Journal of the American Mosquito Control Association, 39(4):258–277, 2023

MOSQUITO-BORNE DISEASES IN INDIA OVER THE PAST 50 YEARS AND THEIR GLOBAL PUBLIC HEALTH IMPLICATIONS: A SYSTEMATIC REVIEW

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ABSTRACT. Mosquito-borne diseases (MBDs) pose a significant public health concern globally, and India, with its unique eco-sociodemographic characteristics, is particularly vulnerable to these diseases. This comprehensive review aims to provide an in-depth overview of MBDs in India, emphasizing their impact and potential implications for global health. The article explores distribution, epidemiology, control or elimination, and economic burden of the prevalent diseases such as malaria, dengue, chikungunya, Japanese encephalitis, and lymphatic filariasis, which collectively contribute to millions of cases annually. It sheds light on their profound effects on morbidity, mortality, and socioeconomic burdens and the potential for international transmission through travel and trade. The challenges and perspectives associated with controlling mosquito populations are highlighted, underscoring the importance of effective public health communication for prevention and early detection. The potential for these diseases to spread beyond national borders is recognized, necessitating a holistic approach to address the challenge. A comprehensive literature search was conducted, covering the past five decades (1972–2022), utilizing databases such as Web of Science, PubMed, and Google Scholar, in addition to in-person library consultations. The literature review analyzed 4,082 articles initially identified through various databases. After screening and eligibility assessment, 252 articles were included for analysis. The review focused on malaria, dengue, chikungunya, Japanese encephalitis, and lymphatic filariasis. The included studies focused on MBDs occurrence in India, while those conducted outside India, lacking statistical analysis, or published before 1970 were excluded. This review provides valuable insights into the status of MBDs in India and underscores the need for concerted efforts to combat these diseases on both national and global scales through consilience.

KEY WORDS Chikungunya, dengue, filariasis Japanese encephalitis, malaria

INTRODUCTION

India, the world's fifth strongest economy, is highly diverse in terms of its multireligious, multiethnic, multicultural, and multilingual compositions. It shares its borders with various countries: on the east, India is bordered by Myanmar and Bangladesh; on the north, its borders brace those of Bhutan, Nepal, and China; on the west, India shares borders with Pakistan; and on the peninsular south lies the Indian Ocean. This geographical positioning grants India a unique blend of cultural influences and trade opportunities. With its rich tapestry of traditions, languages, and customs, India serves as a melting pot of diversity, creating a vibrant and dynamic society (Namrata Goswami 2016).

By the turn of 2022, on one hand, while India emerged as the world's most populous nation with 1.4 billion people, on the other hand, it also witnessed remarkable growth in prosperity, consolidating its position among the five top economies globally. India, an agrarian nation, is fortunate to receive two monsoon rainy seasons: a heavy and prolonged southwest monsoon from May to September, and a shorter and milder northeast monsoon in November and December. This climatic pattern supports year-round agricultural practices, with a particular focus on paddy cultivation (Prasanna 2014). However, this also creates favorable conditions for the proliferation of disease-carrying vectors, such as the *Culex* mosquito species, including *Culex quinquefasciatus* Say*, Culex tritaeniorhynchus* Giles*, Cx. pseudovishnui* Colless*,* and *Cx. gelidus* Theobald. Among the various diseases transmitted by these mosquitoes, Japanese encephalitis has emerged as a significant and debilitating health concern in recent times due mainly to a higher case fatality rate among children below 12 years of age (Tyagi et al. 2015).

Over the past few decades, urban agglomeration and human densification have been a discernible trend, leading to the creation of numerous new urban towns and cities. Many metropolises have transformed into megapolises, attracting malaria (*Anopheles stephensi* Listen), dengue (*Aedes aegypti* (L.)), and filariasis (*Cx. quinquefasciatus*) vectors, which have successfully adapted to diverse urban ecosystems. Changes in El Niño–influenced monsoons have been observed in India, resulting in a slight shift in climate patterns. This, in turn, affects rain-dependent agriculture practices and the behavior of vector mosquitoes in terms of their orientation, biting habits, and breeding patterns. Given the country's demographic nature, India bears a significant burden of MBDs, which disproportionately impact impoverished populations (Mullen and Durden 2019).

