degree of relatedness between publications  $i$  and  $j$ . The parameter  $S$  is the total number of publications included in the citation network visualization. Each publication is represent of this repulsive force.

A clustering algorithm was applied to categorize related publications into distinct groups, enabling closely connected studies to be organized together based on their citation relationships. The core publication function was further utilized to identify the most relevant publications by filtering out less relevant ones. Only publications that received at least one citation were included in constructing the core citation network.

In addition, bibliographic data were used to generate analytical maps, including co-authorship networks, keyword co-occurrence maps, bibliographic coupling, and co-citation networks. The Citation Network Analysis (CNA) technique was applied to systematically analyse scientific literature associated with a specific concept, topic, or theme. This approach supports both quantitative and qualitative evaluation of related publications

and helps establish interconnected clusters based on authorship, research focus, citations, and co-citation patterns. Using VOSviewer, CNA enables the exploration of relationships among research groups and their contributions to a particular scientific domain. This study examined research publications on the malaria burden in India over the past 124 years and analyzed them using Citation Network Analysis (CNA). Compared with conventional literature reviews, CNA offers a more comprehensive quantitative assessment by organizing closely related studies into clusters and sub-clusters within the broader research theme. This approach enables systematic evaluation of publication characteristics, including citations, co-citations, authorship patterns, collaborative networks, contributing countries, and journals publishing related research.

## RESULTS AND DISCUSSION

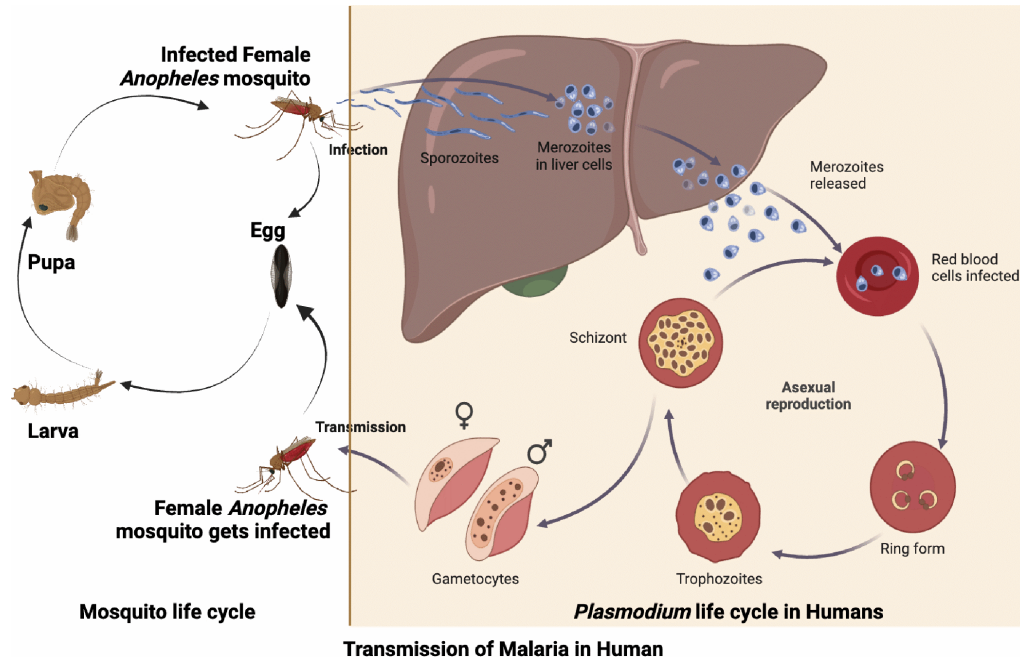
A total of two thousand forty-five ( $n=2045$ ) articles spanned from 1900 to 2024 (124 years) with a total citation score of 34762, h-index of 72, and contributed by 6492 authors from 89 countries. More than 87% of the publications were research articles ( $n=1794$ ), followed by review articles ( $n=140$ , 6.85%), meeting abstracts ( $n=72$ , 3.52%), and proceeding papers (39, 3.52%). The majority of the articles retrieved were published in English ( $n=2037$ , 99.61%), with a few in German ( $n=5$ , 0.24%), French ( $n=2$ , 0.1%), and Spanish ( $n=1$ , 0.05%). The titles and abstracts for these articles were available in English as well.

