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Original Article

Salmonella Typhi research in lower-middle-income economy countries: a bibliometric analysis (1990-2023)

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Abstract

Introduction: *Salmonella Typhi* continues to be a significant global public health concern. The objective of this study was to evaluate the literature pertaining to *S. Typhi* in lower-middle-income countries from 1990 to April 31, 2023.

Methodology: The bibliographic data was collected from the Web of Science database. Various bibliometric tools were utilized to conduct bibliometric analysis and visualization. Numerous bibliometric parameters were assessed, including the top publishing organizations, countries, institutions, authors, journals with the highest publication output, citation counts, commonly used keywords, and emerging research topics.

Results: The current study included a total of 4,031 articles. These articles exhibited an annual growth rate of 8.17%. Over the past 33 years, there has been a gradual increase in the overall quantity of articles. On average, these articles received 18.82 citations. A total of 13,987 authors from 3,665 affiliations and 118 countries contributed to these publications. The majority of publications originated from India (50.31%), Pakistan (15.40%), Nigeria (6.32%), Bangladesh (5.03%), and Iran (4.89%). Among the institutions, Oxford University published the highest number of articles (302), followed by the University of Karachi (124). The frequently used keywords included "*Salmonella Typhi*" (frequency = 231), "antimicrobial activity" (frequency = 191), and "resistance" (frequency = 190).

Conclusions: The findings of this study can serve as a foundation for future studies, enabling researchers to identify knowledge gaps and areas for further investigation. The data can also aid in health planning, providing insights into the current research landscape and highlighting priority areas for intervention and resource allocation.

Key words: Bibliometrics; *Salmonella* Typhi; publications.

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Introduction

Salmonella enterica subspecies *enterica* serovar *Typhi* (*Salmonella Typhi*) causes typhoid fever or enteric fever. This disease causes a systemic infection that is a major cause of morbidity and mortality especially in lower-middle-income countries (LMICs) and still remains a public health problem [1,2]. The people who live in places without access to better sanitation facilities and who are exposed to contaminated water or food are most at risk of developing this infection [3]. *Salmonella* is more prevalent in places where there is social unrest, overcrowding, and inadequate sanitation and is spread through the fecal-oral route by drinking contaminated water, undercooked food, and fomites of infected individuals. Humans are its sole host, and it can only spread from one sick person to another [2]. 57% of samples tested positive in research on the prevalence of *Salmonella* isolates in chicken slaughterhouses in China [4]. The disease's progression can start with early gastroenteritis and end with generalized systemic medical conditions, but it can also result in a variety of complications [2].

In order to explore the global incidence of typhoid fever, a systematic review and meta-analysis study was undertaken in 2019 across three databases (Ovid Medline, PubMed, and Scopus). While recognizing that the prevalence of typhoid fever varied greatly across time and geography, including consecutive years in the same site, this study highlighted Africa and Asia as regions with studies demonstrating a high incidence of typhoid fever. In comparison to the years prior to 2000, more recent research has generally found a lower incidence of typhoid fever. The criteria for collecting blood cultures varied, and there was little consistency among multiplier studies in the types of multipliers employed to estimate incidence, according to this study [5].

Clinical knowledge, accurate diagnosis, and awareness of the disease's epidemiology are all crucial for the control of typhoid fever. Despite extensive research conducted thus far, there are still significant gaps in our understanding of the biology of this bacterial pathogen, which has adapted to survive within the human body, as well as the complexities of the disease in endemic regions, particularly in Africa [6]. Typhoid fever poses a significant public health challenge in economically underdeveloped countries, particularly in economically disadvantaged regions of Asia and sub-Saharan Africa. In these areas, a large portion of the population lacks access to clean water, adequate sanitation, and hygienic infrastructure, further exacerbating the spread of the disease [6,7]. Ongoing transmission is fueled by both acutely infected patients and chronic asymptomatic carriers who shed the bacteria in their feces [7]. There are two primary obstacles to controlling typhoid fever. First, the development of multidrug-resistant strains compromises the effectiveness of antimicrobial treatment. Second, existing vaccines are not sufficiently immunogenic in very young infants. It is therefore essential for clinicians, microbiologists, and epidemiologists worldwide to stay informed about the evolving trends in enteric fever. This knowledge is crucial for effective case management and disease control [6].

The high morbidity and mortality rates of typhoid fever in LMICs underscore the urgent need for an integrated control strategy. By implementing such a strategy, there is potential to achieve disease eradication in the twenty-first century [7]. Bibliometrics is a multidisciplinary science that uses mathematical and statistical techniques to conduct quantitative analyses of works that are published and their references [8]. It is rare to undertake a knowledge mapping study of the literature on the prediction of infectious diseases using strict bibliometric approaches, which is meant to provide additional knowledge structure and distribution [8,9]. In order to objectively assess current trends and research hotspots, we applied a bibliometric analysis on the prediction of *S. Typhi* research in LMICs to serve as a resource for related researchers.

Methodology

Study design

The Web of Science was initially introduced in 1997 and was later rebranded as the Web of Science Core Collection in 2014 [10].

In this bibliometric study, a systematic search was conducted in the Web of Science Core Collection database. Firstly, the titles of all articles were screened for the following terms: '*Salmonella Typhi* ' OR '*S. Typhi*' OR '*Salmonella enterica* serovar *Typhi*'. To improve the quality of results we use the advanced search function, and the search rules were defined as follows: languages = 'all languages', document types = 'all document types', and time range = '1990 - 31 April 2023'.

A total of 8,583 documents in text format from the Web of Science database, spanning the period between 1990 and 31 April 2023, met the inclusion criteria [11]. Additionally, the names of LMICs were obtained based on the World Bank Country Credit Group guidelines for 2022-2023 [11] (Supplementary Table 1). Most LMICs are in Africa and Asia, where this disease is endemic; therefore, we selected these countries.

Since we focused on literature published in these countries, only these countries were selected from the country selection button and publications published by authors from other countries were excluded. In addition, since only research articles were to be analyzed, other publications (reviews, letters, book chapters, etc.) were excluded. The data obtained (titles, author information, keywords, references, and journal information, etc.) were downloaded to the computer in Bibtext and Excel files. The flow chart summarizes the study methodology (Supplementary Figure 1). The data set consisted of 9 separate "Bibtext " files because Web of Science only allows up to 500 results to be downloaded at once in the "BibTeX" " format. We combined these 9 "BibTeX" files. The publications were reviewed by the researchers for duplication.

The exclusion criteria included document types were other than research articles, documents that did not use *S. Typhi* in the research title; published documents in languages other than English and publications from countries other than LMICs.