Global warming, as a consequence of climate change, driven by human activities, has substantial implications for mosquito-borne diseases (MBDs). The rising temperatures associated with global warming create favorable conditions for mosquitoes, enhancing the risk of transmission for diseases they carry. Moreover, climate change influences the geographic distribution

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of mosquitoes, enabling them to expand their range into previously unaffected regions. Changes in precipitation patterns and water availability further impact mosquito breeding habitats, affecting the proliferation and spread of these diseases (Rossati 2017).

Climate change has observable impacts on the transmission and spread of vector-borne diseases, and these effects are expected to worsen. The increase in global temperatures caused by human-driven greenhouse gas emissions profoundly influences the strategies employed to prevent and control these diseases, as warmer conditions favor the proliferation of disease-carrying vectors. Understanding the intricate relationship between climate and disease dynamics, transmission patterns, and geographic distribution is challenging due to the presence of various contributing factors such as rising temperatures and humidity. The burden of vector-borne diseases is particularly significant in tropical and subtropical low- and middle-income countries, demanding focused attention and targeted measures (Rocklov and Dubrow 2020).

India hosts a diverse range of 415 mosquito species, as documented by Tyagi et al. (2015). It is worth noting that among these species, fewer than 20 have been identified as primary or secondary vectors of diseases. However, it is important to acknowledge the possibility of additional cryptic, sibling, or subtypes of species that have not been considered in this analysis. In India, the following diseases are associated with specific genera and dominant vector species (Tyagi 2008, Kumar and Ghosh 2020):

i. Malaria: *Anopheles culicifacies* Giles*, An. stephensi, An. philippinensis* Ludlow*, An. fluviatilis* James*, An. minimus* Theobald*, An. baimaii*, An. sundaicus* (Rodenwaldt).
ii. Dengue and chikungunya: *Aedes aegypti, Ae. albopictus* (Skuse).
iii. Lymphatic filariasis: *Culex quinquefasciatus*.
iv. Japanese encephalitis: *Culex. tritaeniorhynchus, Cx. gelidus, Cx. vishnui* Theobald*, Cx. pseudovishnui*.

Mosquitoes serve as vectors for a range of human illnesses caused by protozoa, helminths, and viruses (Tyagi 2003, Service 2008). Mosquito-borne diseases pose a significant risk to more than 80% of the global population, making them the primary contributor to the burden of human vector-borne diseases. There is a growing concern regarding the increasing incidence and geographical spread of MBDs worldwide, with new areas experiencing the emergence of these diseases (Franklinos et al. 2019). These diseases, including malaria, dengue, chikungunya, Japanese encephalitis, and lymphatic filariasis, pose a significant global public health challenge, affecting a substantial number of individuals. Transmission occurs primarily through mosquito bites, which play a pivotal role in the spread of these diseases (Lee et al. 2018, Thongsripong et al. 2021). Collectively, vector-borne diseases account for more than 17% of all infectious diseases globally and are responsible for more than 700,000 deaths annually. Among these diseases, malaria and dengue alone contribute to nearly 450,000 fatalities (WHO 2022a).

In 2017 the World Health Assembly approved the "Global Vector Control Response" (GVCR) 2017–2030. This initiative provides strategic guidance to countries and development partners, emphasizing the urgent need to strengthen vector control as a crucial method for preventing diseases and responding to disease outbreaks. It calls for the realignment of vector control programs, improved technical capacity, enhanced infrastructure, strengthened monitoring and surveillance systems, and community mobilization. By implementing a comprehensive approach to vector control, the GVCR aims to support the achievement of disease-specific national and global goals, while contributing to the attainment of the Sustainable Development Goals and Universal Health Coverage. Efforts are currently underway in India to eliminate these diseases by the year 2030 (WHO 2022b).

A systematic review of MBDs in India over the past 50 years is important for several reasons. First, it can provide a comprehensive understanding of the trends and patterns of MBDs in the country, which can inform the development of effective prevention and control strategies. Second, the global public health implications of MBDs in India are significant. The country's extensive engagement with the international community through travel and trade increases the risk of both importing and exporting these diseases. As a result, addressing MBDs in India becomes crucial not only for safeguarding the health of its own population, but also for global public health, considering the potential for global spread.