### Article published and citation trend

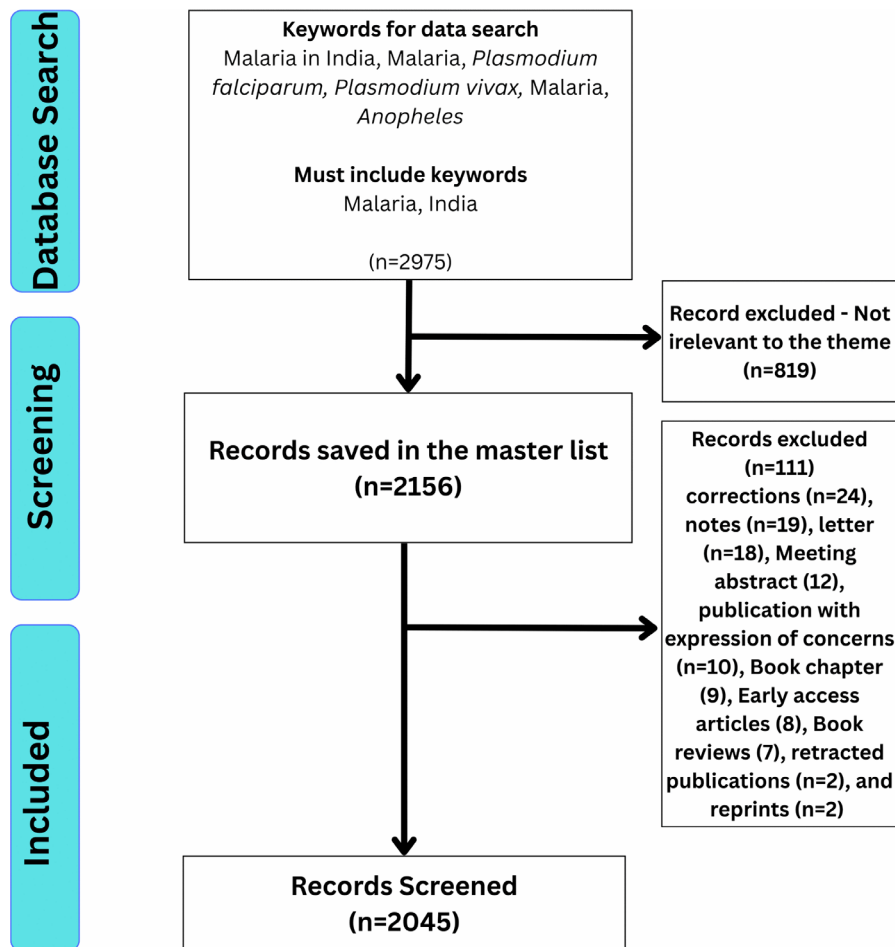
During the span of 124 years of research on malaria in India, the first article that appeared in the database was published by Leslie (1909) entitled "An address on malaria in India" in the Lancet. The maximum number of publications ( $n=108$ ) was recorded in the year 2022, and the maximum number of citations ( $n=243$ ) was recorded in 2013. The data comprised two centuries (20<sup>th</sup> and 21<sup>st</sup>), and a steep increase in article publication was observed from 2012 (Figure 3).