Statistics and visual analysis

Visualization is crucial to the execution of bibliometrics analysis due to its ability to depict the composition and development of a specific research field [12]. There are many visualization tools available today to make bibliometric research more convenient. The included data were imported into Biblioshiny, bibliometrix version R 4.2.2 (an R-tool/Biblioshiny R version 4.2.2). This is an analysis program for bibliometric assessments. R is a free open-source program [13].

Additionally, the data (full record and references) were exported as 'tab delimited' format files uploaded to the Literature Metrology Online Analysis Platform

(https://bibliometric.com/app) for advanced bibliometric analysis.

The data set consisted of 9 separate "tab delimited" format files because the Web of Science database only allows up to 500 results to be downloaded at once in the "tab delimited filewere" format. We combined these 9 "tab delimited filewere" files.

The citation metrics that measure the bibliometric impact of specific authors, researchers, scholars, etc. are known as author-level metrics. Numerous metrics have been created that account for a variety of variables, from simply counting the total number of citations to analyzing how they are distributed among various papers or journals by using statistical or graph-theoretical methods [14]. The term "h-index" refers to the highest value of h for which a given author or journal has published at least h papers, each of which has received at least h citations [15]. The total number of citations or publications are simpler metrics that the h index is intended to outperform. Due to the vast differences in citation practices between different fields, the h index performs best when comparing researchers working in the same field [16].

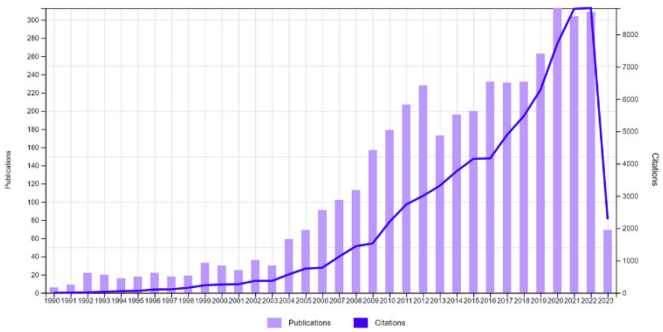
Leo Egghe proposed the g-index as an author-level metric in 2006 [17]. The g-index is a replacement for the more traditional h-index. There is no average number of citations in the h-index. The h-index, on the other hand, disregards the number of citations for very highly cited papers and only demands a minimum of n for the least-cited article in the set. In general, the effect is that as h increases, there are a greater number of papers with a certain quality threshold, and g allows citations from higher-cited papers to be used to support lower-cited papers in reaching this threshold. The g-index is essentially the highest possible value of the h-index if a fixed number of citations can be freely distributed among a fixed number of papers [17,18].

The m-index, which is the h-index divided by the time since initial publication, is another variation of the h-index. The h-index tends to rise as a career progresses, thus the m-index can be employed in circumstances when this is a weakness, such as when comparing academics in the same field but with completely different career trajectories. The m-index presupposes by default that there has been continuous research effort since the first publication [19].

Total citations (TC) refers to the total number of citations that a piece of writing that is part of a chosen collection has acquired from sources that are cataloged in a bibliographic database. As a result, TC counts citations for a chosen article from "all over the world". Bibliometrix counts the local citations or the citations that a reference — a document contained in at least one of the bibliographies of the articles in the specified collection — has received from other documents in the selected collection, in the most cited references section [13,20].

Consequently, we employed this technique to carry out a statistical analysis of each article published in the past 33 years with *S. Typhi* as the main research topic, including the primary information of the articles, the number of articles published each year, the annual citations, annual growth rate of the articles, main keywords, sources, authors, institutions, and countries, evolution, and trend of the themes, cooperation relationship among countries, primarily studied topics, etc.

Figure 1. Cumulative temporal trends in citation frequency and scholarly publications.



Results

General information

The present study included a total of 4031 articles on *S. Typhi* contributed by researchers from LMICs between 1990 - 31 April 2023. The annual growth rate of the articles was 8.17%. The actual annual production of articles during the research period is shown in Figure 1. It is obvious that during the past 33 years, the overall number of articles has gradually risen. 2020 was the year with the highest number of publications (n: 373). Also, 2021 and 2022 were the years with the highest number of citations (> 8000 citations). In Figure 1, the blue line shows the number of citations (including self-citation) and the bars show the number of articles. The data for Figure 1 was automatically retrieved from the Web of Science database.

The main language used for publishing the retrieved documents followed a similar trend to that of other international publications. Approximately 99.727% of the articles were published in English, while 0.223% were in French. A very small percentage, specifically 0.025%, were published in Indonesian and Russian. No papers were published in other languages.

Table 1 provides descriptive information concerning the articles identified in the dataset. On average, 8.17 articles are published annually on the subject. These articles received an average of 18.82 citations each. There were 69 articles that were single authored, while 3,968 articles involved multiple authors. On average, each article has 5.92 co-authors.

Most relevant countries, affiliations/universities and authors

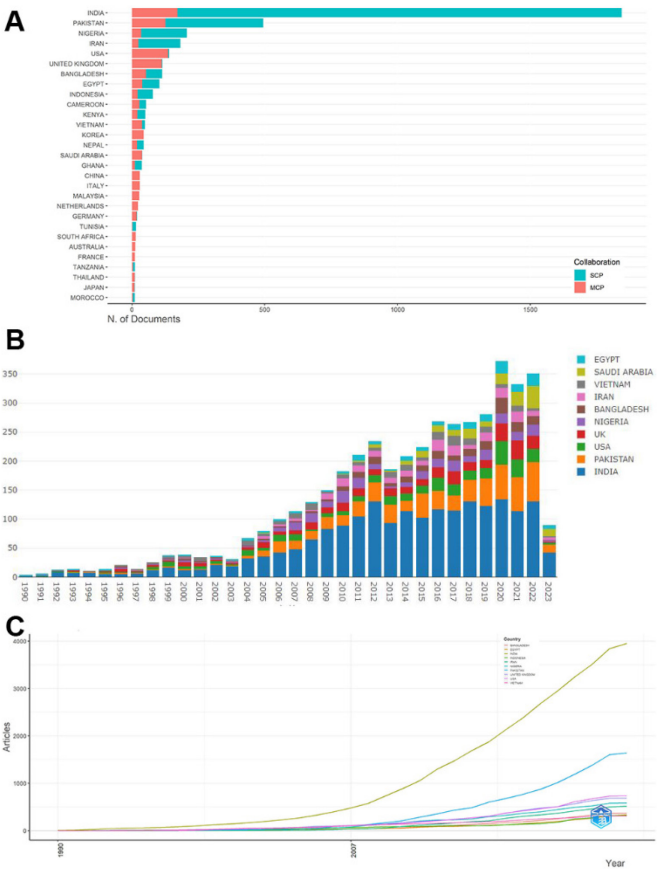
Based on our data, 13,987 authors from 3,665 affiliations and 118 LMIC countries published literature on *S. Typhi* between 1990 and 31 April 2023. Among them, the authors from India (n: 2029, 50.31%), Pakistan (n: 621, 15.40%), Nigeria (n: 255, 6.32%), Bangladesh (n: 203, 5.03%), and Iran (n: 197, 4.89%) published most of the publications on *S. Typhi*.