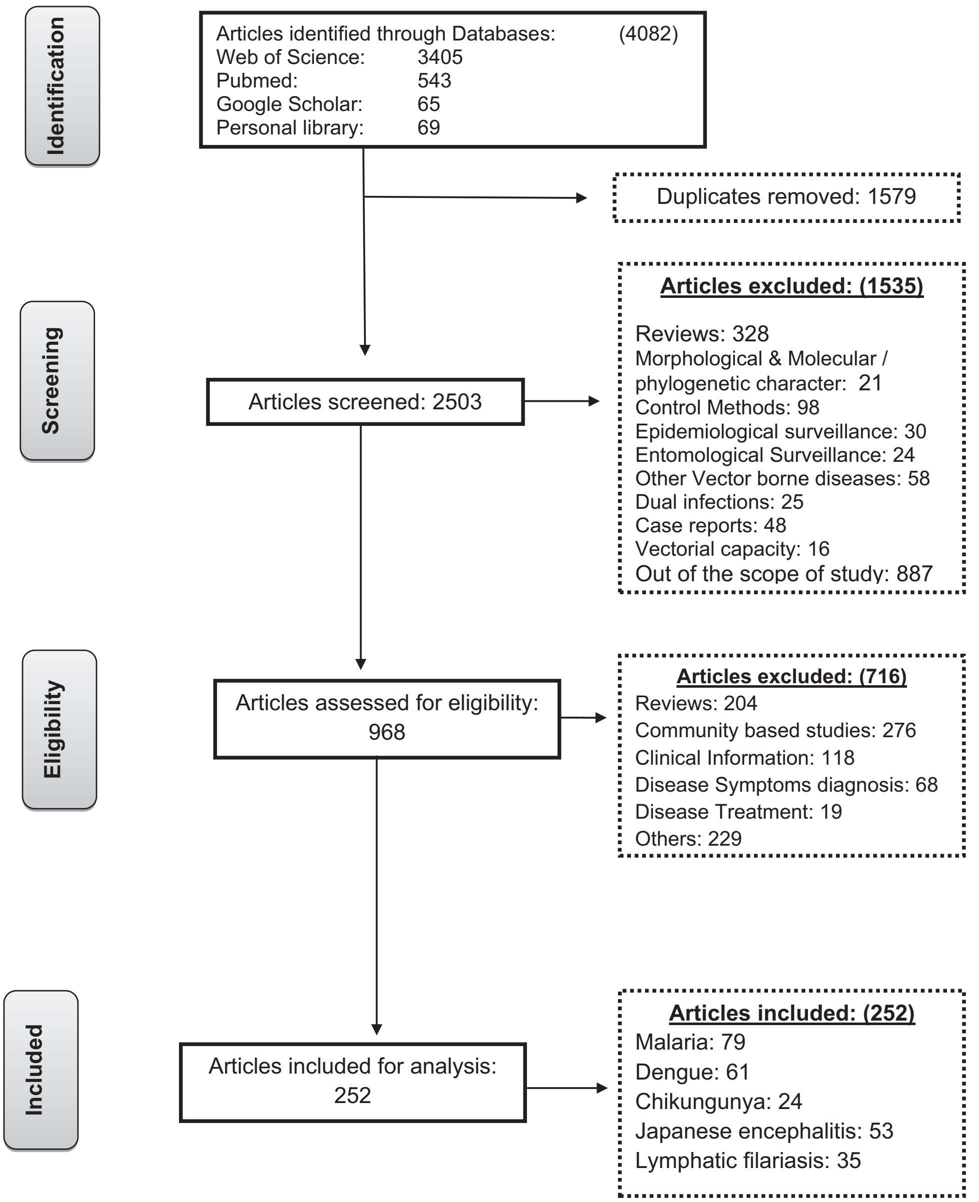
METHODOLOGY

Literature review: A comprehensive literature review of relevant articles was conducted across multiple databases and sources. The results of the search are summarized in Table 1. The search process involved querying various databases, namely, Web of Science (3,405 articles), PubMed (543 articles), and Google Scholar (65 articles), using specific keywords related to MBDs in India, including malaria, dengue, chikungunya, Japanese encephalitis, and lymphatic filariasis. Additionally, 69 articles were obtained from personal libraries and in-person consultations. In total, the initial search yielded 4,082 articles.

Following the initial search, a screening procedure was performed based on the titles and abstracts of the articles, resulting in the exclusion of 2,503 articles deemed irrelevant or duplicative. The remaining articles underwent a thorough eligibility assessment based on predetermined inclusion and exclusion criteria. A total of 968 articles were evaluated for eligibility, and 716 articles were excluded based on the criteria outlined in Table 1. The reasons for exclusion included being reviews, community-based studies, clinical information, disease symptom diagnosis, disease treatment, or falling into other categories.