### Geographical distribution of Publications

Publications from 89 countries originated on the theme; the geographical location of some of the publications ( $n=32$ , 1.57%) was not available. India accounted for more than 85% of publications, followed by the USA (14.52%) and England (7.43%). Although 1.565% of the articles were devoid of location data ( $n=32$ ). Network analysis of co-authorship among countries was calculated, with a maximum of 25 countries per publication, excluding citations. The VOSviewer calculated the total strength of co-authorships linked with other countries; the countries with the greatest total strength were selected. Of the 89 countries, 79 build a stronger network of 12 clusters, each represented by a circle in a unique colour. Clusters are groups of closely related items (co-authorship by countries in this case); the more items, the circle becomes bulky (Figure 4).



**Figure 1:** Schematic representation of the malaria transmission cycle in humans, illustrating the role of infected female *Anopheles* mosquitoes in transmitting *Plasmodium* parasites during blood feeding, followed by parasite development in the human liver and red blood cells, leading to clinical manifestations and continuation of the transmission cycle.



**Figure 2:** The workflow illustrates the retrieval and screening of publication data from the Web of Science (WoS) database, including keyword-based searching, application of Boolean operators, manual screening, exclusion of ineligible records, and final selection of articles for bibliographic and citation network analysis.

### Journal trend

Most journals are specialised and publish articles on a single subject or theme, such as the Malaria Journal, which focuses on any aspect of malaria. A total of 542 journals published 2045 articles, the top 10 journals published 39.22% ( $n=802$ ) articles and having 42.28% ( $n=14718$ ) citations. Malaria Journal published the maximum articles ( $n=210$ , 10.27%), followed by Journal of Vector Borne Diseases ( $n=116$ , 5.67%) and American Journal of Tropical Medicine and Hygiene ( $n=105$ , 5.13%). Malaria Journal also accumulated the highest number of citations among journals ( $n=4801$ , 13.81%) (Table 1).

### Top Ranking Publications

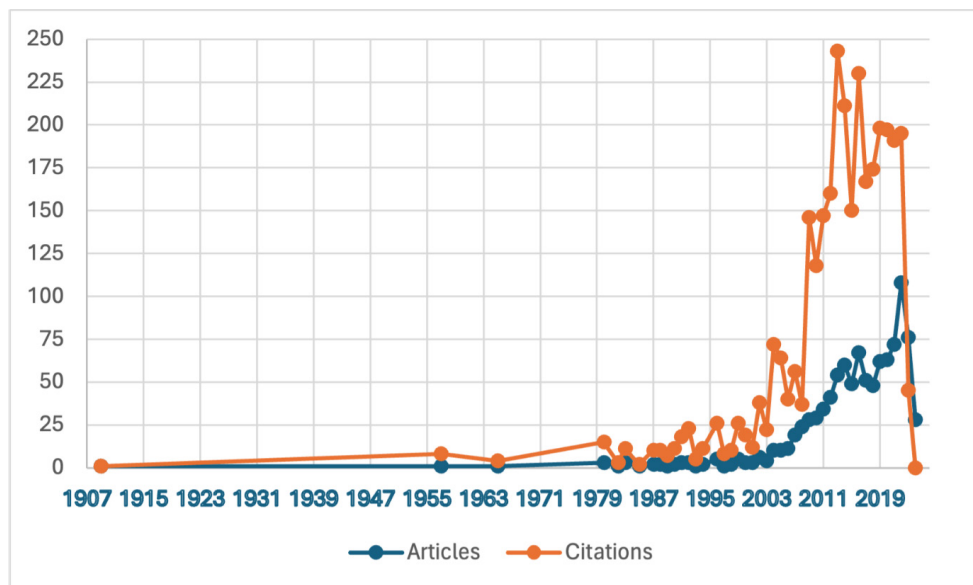
Citations to an article is the basic criteria in ranking the publications and consequently improving the journal ranking. In this study, the article entitled “Artesunate versus quinine for treatment of severe *falciparum malaria*: a randomised trial” has the maximum number of citations ( $n=744$ ) published in the journal The Lancet (Dondorp *et al.*, 2005) followed by “A Long Neglected World Malaria Map: *Plasmodium vivax* Endemicity in 2010” ( $n=395$ ) published in PLOS Neglected Tropical Diseases by Gething and “Indoor residual spraying for preventing malaria” ( $n=313$ ) published in Cochrane Database of Systematic Reviews by Pryce *et al.* (2010) (Table 2). Citation Network Analysis (CNA) of articles with at least one citation was also performed with VOSviewer; out of the 2045 articles, 1718 met the threshold criteria. By default, the software can only handle the best 1000 articles. For each of the 1718 articles, citation links were calculated, 1000 articles with the largest number of links were selected. CNA grouped the publications into 16 clusters (Figure 5).