Figure 2A, 2B, and 2C present the pertinent data on the number of articles based on countries, the status of the study from one or more countries, and the number of articles per year. Publications from the countries in Figure 2A and Figure 2C were calculated by the Biblioshiny program based on the country to which the corresponding author belongs. Country collaboration, single (intra) country cooperation (SCP), and multi or cross-country cooperation (MCP) indices are presented in Figure 2A. Figure 2B was created with the Literature Metrology Online Analysis Platform. Since 2007, there has been an upward trend in the publications from the top 10 countries with the highest number of publications, with a particularly high growth trend in Indian publications (Figure 2C). 2020 was the year with the highest number of articles (number of articles: 313) published. Between 2020 and 2022, at least 300 articles were published per year and most articles were published in India (Figure 2B). Figure 3 presents the

Table 1. Descriptive information about the articles.

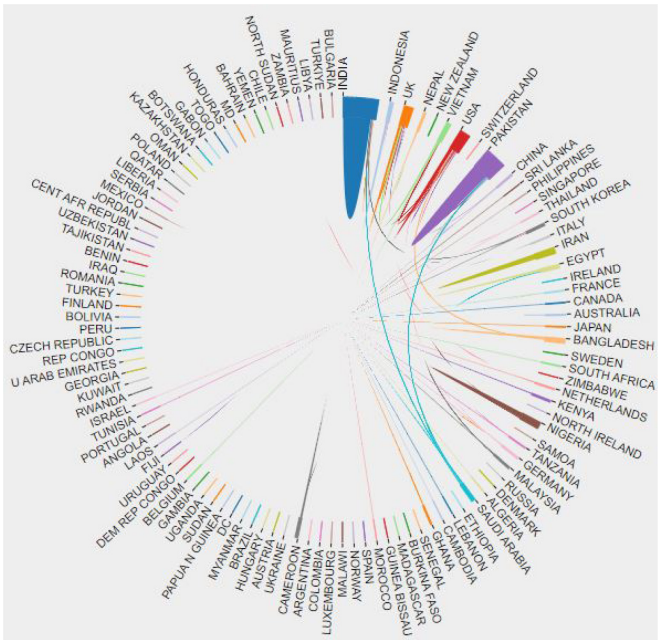
General information	n
Sources (journals, books, etc)	1035
Number of articles	4031
Annual growth rate %	8.17
Document average age	9.13
Average citations per article	18.82
References	91688
Document contents	
Keywords plus (ID)	5207
Author's keywords (DE)	7497
Authors	
Authors	13987
Authors of single-authored articles	63
Authors of multiple-authored articles	3968
Authors collaboration	
Single-authored articles	69
Co-authors per article	5.92
International co-authorships %	30.66

Figure 2 A. The countries of corresponding authors; **B.** Comprehensive analysis of literature distribution across predominantly publishing countries; **C.** Temporal evolution of research output in the leading publishing countries.



SCP: single country publication; MCP: multiple country publication.

Figure 3. Interrelationship among the primary publishing countries.



relationship between countries and was created with the Literature Metrology Online Analysis Platform. As visualized in Figure 3, publication links between countries are limited. The most cross-country links are between authors from India and Saudi Arabia.

The top 5 affiliations/universities with the most publications were located in England, Pakistan, Saudi Arabia, and India. Oxford University (302 articles) and University of Karachi (124 articles) accounted for 10.56% of all publications. The relevant data according to the number of articles based on affiliations/universities (number of responsible authors' affiliations/universities) is presented in Table 2. Additionally, Figure 4 displays the production of institutions' publication production over time. After 2007, there has been an increasing trend in the publications from the universities that produced the most publications, especially Oxford University (Figure 4).

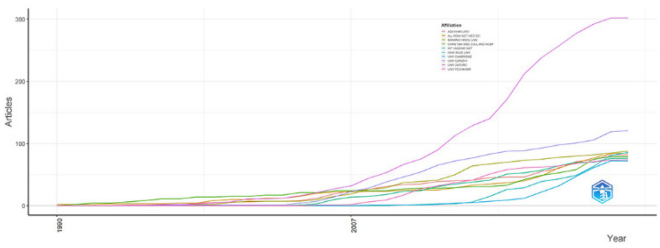
Based on the Web of Science database, 13,987 researchers were working on projects that are relevant to the study of *S. Typhi* in LMICs between 1990 and April 2023. Table 3 provides information on the 25 authors who published the most on the topic, including information on publication years, global total citation

Table 2. Most relevant affiliations/universities.

Affiliation/University	Number of articles	Total citations (including self citations)
Oxford University, England	302	3676
University of Karachi, Pakistan	124	1698
King Saud University, Saudi Arabia	89	1175
Banaras Hindu University, India	88	250
All India Institute of Medical Sciences, India	85	835
Aga Khan University, Pakistan	82	1254
Christian Medical College & Hospital, India	79	345
International Vaccine Institute, Korea	76	773
The University of Peshawar, Pakistan	75	101
the University of Cambridge, England	72	601
The Islamic Azad University, Iran	68	68
The London School of Hygiene & Tropical Medicine, England	66	842
Centers for Disease Control and Prevention, the United States	65	39
National Institute of Cholera and Enteric Diseases, India	62	668
Panjab University, Pakistan	62	109
Bahauddin Zakariya University, Pakistan	59	268
Wellcome Trust Sanger Institute, England	57	1136
The *National Research Centre* , Egypt	55	53
University of Nigeria, Nigeria	54	51
Annamalai University, France	50	34
The Bharathiar University, India	50	55
The University of Melbourne, Australia	50	829
The University of Yaoundé I, Cameroun	49	39
Duke University, the United States	48	765
Madurai Kamaraj University, India	48	75

*Web of Science database data.

Figure 4. Temporal trends in research output for top publishing institutions.



counts, index scores (h, g, and m index), and the number of publications. Professor Stephen Baker, Professor Gordon Dougan, and Professor John Wain were the most prolific contributors to publications on the study of *S. Typhi* in LMICs between 1990 and April 2023 (Table 3 and Figure 5A). Figure 5B presents the distribution of the studies by the mostly prolific authors by year.

Figure 5 A. Authors with the most publications; **B.** Production of authors with the most publications over time; **C.** Collaboration network analysis among predominantly publishing authors.