A total of 252 articles that satisfied the predetermined inclusion criteria were selected and subjected to analysis.

Table 1. Flow chart of the literature review from article identification, screening, eligibility assessment, to inclusions.



These articles encompassed a range of diseases, as specified in Table 1, with distinct quantities assigned to each disease (malaria: 79 articles; dengue: 61 articles; chikungunya: 24 articles; Japanese encephalitis: 53 articles; lymphatic filariasis: 35 articles). Through an in-depth examination, publicly accessible data regarding cases and fatalities spanning a period of 50 years were utilized in the analysis.

Normalization of data: Normalization is a crucial step in the study to address the wide range of reported cases and deaths associated with diseases like malaria, dengue, chikungunya, Japanese encephalitis, and lymphatic filariasis. The reported cases varied from thousands to millions, while deaths ranged from hundreds to thousands. To enable accurate comparisons and a comprehensive evaluation of disease patterns and severity over the five-decade period, a standardized normalization method was employed. By employing the standardized normalization method, biases stemming from variations in the data were mitigated, considering factors beyond population size. The dataset was transformed to ensure fair and consistent comparisons, avoiding potential biases that could distort the analysis and interpretation of the data. Normalization plays a critical role in providing a more objective and accurate assessment of disease patterns and severity by accounting for these inherent variations and enabling a comprehensive evaluation. The normalization process helps in mitigating variations and biases that may arise due to differences in population size or other factors. By utilizing the normalization formula, the dataset was transformed to ensure fair and consistent comparisons, reducing the influence of potential biases. The formula used for Min-Max normalization was

$$\text{Normalization} = (X - X\,\text{minimum}) / (X\,\text{maximum} - X\,\text{minimum}).$$

This formula scaled the feature values to a range between 0 and 1, allowing standardized comparisons across the entire dataset. This normalization technique facilitated a more precise understanding of the trends and magnitudes of these MBDs. The meticulously curated and normalized data are visually presented in Figs. 1 and 2, providing valuable insights into the long-term dynamics of these diseases.

THE BURDEN OF MOSQUITO-BORNE DISEASES IN INDIA

1. Malaria: In 1897, Sir Ronald Ross made a groundbreaking discovery in Secunderabad, India, by demonstrating the role of the *Anopheles* mosquito and *Plasmodium* parasite in the transmission of malaria (CDC 2015). Since then, mosquito control has been a major public health concern worldwide. Malaria has been devastating to humanity for centuries, claiming the lives of millions of people. India was particularly affected during the colonial period, from the early 18th century to 1947 when it gained independence (Watts 1999). Although India has made significant progress in controlling and reducing the burden of malaria over the past 75 years, the disease remains a significant problem, particularly in the central and eastern regions of the country (Wangdi et al. 2016; Dev 2020, 2022).

India has been severely affected by malaria (Sharma 1999; Tyagi 1994). Although no systematic countrywide survey was conducted before independence in 1947, it is estimated that more than 100 million people contract malaria each year, resulting in approximately one million deaths annually (Dhingra et al. 2010). To address the devastating impact of malaria, the Government of India established the National Malaria Control Program (NMCP) in 1953, which was later upgraded to the National Malaria Eradication Program (NMEP) in 1958, primarily with two objectives: 1) to prevent deaths from malaria and 2) to curb the spread of malaria through active surveillance and early case management (Sharma and Mehrotra 1986).

As a result of extensive indoor residual spraying of dichloro-diphenyl-trichloroethane (DDT) and a robust surveillance system, malaria was nearly eradicated in India by the mid-1960s, with fewer than one million cases and no reported deaths (Gunasekaran et al. 2005). However, this progress was short-lived, and the disease resurged as a major public health problem in the mid-1970s, with 6.45 million cases and several thousand deaths. During this time, many dominant mosquito vectors developed resistance to preferred insecticides such as DDT and malathion (Anvikar et al. 2014).