### Top publishers and trends for Terms and Keywords

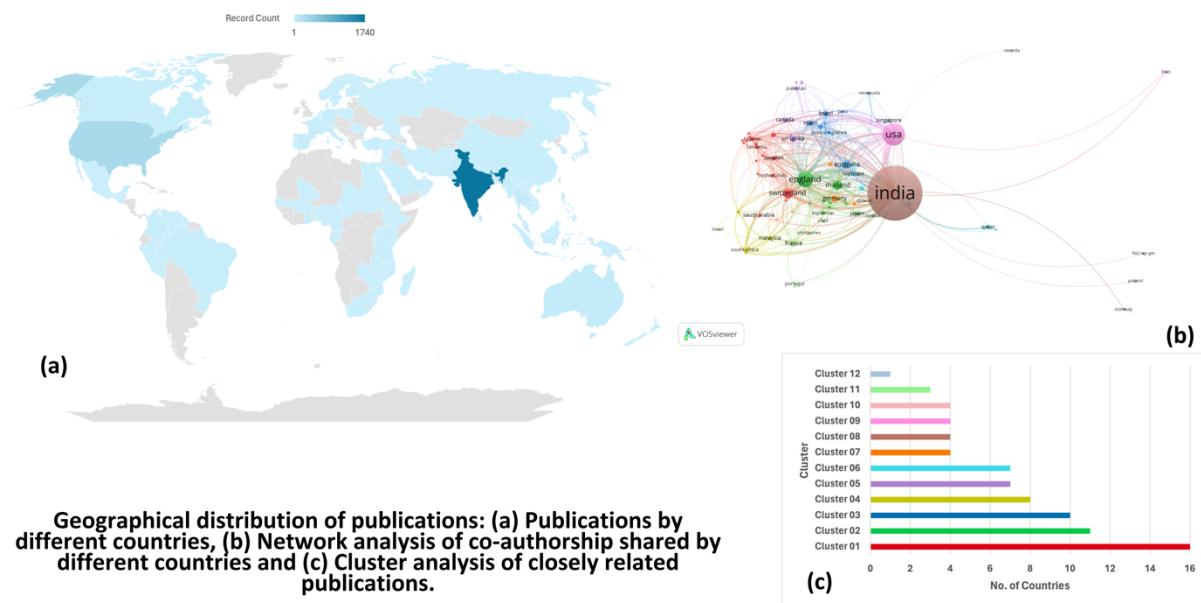
The 542 journals were published by the 189 publishers; some publishers publish journals in two-digit numbers. The top ten

**Table 1: Top 10 journals contributing to malaria research, ranked by the number of publications and corresponding citation counts, highlighting the leading sources of scholarly output and their overall research impact in the field.**

Publication Titles	Publication (n, %)	Citations (n, %)
Malaria Journal	210 (10.27)	4801 (13.81)
Journal of Vector Borne Diseases	116 (5.67)	784 (2.2)
American Journal of Tropical Medicine and Hygiene	105 (5.13)	2001 (5.76)
Acta Tropica	71 (3.47)	1238 (3.56)
Indian Journal of Medical Research	69 (3.37)	1174 (3.38)
Transactions of The Royal Society of Tropical Medicine and Hygiene	60 (2.93)	1235 (3.55)
PLOS One	48 (2.34)	1107 (3.18)
Tropical Medicine International Health	45 (2.20)	1139 (3.28)
Annals of Tropical Medicine and Parasitology	41 (2.01)	856 (2.46)
Infection Genetics and Evolution	37 (1.81)	383 (1.10)



**Figure 3:** Annual trend of malaria-related publications and their corresponding citation counts from 1900 to 2024, illustrating the growth in research output and scholarly impact over time.