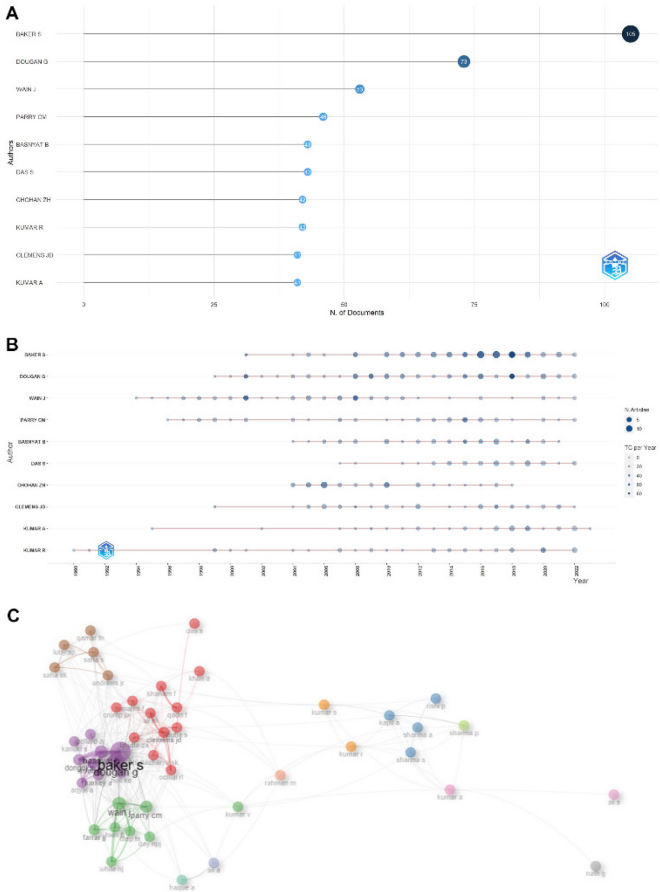


Table 3. Local impact of authors with most publications.

Authors	h_index	g_index	m_index	TC	NP	PY_start
Baker S	37	71	1,609	5293	105	2001
Dougan G	37	71	1,48	5125	73	1999
Waın J	36	53	1,2	4681	53	1994
Farrar JJ	29	36	1,16	1856	36	1999
Basnyat B	27	43	1,35	2163	43	2004
Dolecek C	26	29	1,444	2472	29	2006
Parry CM	26	46	0,929	2374	46	1996
Chohan ZH	25	42	1,25	2368	42	2004
Clemens JD	22	41	0,88	2182	41	1999
Hıen TT	22	25	0,733	2318	25	1994
Whıte NJ	22	29	0,733	1707	29	1994
Bhutta ZA	21	29	0,656	2072	29	1992
Holt KE	21	32	1,235	2360	32	2007
Crump JA	20	31	0,952	2445	31	2003
Dıep TS	20	24	0,667	1667	24	1994
Dongol S	20	33	1,429	1368	33	2010
Arjyal A	18	23	1,059	990	23	2007
Breıman RF	18	21	0,947	1487	21	2005
Farrar J	18	21	0,783	2430	21	2001
Karkey A	18	30	1,286	1252	30	2010
Nath G	17	32	0,63	1081	33	1997
Ochıaı RL	17	24	0,85	1380	24	2004
Patıl SA	17	23	1,063	1086	23	2008
Alı M	16	32	0,8	1368	32	2004
Campbell JI	16	19	0,889	1455	19	2006

*H index: Hirsch index; TC: total citations; NP: number of publications; PY start: publication year start [biblioshiny data].

Table 4. Publications with most global citations.

Article name, publishing year, journal	DOI	Total citations	Total citations per year
Parkhıll J, 2001, Nature	10.1038/35101607	938	40.78
Crump JA, 2010, Clın Infect Dıs	10.1086/649541	564	40.29
Ahmad I, 1998, J Ethnopharmacol	10.1016/S0378-8741(98)00055-5	500	19.23
Devı KP, 2010, J Ethnopharmacol	10.1016/j.jep.2010.04.025	475	33.93
Ochıaı RL, 2008, B World Health Organ	10.2471/BLT.06.039818	414	25.88
Nanda A, 2009, Nanomed-Nanotechnol	10.1016/j.nano.2009.01.012	413	27.53
Holt KE, 2008, Nat Genet	10.1038/ng.195	391	24.44
Kıngsley RA, 2009, Genome Res	10.1101/gr.091017.109	388	25.87
Klemm EJ, 2018, MBıo	10.1128/mBio.00105-18	350	58.33
Ingle A, 2008, Curr Nanoscı	10.2174/157341308784340804	336	21.00
Lın FYC, 2001, New Engl J Med	10.1056/NEJM200104263441701	325	14.13
Bagıhallı GB, 2008, Eur J Med Chem	10.1016/j.ejmech.2008.02.013	309	19.31
Sınha A, 1999, Lancet	10.1016/S0140-6736(98)09001-1	287	11.48
Wong VK, 2015, Nat Genet	10.1038/ng.3281	283	31.44
Stanaway JD, 2019, Lancet Infect Dıs	10.1016/S1473-3099(18)30685-6	281	56.20
Mostafa AA, 2018, Saudı J Bıol Scı	10.1016/j.sjbs.2017.02.004	271	45.17
Arora DS, 1999, Int J Antımıcrob Ag	10.1016/S0924-8579(99)00074-6	260	10.40
Roumagnac P, 2006, Scıence	10.1126/science.1134933	258	14.33
Chohan ZH, 2010, Eur J Med Chem	10.1016/j.ejmech.2010.02.053	248	17.71
Bonde CG, 2004, Bıoorgan Med Chem	10.1016/j.bmc.2004.02.024	247	12.35

Table 5. Journals with the most publications.

Sources	Articles	Country	Index
Internatıonal Journal of Pharmaceutıcal Scıences and Research	69	India	ESCI
Clınıcal Infectıous Dıseases	65	The United States	SCIE
Journal of Pure and Applıed Mıcrobıology	52	India	ESCI
Afrıcan Journal Of Bıotechnology***	51	NI**	NI**
PLoS Neglected Tropıcal Dıseases	51	United States	SCIE
PLoS One	50	United States	SCIE
Amerıcan Journal of Tropıcal Medıcıne and Hygıene	49	United States	SCIE
Pakıstan Journal of Pharmaceutıcal Scıences	44	Pakistan	SCIE
Indıan Journal of Medıcal Research	43	India	SCIE
Journal of Infectıon in Developıng Countrıes	42	Italy	SCIE

SCEI: Science Citation Index Expanded; ESCI: Emerging Sources Citation Index; **NI: no information; *** The journal has stopped updating.