Efforts were made to combat malaria through the implementation of the Urban Malaria Scheme (UMS) in 1971–72 and the Modified Plan of Operation (MPO) in 1977. These initiatives helped reduce malaria cases to around two million. However, the impact was more

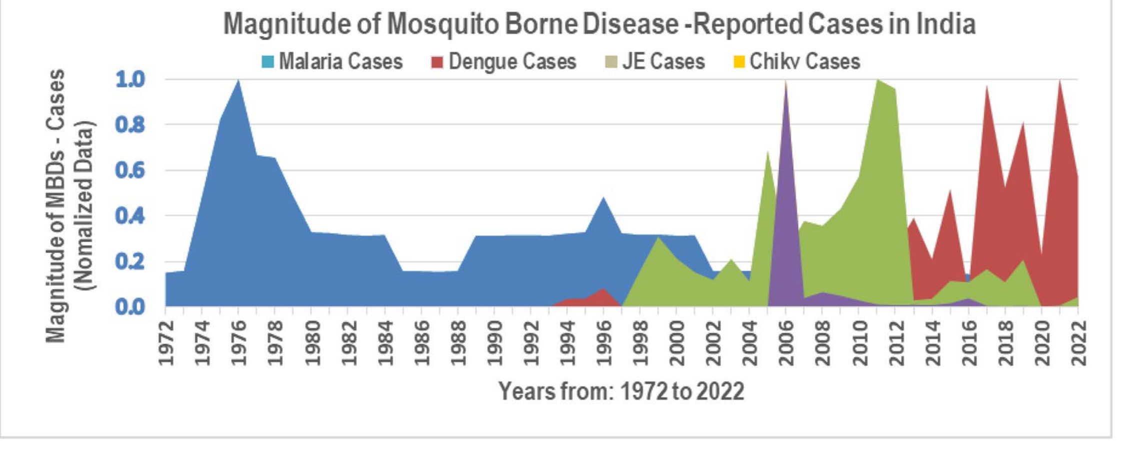


Fig. 1. Magnitude of reported cases of malaria, degue, Japanese encephalitis, and chikungunya in India, 1972–2022.

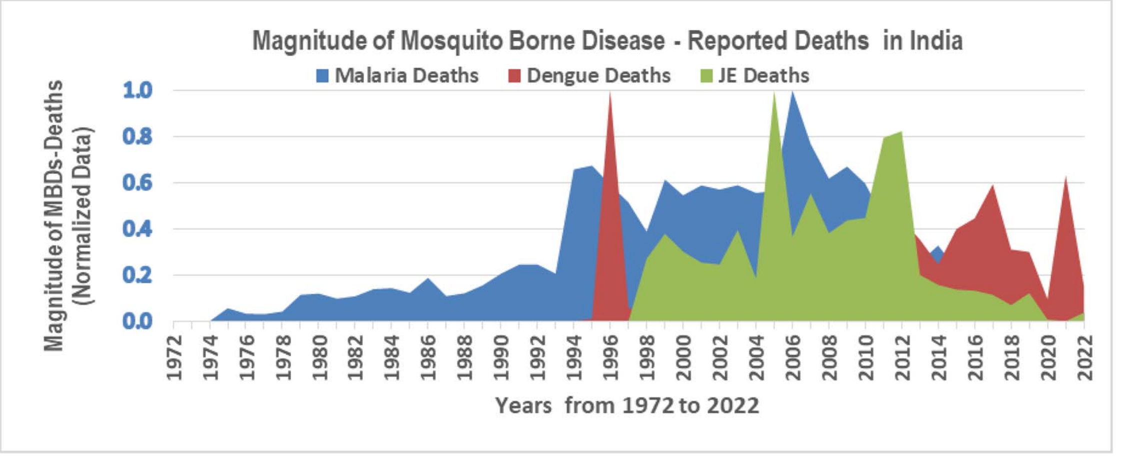


Fig. 2. Magnitude of reported deaths from malaria, dengue, and Japanese encephalitis in India, 1972–2022.

noticeable on vivax malaria, while falciparum malaria continued to show an upward trend despite the *Plasmodium falciparum* Containment Program (PfCP), launched in the 1970s and subsequent years (Shiv et al. 2000, Kumar et al. 2007).