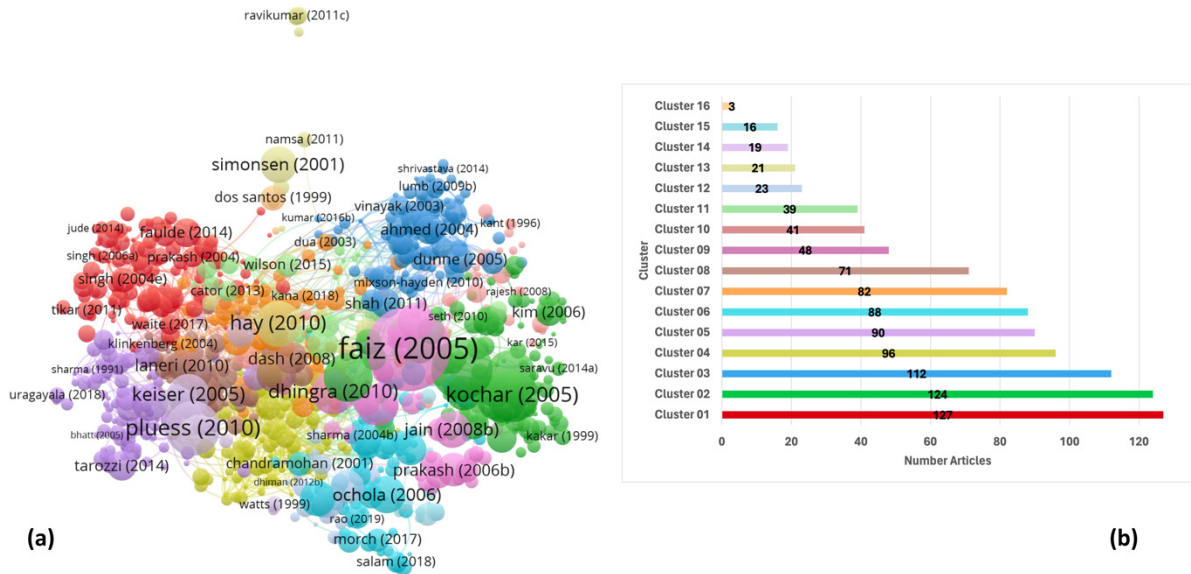


**Geographical distribution of publications: (a) Publications by different countries, (b) Network analysis of co-authorship shared by different countries and (c) Cluster analysis of closely related publications.**