In this study, we also examined the author's indexes (h, g, and m indexes) of the most published authors with the help of the Biblioshiny program. Professor Stephen Baker had the highest authors' index levels (Table 3). Figure 5C shows the collaboration network of the authors who published the most. The network analysis technique was used to depict the authors' relationship in Figure 5C. By determining the relationship between the most publishing authors, the software was able to group each in a different color.

Status of citations

The article by Parkhill J. published in Nature, had garnered 938 citations, as summarized in Table 4. Additionally, Figure 6 visualizes the most locally cited researchers, including Professor Stephen Baker (1,240 local citations), Professor John Wain (1,184 local citations), and Professor Gordon Dougan (1,093 local citations).

Sources

The articles on *S. Typhi* from LMICs were published in 1,035 different journals. Table 5 lists the top 10 journals according to the number of publications. The International Journal of Pharmaceutical Sciences and Research published the most research on *S. Typhi* from LMICs among the top 10 journals (n: 69). Clinical Infectious Diseases (CID) (n: 65) and Journal of Pure and Applied Microbiology (n: 52) were among the journals with the most publications. Figure 7A and Figure 7B show the production of the top journals over time.

Figure 6. Authors with highest local citations.

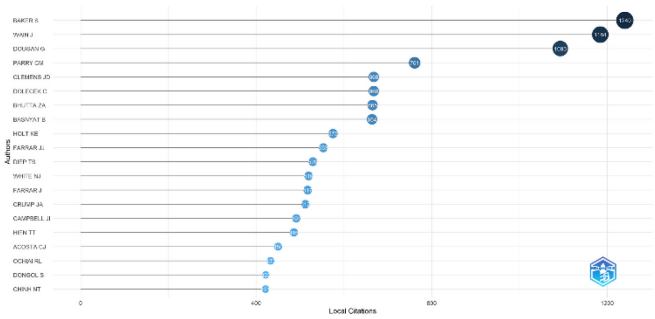
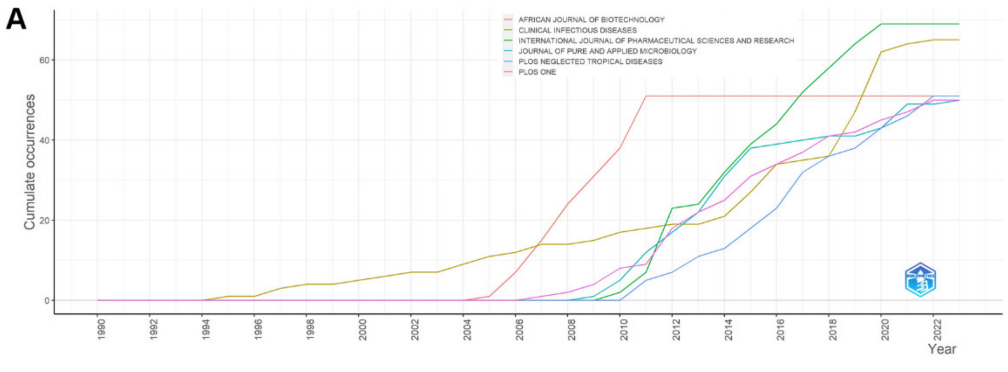


Figure 7 A. Temporal productivity analysis of leading publishing journals; **B.** Quantifying article output of top publishing journals over time.



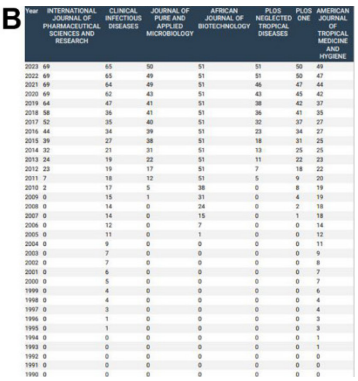


Table 6. Trending topics.

Keyword*	frequency	year_q1	year_med	year_q3
Antibacterial activity	382	2011	2015	2020
Salmonella typhi	365	2010	2016	2020
Antimicrobial activity	312	2010	2012	2017
Enteric fever	140	2013	2018	2020
Antioxidant	115	2016	2020	2021
Silver nanoparticles	69	2017	2019	2021
Antifungal activity	59	2010	2014	2018
Minimum inhibitory concentration	55	2010	2013	2016
Molecular docking	49	2019	2021	2022
Antibiotic resistance	48	2013	2017	2019
Metal complexes	46	2006	2010	2019
Phytochemical	26	2009	2011	2017
Essential oil composition	20	2007	2009	2011
Sulfonamides	12	2006	2008	2012
Ofloxacin	11	1998	2005	2016
İndonesia	11	2006	2007	2014

*With minimum 10 occurrences.

Key words and trend topics

Tables 6 and 7 demonstrate the trends in topics and the frequency of occurrence of the key words. The most used key word was “fever” (frequency = 375). However, it was observed that the terms "*Salmonella Typhi*” (frequency = 231), “antimicrobial activity” (frequency = 191), and “resistance” (frequency = 190) were among the frequently used keywords. Figure 8A indicates the frequency of occurrence of keywords over time. Figure 8B indicates the frequency rate of occurrence of keywords. Figure 8C shows the trend topics by year.

Discussion

Over the past few decades, numerous bibliometric analyses have been conducted on infectious diseases. However, there is a notable absence of comprehensive scientometric analyses specifically focused on *S. Typhi* research in LMICs. This study aims to fill that gap by conducting a bibliometric analysis of studies related to *S. Typhi* research in LMICs from 1990 to April 2023.

Figure 8 A. Evolution of top keywords over the years; **B.** Representation and analysis of data using TreeMap visualization; **C.** Emerging trend topics in publications.