The reduction of funding for anti-malaria programs following successful elimination has been a significant contributing factor to the resurgence of malaria in certain countries, including India. In the late 1950s, the provision of DDT by the United States Agency for International Development (USAID) led to a substantial decline in malaria prevalence in India, from an estimated 100 million cases per year in the early 20th century to about 100,000 cases in 1965 (Sharma and Mehrotra 1986). However, as malaria incidence decreased, USAID withdrew its funding, expecting the Indian government to bear the financial burden. Unfortunately, India faced challenges in producing or procuring the large quantities of DDT required, leading to a lack of effective control measures. This, in turn, resulted in the reestablishment of malaria, with cases peaking at 6 million by 1976 (Sharma and Mehrotra 1986). Insufficient vigilance in malaria control efforts and the scaling back of intervention programs have also contributed to the reestablishment of malaria in certain regions. Inadequate availability and dissemination of information about the malaria status in different areas, lack of awareness about the possibility of reestablishment, challenges in border control and population movement, and limited training and preparedness in malaria control have further compounded the issue (WHO 2007). Additionally, factors such as drug and insecticide resistance, natural disasters, and conflicts can exacerbate the inherent risk of malaria transmission and increase the potential for reestablishment.

Malaria was initially regarded a disease of rural India (Tyagi 2002). However, due to diverse pressure malaria became prevalent in various ecotypes such as forest malaria, urban malaria, rural malaria, industrial malaria, border malaria, and migration malaria. A new malaria paradigm, "Desert Malaria," was recently described *de novo* by Tyagi (2023). Control of malaria in such diverse systems of ecotypes became a complex enterprise, and its management required decentralization and approaches based on local transmission involving multisectoral action and community participation through consilience (Pattanayak et al. 1994, Ranjha and Sharma 2021).

The National Malaria Eradication Program (NMEP) underwent a notable transformation in 1998, leading to its renaming as the National Anti-Malaria Program (NAMP), in order to align with the altered focus. In 2003, recognizing the synergies in the prevention and control of vector-borne diseases, including Japanese encephalitis and dengue, the program underwent further restructuring. It was renamed as the National Vector Borne Disease Control Program (NVBDCP) by integrating the three ongoing centrally sponsored schemes: NAMP, the National Filaria Control Program (NFCP), and the Kala-Azar Control Program (DGHS 2023).

Even then, the program faced challenges in technical, financial, and operational management, prompting critical reviews. As a result, in 2022 the National Centre for Vector-Borne Disease Control (NCVBDC) was established to address these challenges and enhance the efforts in preventing and controlling vector-borne diseases, including malaria, Japanese encephalitis, dengue, and others. The establishment of NCVBDC marked a significant milestone in the ongoing efforts to combat vector-borne diseases in India. Over the past four decades, the efforts of the government of India have yielded significant progress, with malaria cases declining to fewer than 0.02 million and only 64 deaths in 2022. The aim is to eliminate not only malaria, but also other vector-borne diseases, with a target of eliminating malaria and filariasis by 2030 (Ghosh and Rahi 2019, NCVBDC 2023).

Several key milestones mark the trajectory of malaria in India; during the 1970s, there was a significant increase in malaria cases with 1.42 million malaria cases during 1972, which increased to 6.46 million in 1976. In subsequent years, efforts to combat malaria led to a decline in cases, although some fluctuations were observed. The number of malaria cases declined to around 0.88 million in 2013, but then increased to 1.09 million cases in 2016, and started declining again after the year 2017. Overall, the number of malaria cases has declined significantly in recent years, from 6.46 million cases in 1976 to 0.017 million cases in 2022 (Narain and Nath 2018, CBHI 2023, WHO 2023b).

Overall analysis shows a notable decline in malaria cases since 1997, as depicted in Fig. 1. Conversely, Fig. 2 depicts a proportionate increase in the number of malaria-related deaths from 1994 to 2014 with an average of 963 deaths per year, and the highest recorded number of deaths (1707) reported in 2006. However, there is a positive trend of declining death rates in recent years from 2010 onwards, which is an encouraging development. To ensure that this declining trend continues, it is crucial to learn from past experiences and take proactive measures to prevent a resurgence of the disease (Dhiman 2019).

It is important to acknowledge that the reported figures may not fully reflect the true magnitude of malaria cases in India, as a significant number of cases may go unreported or undiagnosed. Furthermore, the COVID-19 pandemic has disrupted malaria control efforts in India (Rogerson et al. 2020, Sharma et al. 2022, Park et al. 2023). When considering the regional distribution of malaria cases, states like Odisha, Chhattisgarh, and Jharkhand consistently have reported the highest numbers over the past decade.