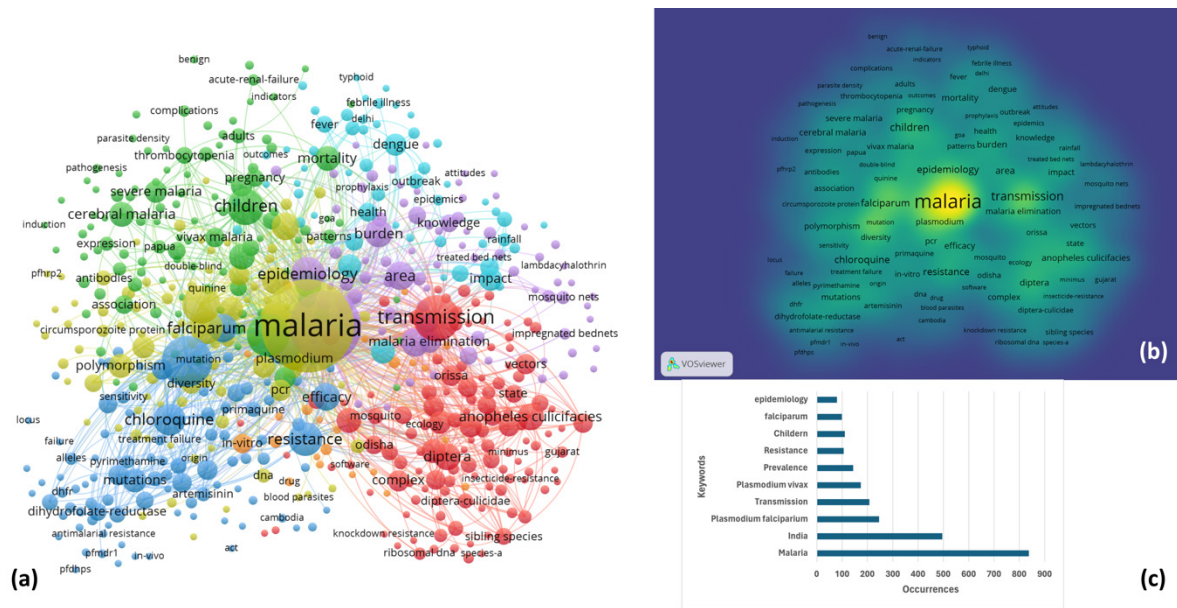
**Figure 4:** Geographical distribution and international collaboration patterns of malaria research publications related to India. (a) Global distribution of publications by country, indicating the contribution intensity of different nations. (b) Network visualization of international co-authorship among countries generated using VOSviewer, where node size represents publication contribution and link strength indicates collaboration intensity. (c) Cluster analysis showing groups of closely connected countries involved in collaborative malaria research, highlighting the structure of global research networks.

**Table 2: Top 10 most cited articles in malaria research, ranked by total citation count, highlighting the most influential studies contributing to advancements in malaria epidemiology, treatment strategies, and control interventions.**

Authors	Title	Journal	Citations
Dondorp et al. (2005)	Artesunate versus quinine for treatment of severe <i>falciparum</i> malaria: a randomised trial.	Lancet	744
Gething et al. (2012)	A Long-Neglected World Malaria Map: <i>Plasmodium vivax</i> Endemicity in 2010.	PLOS Neglected Tropical Diseases	395
Pryce et al. (2010)	Indoor residual spraying for preventing malaria.	Cochrane Database of Systematic Reviews	313
Kochar et al. (2005)	<i>Plasmodium vivax</i> malaria.	Emerging Infectious Diseases	285
Kochar et al. (2009)	Severe <i>Plasmodium vivax</i> Malaria: A Report on Serial Cases from Bikaner in Northwestern India.	American Journal of Tropical Medicine and Hygiene	275
Price et al. (2009)	New developments in <i>Plasmodium vivax</i> malaria: severe disease and the rise of chloroquine resistance.	Current Opinion in Infectious Diseases	265
Kumar et al. (2007)	Burden of malaria in India: Retrospective and prospective view.	American Journal of Tropical Medicine and Hygiene	258
Hay et al. (2010)	Estimating the Global Clinical Burden of <i>Plasmodium falciparum</i> Malaria in 2007.	PLOS Medicine	222
Dhingra et al. (2010)	Adult and child malaria mortality in India: a nationally representative mortality survey.	Lancet	202
Llanos-Cuentas et al. (2014)	Tafenoquine plus chloroquine for the treatment and relapse prevention of <i>Plasmodium vivax</i> malaria (DETECTIVE): a multicentre, double-blind, randomised, phase 2b dose-selection study.	Lancet	190



**Figure 5:** Visualization of highly cited publications through Citation Network Analysis (CNA). (a) Citation network map showing the interconnections among highly cited articles, with nodes representing publications and links indicating citation relationships. (b) Cluster analysis of publications based on shared citations, highlighting thematic research clusters within malaria research.