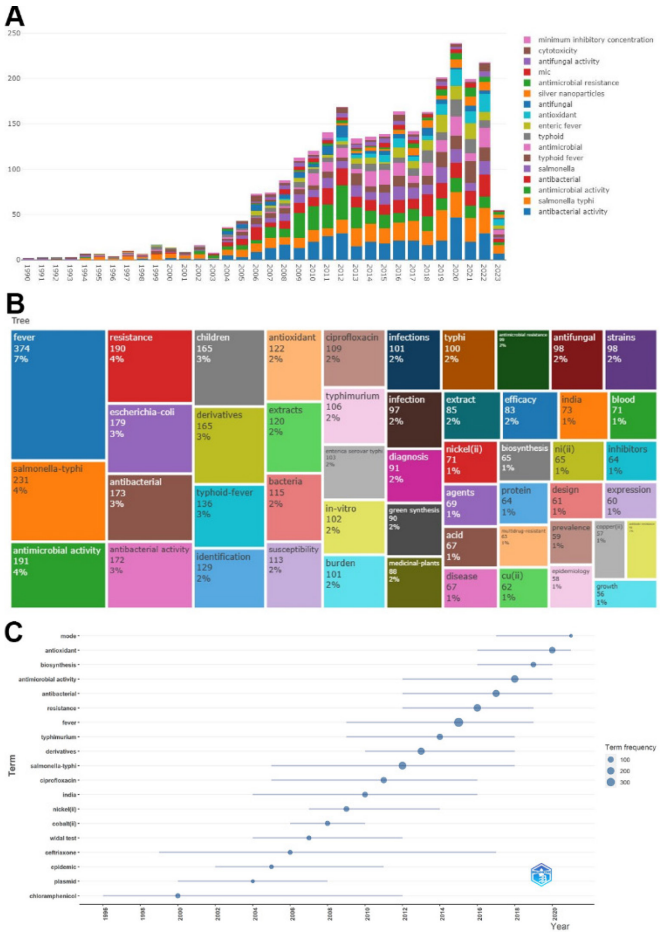


Table 7. Keyword frequency.

Terms	Frequency
Fever	374
Salmonella-typhi	231
Antimicrobial activity	191
Resistance	190
Escherichia-coli	179
Antibacterial	173
Antibacterial activity	172
Children	165
Derivatives	165
Typhoid-fever	136
İdentification	129
Antioxidant	122
Extracts	120
Bacteria	115
Susceptibility	113
Ciprofloxacin	109
typhimurium	106
enterica serovar Typhi	103
İn-vitro	102
Burden	101
İnfections	101
Typhi	100

The analysis included identifying publications on the topic from various journals, authors, universities, and publishing countries. Furthermore, *S. Typhi*-related keywords, citations, trending literature titles, and author clusters were examined to gain deeper insights into the research landscape. By conducting this scientometric analysis, the study aimed to provide a comprehensive overview of the research conducted on *S. Typhi* in LMICs, shedding light on key contributors, research trends, and significant literature in the field.

This study employed Biblioshiny, a bibliometric software, as a primary novel tool to conduct an objective analysis of the current state and research hotspots from a bibliometrics perspective [20]. Additionally, the researchers utilized the Literature Metrology Online Analysis Platform (https://bibliometric.com/app) for advanced bibliometric analysis. These tools facilitated the systematic and comprehensive examination of various bibliometric indicators, enabling the study to gain valuable insights into the *S. Typhi* research landscape in LMICs.

In accordance with the dataset retrieved from the Web of Science Core Collection, an extensive compilation of 4,031 publications concerning the investigation of *S. Typhi* in LMICs during the period spanning from 1990 to April 2023 was identified. This corpus of work encompassed contributions from a total of 13,987 authors affiliated with 3,665 distinct affiliations and originating from 118 countries. Notably, subsequent to 2007, the number of publications focusing on *S. Typhi* studies in LMICs

experienced a rapid expansion, with an annual growth rate of 8.17%.

By the year 2020, the publication rate had increased to 373 papers per year. Furthermore, it is of significance to highlight that 2020 emerged as the year with the highest frequency of publications, amounting to 373 articles. Additionally, both 2021 and 2022 displayed an extraordinary concentration of citations, surpassing 8,000 citations in each year. On average, each of these articles garnered approximately 18.82 citations.

The World Health Organization (WHO) has reported a significant decline in the morbidity and mortality rates associated with *S. Typhi* infections in developed nations due to improved living conditions and the availability of antibiotics. However, many developing nations in the WHO's African, Eastern Mediterranean, South-East Asia, and Western Pacific Regions continue to face challenges in combating this disease. According to estimates from 2019, there are approximately 9 million cases of typhoid fever annually, resulting in about 110,000 deaths. Children are particularly vulnerable, and populations lacking access to clean water and adequate sanitation facilities are at a higher risk of contracting typhoid [21]. In our study, we specifically focused on publications from LMICs in order to analyze the publications on *S. Typhi* in developing economies, as defined by the World Bank Country Credit Group guidelines for 2022-2023 [11]. Our findings revealed that out of the 52 countries classified as LMICs, 18 countries (Bhutan, Cape Verde, Djibouti, El Salvador, Eswatini, Ivory Coast, Kiribati, Kyrgyzstan, Lesotho, Mauritania, Micronesia, Mongolia, Nicaragua, Palestine, Sao Tome and Principe, Solomon Islands, Timor-Leste, and Vanuatu) had no publications on this topic. Furthermore, 11 countries (Angola, Bolivia, Comoros, Haiti, Honduras, Myanmar, Samoa, Sri Lanka, Tajikistan, Ukraine, and Uzbekistan) had only 1-5 publications, and four countries (Benin, Papua New Guinea, Republic of the Congo, and Senegal) had 6-10 publications. Among LMICs, only 19 countries had published more than 11 articles on *S. Typhi* within the last 33 years (Supplementary Table 2). In terms of the authorship distribution, our analysis revealed that the majority of publications were contributed by authors from India (50.31%), followed by Pakistan (15.40%), Nigeria (6.32%), Bangladesh (5.03%), and Iran (4.89%). Notably, India emerged as the leading country in terms of publications within this field, considering contributions from both within the country and the broader region.

According to large-scale community research carried out in an urban slum in India, *S. Typhi* infections affect as many as 2/1000 children under the age of five and 5.1/1000 children under the age of 10 per year [22]. Another study from north India reported that children between 5 to 12 years old accounted for the majority of typhoid fever cases, with children under five years old accounting for 24.8% of cases [23]. Considering the importance and prevalence of *S. Typhi* infections in India as seen in these studies [22,23], the highest number of publications can be attributed to this situation. In addition, the fact that the journals that publish the most publications originate from India may be another reason.

By analyzing the contributions of important researchers and affiliations/universities in a certain topic, academics might advance that field in new and innovative ways [24,25]. Based on our findings, the analysis of affiliations/universities involved in *S. Typhi* publications revealed that the top five institutions were situated in England, Pakistan, Saudi Arabia, and India. Notably, Oxford University and the University of Karachi were the leading universities in terms of their institutional contributions to this field of research. Furthermore, when considering author contributions, Professor Stephen Baker, Professor Gordon Dougan, and Professor John Wain emerged as the top three authors in terms of their publication output. It is worth highlighting that Professor Stephen Baker attained the highest author index levels among them.

Evaluating the journals with the highest number of publications on a topic can help researchers find journals to publish their research [25,26]. Based on our findings, the International Journal of Pharmaceutical Sciences and Research, based in India, emerged as the primary publisher of *S. Typhi* publications from LMICs. This journal focuses specifically on articles related to Pharmaceutical Sciences. In addition to that, two other prominent publishing journals in this field were identified: Clinical Infectious Diseases, published in the United States, and the Journal of Pure and Applied Microbiology, also published in India. Both of these journals cover a wide range of topics within the realms of microbiology and clinical infectious diseases. The research hotspots and directions in a certain topic might be reflected in keywords [25,27].