On a global scale, the latest World Malaria Report indicates that there were 247 million malaria cases in 2021, slightly higher than the 245 million cases reported in 2020 (WHO 2023a). This highlights the need for innovative technological advancements to combat this deadly disease (Damodaran et al. 2011, Ghosh and Rahi 2019). However, India has made significant progress in the fight against malaria, achieving an impressive reduction of 83% in malaria morbidity and 92% in malaria mortality between 2000 and 2019 (MOHFW 2022). Building upon this progress, India has developed a comprehensive roadmap, known as the National Strategic Plan for the Elimination of Malaria 2023–2027. Guided by this strategic plan, the Indian government has been actively implementing various strategies to combat malaria and is resolute to eliminate the disease within its borders. With a vision of a malaria-free nation by 2027 and complete eradication by 2030, this plan outlines a clear path towards achieving this goal (Rahi and Sharma 2020, WHO 2023b).

2. Dengue: Dengue is another significant mosquito-borne viral disease that is prevalent in many parts of India (Baruah et al. 2021). It was primarily confined to a few Southeast Asian countries during the 1950s and 1960s. However, it subsequently spread globally, leading to regional and worldwide epidemics in the 1970s and beyond (Dar et al. 1999, Dash et al. 2012, Mondal 2023). It is caused by the dengue virus, which is transmitted by *Ae. aegypti* as a major vector and *Ae. albopictus* as a minor vector (Chetry et al. 2020). It is a self-limiting, systemic viral infection transmitted between humans by these mosquitoes. Dengue fever is caused by one of four ssRNA viruses, DENV-I, DENV-II, DENV-III, and DENV-IV, also referred to as serotypes of the genus *Flavivirus,* belonging to the family Flaviviridae (Lall and Dhanda 1996, Sharma et al. 2000, Chakravarti et al. 2012, Gupta et al. 2012, Sivagnaname et al. 2012, Ganeshkumar et al. 2018).

Dengue fever has indeed been a significant public health concern in India for the past three decades, with a widespread impact on several states, particularly in urban areas (Paulson 2022). It has become endemic in almost all states across the country, as illustrated in Fig. 3. In 1996, India faced a major outbreak of dengue, affecting a substantial number of individuals. The reported cases amounted to 16,517, resulting in a devastating toll of 545 fatalities. It is worth mentioning that the city of Delhi alone accounted for 10,252 cases and 423 deaths. This outbreak served as a pivotal moment, highlighting the emergence of dengue as a significant public health concern in India (Chakravati et al. 2012, NVBDCP 2020). In 2003 one of the most severe outbreaks of dengue occurred, resulting in 75,808 reported cases and 195 deaths. Kerala State was particularly affected, with more than 3,000 cases and more than five dozen deaths documented (Tyagi et al. 2006). Subsequently, numerous outbreaks of dengue have been reported in various states of India. This persistent rise in cases has raised concerns among health authorities and experts regarding the control and prevention of dengue in the country (Wilder-Smith and Rupali, 2019).

Between 1997 and 2012, India reported an average of 11,151 dengue cases and 95 deaths annually. However, experts suggest that this number significantly underestimates the true impact of the disease. A case study conducted in Madurai district and an expert Delphi panel estimated an average of 5,778,406 clinically diagnosed dengue cases per year during this period, which is 282 times higher than the reported number (Mariappan 2013, Shepard et al. 2014, Hariharan et al. 2019). As per the NCVBDC, India recorded 75,808 cases and 195 deaths attributed to dengue fever in 2013. The following year, in 2014 there were 40,571 reported cases and 137 deaths. The number of dengue cases continued to rise, reaching 99,913 in 2015, resulting in 220 deaths. However, the most severe outbreak took place in 2017, with a staggering 188,401 reported cases and 325 deaths recorded nationwide (Chakravati et al. 2012, NCVBDC 2023).