**Figure 6:** Keyword-based bibliometric visualization of malaria research publications. (a) Citation network analysis of keywords showing relationships and co-occurrence patterns among frequently used research terms. (b) Density visualization map indicating the intensity of keyword usage, where yellow represents highly frequent and strongly connected keywords and green indicates comparatively lower density. (c) Bar chart depicting the top ten most frequently occurring keywords in the analysed research articles, highlighting dominant research themes such as “Malaria”, “India”, and *Plasmodium falciparum*.

publishers published more than 71% of the journals. Springer Nature published the most journals ( $n=382$ , 18.68%), followed by Elsevier ( $n=385$ , 15.89%) and Wolters Kluwer Medknow Publications ( $n=215$ , 10.51%) (Table 3). The co-occurrences of the keywords were analysed using CNA, with a minimum of 5 occurrences per keyword. A total of 5619 keywords were analysed, out of which 575 met the threshold criteria of five occurrences. Total strength of occurrences with other keywords was analysed, and the keywords with the greatest total strength were calculated.

The related 575 keywords were grouped into seven clusters as per their shared strength and depicted in different colours. The density visualisation network of the keyword strength was also generated. Yellow colour represents the maximum number of keywords and greater density; green colour represents fewer keywords and lower density. The top-most word with maximum occurrences in all research articles was “Malaria”, followed by “India” and “*Plasmodium falciparum*” (Figure 6).

**Table 3: Top 10 publishers contributing to malaria research publications, ranked by the number of journals and articles published, highlighting the major publishing houses disseminating research in this field.**

Publishers	No. of Journals (n, %)
Springer Nature	382 (18.68)
Elsevier	325 (15.89)
Wolters Kluwer Medknow Publications	215 (10.51)
Wiley	112 (5.47)
Amer Soc Trop Med and Hygiene	105 (5.13)
Oxford Univ Press	99 (4.84)
Taylor and Francis	94 (4.60)
Public Library Science	62 (3.03)
Indian Acad Sciences	33 (1.61)
Amer Soc Microbiology	27 (1.32)

## CONCLUSION

In the shadow of mosquitoes, a comprehensive bibliographic analysis spanning from 1900 to 2024 illuminates the persistent struggle against malaria in India. Dating back to ancient civilizations, this disease has been documented in historical texts, shaping the trajectory of human societies. Over more than a century of research, the journey from the first recorded article in 1909 to the present day reflects a significant increase in both publication volume and citations, indicative of evolving efforts to understand and combat malaria. During the span of approximately 124 years, thousands of articles were published. Relevant articles were extracted from the Web of Science database and analysed using VOSviewer software, including co-citations, shared authorship, countries, and top-rated keywords. India, bearing the brunt of this burden, emerges as a focal point in the analysis, contributing over 85% of the publications. The collaborative network of researchers spanning countries and disciplines underscores the global effort to address malaria. Specialized journals like the Malaria Journal have played a pivotal role in disseminating research findings and driving discourse on the subject. Key publications, such as those examining treatment strategies and mapping endemicity, have garnered substantial citations, reflecting their impact on advancing knowledge and guiding interventions. Through citation network analysis, insights into the interconnectedness of research endeavors emerge, revealing clusters of shared collaboration and knowledge exchange. As the pursuit of malaria elimination continues, continued investment in research, innovation, and partnerships remains imperative. By leveraging the wealth of data and insights gleaned from bibliographic analyses, stakeholders can inform evidence-based policies and interventions, ultimately improving health outcomes for vulnerable populations. Thus, this bibliographic journey not only sheds light on the historical burden of malaria but also paves the way forward in the ongoing fight against this ancient scourge.

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## ABBREVIATIONS

**CNA:** Citation Network Analysis; **ICMR:** Indian Council of Medical Research; **NVBDCP:** National Vector Borne Disease Control Programme; **WHO:** World Health Organization; **WoS:** Web of Science.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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## AUTHOR'S CONTRIBUTIONS

YPS conceptualised and analysed the data, AS prepared the draft manuscript, RPW, CM and KR retrieved the data. All authors read and approved the final manuscript.

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