The disease control strategies must include early diagnosis, surveillance, and a vaccine to prevent the disease. Another important factor in lessening the impact of this disease is sanitation and hygiene. Effective prevention and control strategies have been recommended taking into account the present state of

diagnostics, recent surveillance procedures, and vaccine research activities. But the difficulties in each of these areas continue, which makes it difficult to employ the tools that are accessible. Therefore, a comprehensive policy framework and integrative approach are needed for the prevention, control, and eradication of typhoid fever [28].

A previous study has indicated that fluoroquinolone (FQ) resistance is progressively replacing multidrug-resistant (MDR) strains of enteric fever in India [29]. Another study conducted between 2016 and 2019 investigated antimicrobial resistance in typhoidal *Salmonella*, involving 8,705 confirmed cases of enteric fever through blood culture. The majority of cases (56%) were reported from Bangladesh, followed by Nepal (18%) and Pakistan (26%). Out of these cases, 87% were identified as *S. Typhi*. The prevalence of MDR *S. Typhi* isolates was 17% in Bangladesh, 1% in Nepal, 16% in Pakistan, and 64% were classified as extensively drug-resistant (XDR) in Pakistan. Quinolone insensitivity was observed in 98% of *S. Typhi* isolates from Bangladesh, 95% from Pakistan, and 87% from Nepal. Additionally, azithromycin insensitivity was identified in 2% of isolates in Bangladesh, 67% in Nepal, and 0.59% in Pakistan [30]. In our study, it was evident that keywords such as "*Salmonella Typhi*" (frequency = 231), "antimicrobial activity" (frequency = 191), and "resistance" (frequency = 190) were frequently utilized. This suggests that antibiotic resistance is a significant and trending topic within the field. Notably, studies addressing this subject have gained considerable importance, particularly in recent years.

Conclusions

This pioneering study is the first to comprehensively investigate research articles on *S. Typhi* originating from LMICs within the time frame of 1990 to 31 April 2023. In addition to novel bibliometric tools, such as the R-based tool Biblioshiny, our study employed advanced analytical approaches to provide a detailed analysis of the subject. The primary findings of this study reveal a consistent and noteworthy increase in the number of publications on *S. Typhi* from LMICs, with a particular emphasis on the substantial growth observed in India. However, it is concerning to note that there are LMIC countries where no publications have been generated regarding *S. Typhi*. This underscores the urgent need for increased support and resources to empower researchers in these countries, allowing them to contribute to the field and address the existing knowledge gaps pertaining to *S. Typhi*. Such support is crucial to facilitate a more comprehensive understanding of this infectious disease and to enhance global efforts in combating it effectively.

Limitations

This study employed a single database to retrieve data, utilizing selected keywords and a time span limited from 1990 to April 2023. However, it is important to acknowledge that the inclusion of data from the year 2023 may introduce potential biases, as the update of the Web of Science database may not have been completed at the time of data collection. Consequently, the dataset obtained may not fully encompass the entirety of the available literature. Furthermore, it is crucial to recognize that the presence of articles that do not specify countries can also introduce bias into the analysis. The absence of country-specific information may limit the accuracy and comprehensiveness of the findings. These limitations highlight the need for caution in interpreting the results, emphasizing that the conclusions drawn from this study should be considered within the context of these potential biases and limitations. Future studies could aim to address these limitations by employing multiple databases and implementing additional strategies to ensure a more comprehensive and unbiased analysis of *S. Typhi* research articles from LMICs.

Ethical approval

In this study, ethical standards were followed. As the data used in this study was obtained from the Web of Science database and consisted of bibliometric data, which does not involve human subjects or sensitive information, ethical approval was not necessary. The use of publicly available data from reputable sources like the Web of Science database does not typically require specific ethical clearance. Nonetheless, the study was conducted in accordance with professional standards and guidelines for data analysis and reporting.

References

1. GBD 2017 Disease and Injury Incidence and Prevalence Collaborators (2018) Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories Lancet 392: 1789-1858. doi: 10.1016/S0140-6736(18)32279-7.
2. Bhandari J, Thada PK, DeVos E (2022) Typhoid Fever. StatPearls Publishing. Available: https://www.ncbi.nlm.nih.gov/books/NBK557513/. Accessed: 1 May 2023.
3. Soper G (1907) The work of a chronic typhoid germ distributor. J Am Med Assoc XLVIII: 2019-2022. doi: 10.1001/jama.1907.25220500025002d.
4. Gu D, Wang Z, Tian Y, Kang X, Meng C, Chen X, Pan Z, Jiao X (2020) Prevalence of *Salmonella* isolates and their

distribution based on whole-genome sequence in a chicken slaughterhouse in Jiangsu, China. Front Vet Sci 7: 29. doi: 10.3389/fvets.2020.00029.
5. Marchello CS, Hong CY, Crump JA (2019) Global typhoid fever incidence: a systematic review and meta-analysis. Clin Infect Dis 68 Suppl 2: S105-S116. doi: 10.1093/cid/ciy1094.
6. Wain J, Hendriksen RS, Mikoleit ML, Keddy KH, Ochiai RL (2015). Typhoid fever. Lancet 385: 1136-1145. doi: 10.1016/S0140-6736(13)62708-7.
7. Khanam F, Ross AG, McMillan NAJ, Qadri F (2022) Toward typhoid fever elimination. Int J Infect Dis 119: 41-43. doi: 10.1016/j.ijid.2022.03.036.
8. Osareh F (1996) Bibliometrics, citation analysis and co-citation analysis: a review of literature. Libri 46: 149-158. doi: 10.1515/libr.1996.46.3.149.
9. Yang W, Zhang J, Ma R (2020) The prediction of infectious diseases: a bibliometric analysis. Int J Environ Res Public Health 17: 6218. doi: 10.3390/ijerph17176218.
10. Liu W (2019) The data source of this study is Web of Science Core Collection? Not enough. Scientometrics 121: 1815-1824. doi: 10.1007/s11192-019-03238-1.
11. The World Bank (2023) 2022-2023 World Bank country lending group guidelines. Lower-middle-income economy countries. Available: https://worldpopulationreview.com/country-rankings/middle-income-countries. Accessed: 1 May 2023.
12. Small H (1999) Visualizing science by citation mapping. J Am Soc Inf Sci 50: 799-813. doi: 10.1002/(SICI)1097-4571(1999)50:9<799::AID-ASI9>3.0.CO;2-G.
13. Aria M, Cuccurullo C (2017). Bibliometrix: an R-tool for comprehensive science mapping analysis. Journal of Informetrics 11: 959-975. doi: 10.1016/j.joi.2017.08.007.
14. Wikipedia (nd) Author-level metrics. Available: https://en.wikipedia.org/wiki/Author-level_metrics. Accessed: 1 May 2023.
15. McDonald K (2005) Physicist proposes new way to rank scientific output. PhysOrg. Available: https://en.wikipedia.org/wiki/Phys.org. Accessed: 1 May 2023.
16. London School of Economics (nd) Impact of social sciences - 3: key measures of academic influence. LSE impact of social sciences blog (section 3.2). Available: https://blogs.lse.ac.uk/impactofsocialsciences/the-handbook/chapter-3-key-measures-of-academic-influence/#journals. Accessed: 1 May 2023.
17. Egghe L (2006). Theory and practise of the g-index. Scientometrics 69: 131-152. doi: 10.1007/s11192-006-0144-7.
18. Tol Richard SJ (2008). A rational, successive g-index applied to economics departments in Ireland. J Informetr 2: 149-155. doi: 10.1016/j.joi.2008.01.001.
19. University of Pittsburgh Library System (nd) Author-level metrics. Available: https://pitt.libguides.com/bibliometricIndicators/AuthorMetrics. Accessed: 5 May 2023.
20. Aria M, Cuccurullo C (2023) Package 'bibliometrix' March 7, 2023. Available: https://cran.r-project.org/web/packages/bibliometrix/bibliometrix.pdf. Accessed: 1 May 2023.
21. World Health Organization (2023) Typhoid. Available: https://www.who.int/news-room/fact-sheets/detail/typhoid. Accessed: 5 May 2023.
22. Sur D, von Seidlein L, Manna B, Dutta S, Deb AK, Sarkar BL, Kanungo S, Deen JL, Ali M, Kim DR, Gupta VK, Ochiai RL, Tsuzuki A, Acosta CJ, Clemens JD, Bhattacharya SK (2006). The malaria and typhoid fever burden in the slums of Kolkata, India: data from a prospective community-based study. Trans R Soc Trop Med Hyg 100: 725-733. doi: 10.1016/j.trstmh.2005.10.019.
23. Walia M, Gaind R, Paul P, Mehta R, Aggarwal P, Kalaivani M (2006) Age-related clinical and microbiological characteristics of enteric fever in India. Trans R Soc Trop Med Hyg 100: 942-948. doi: 10.1016/j.trstmh.2006.02.015.
24. Kodonas K, Fardi A, Gogos C, Economides N (2021) Scientometric analysis of vital pulp therapy studies. Int Endod J 54: 220-230. doi: 10.1111/iej.13422.
25. Ekici A, Alkan S, Aydemir S, Gurbuz E, Unlu AH (2022) Trends in *Naegleria fowleri* global research: a bibliometric analysis study. Acta Trop 234: 106603. doi: 10.1016/j.actatropica.2022.106603.
26. Escobedo AA, Arencibia R, Vega RL, Rodríguez-Morales AJ, Almirall P, Alfonso M (2015) A bibliometric study of international scientific productivity in giardiasis covering the period 1971-2010. J Infect Dev Ctries 9: 76-86. doi: 10.3855/jidc.5785.
27. Şahin S, Alkan S (2023) Contribution of Turkey in heart transplant research: a Web of Science database search. Exp Clin Transplant 21: 150-157. doi: 10.6002/ect.2022.0291.
28. Mukhopadhyay B, Sur D, Gupta SS, Ganguly NK (2019). Typhoid fever: control & challenges in India. Indian J Med Res 150: 437-447. doi: 10.4103/ijmr.IJMR_411_18.
29. Britto CD, John J, Verghese VP, Pollard AJ (2019) A systematic review of antimicrobial resistance of typhoidal *Salmonella* in India. Indian J Med Res 149: 151-163. doi: 10.4103/ijmr.IJMR_830_18.
30. Qamar FN, Yousafzai MT, Dehraj IF, Shakoor S, Irfan S, Hotwani A, Hunzai MJ, Thobani RS, Rahman N, Mehmood J, Hemlock C, Memon AM, Andrews JR, Luby SP, Garrett DO, Longley AT, Date K, Saha SK (2020) Antimicrobial resistance in typhoidal *Salmonella*: surveillance for enteric fever in Asia project, 2016-2019. Clin Infect Dis 71 Suppl 3: S276-S284. doi: 10.1093/cid/ciaa1323.

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Annex – Supplementary items

Supplementary Table 1. Lower-middle-ıncome economy countries.

Algeria	Ghana	Micronesia	Sao Tome and Principe
Angola	Haiti	Mongolia	Senegal
Bangladesh	Honduras	Morocco	Solomon Islands
Benin	India	Myanmar	Sri Lanka
Bhutan	Indonesia	Nepal	Tajikistan
Bolivia	Iran	Nicaragua	Tanzania
Cambodia	Ivory Coast	Nigeria	Timor-Leste
Cameroon	Kenya	Pakistan	Tunisia
Cape Verde	Kiribati	Palestine	Ukraine
Comoros	Kyrgyzstan	Papua New Guinea	Uzbekistan
Djibouti	Laos	Philippines	Vanuatu
Egypt	Lebanon	Republic of the Congo	Vietnam
El Salvador	Lesotho	Samoa	Zimbabwe
Eswatini	Mauritania		

Supplementary Table 2. Number of articles from lower-middle-ıncome economy countries.

Country	Number of articles	Country	Number of articles
Algeria	17	Mauritania	0
Angola	1	Micronesia	0
Bangladesh	203	Mongolia	0
Benin		Morocco	16
Bhutan	7	Myanmar	4
Bolivia	2	Nepal	111
Cambodia	26	Nicaragua	0
Cameroon	65	Nigeria	255
Cape Verde	0	Pakistan	621
Comoros	1	Palestine	0
Djibouti	0	Papua New Guinea	6
Egypt	173	Philippines	17
El Salvador	0	Republic of the Congo	9
Eswatini	0	Samoa	4
Ghana	67	Sao Tome and Principe	0
Haiti	1	Senegal	9
Honduras	1	Solomon Islands	0
India	2030	Sri Lanka	5
Indonesia	116	Tajikistan	2
Iran	197	Tanzania	45
Ivory Coast	0	Timor-Leste	0
Kenya	83	Tunisia	21
Kiribati	0	Ukraine	4
Kyrgyzstan	0	Uzbekistan	2
Laos	15	Vanuatu	0
Lebanon	8	Vietnam	191
Lesotho	0	Zimbabwe	11

This table summarizes the corresponding authors' country (the Web of Science database data).

Supplementary Figure 1. Search methodology in publication analysis.