Although the number of dengue cases in India significantly decreased in 2020, possibly due to the COVID-19 pandemic and subsequent lockdowns (Sharma et al. 2022), cases began to rise again in 2021 with more than

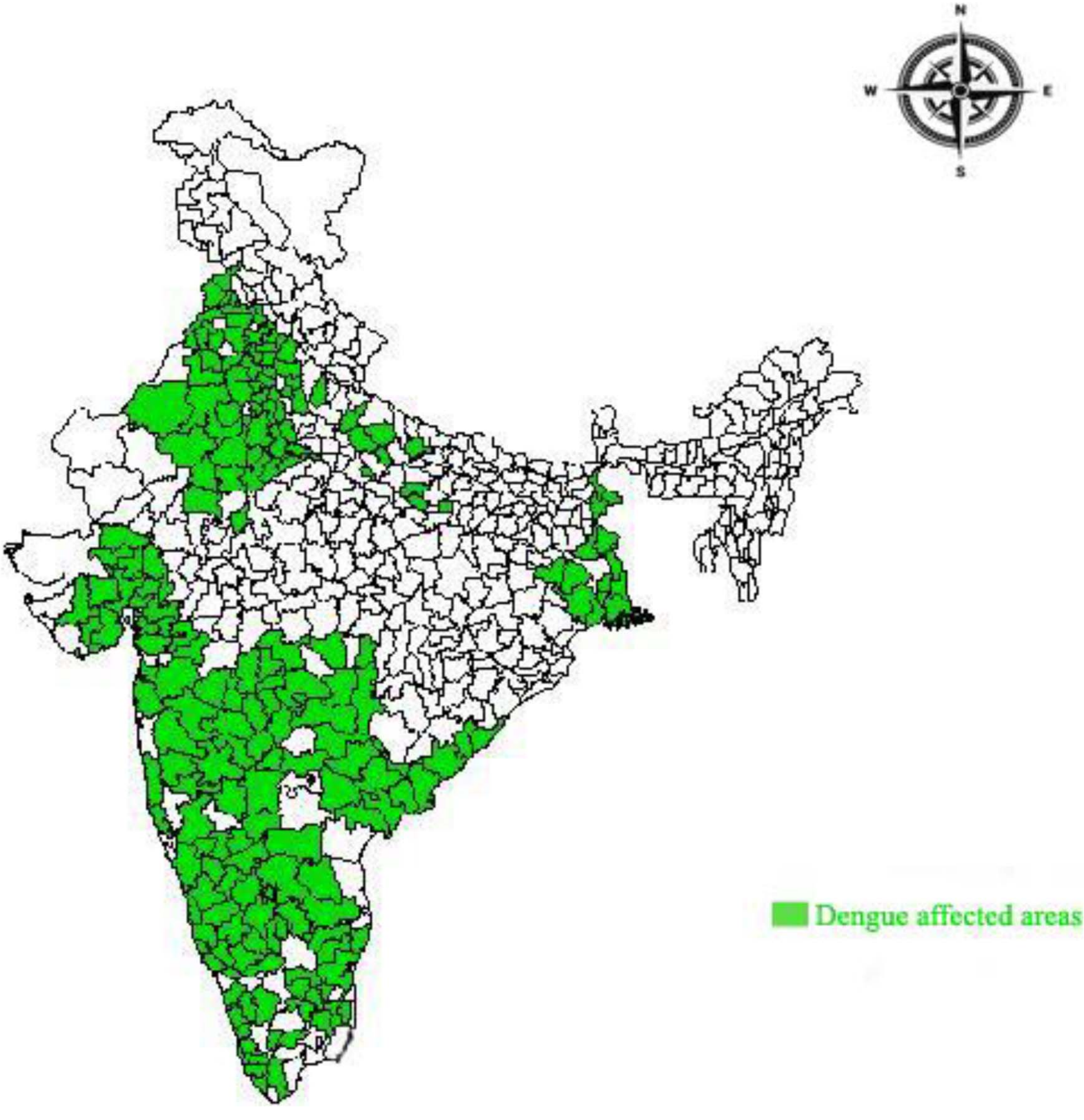


Fig. 3. Distribution of dengue fever cases in India. Source: NCVBDC, https://ncvbdc.mohfw.gov.in/index4.php?lang=1&level=0&linkid=432&lid=3714.

193,445 cases and 346 deaths reported (NCVBDC 2023). This demonstrates the unpredictable nature of dengue. Overall, the data presented in Fig. 1 and Fig. 2 highlight that dengue fever continues to be a major public health concern in India. At present 27 out of 36 states and union territories are affected by dengue (Fig. 3), transmitted by *Ae. aegypti* and *Ae. albopictus.* The above figures demonstrate the need for ongoing efforts to control and manage the disease effectively (Chakravati et al. 2012). The incidence of dengue cases is highest during the monsoon season, from July to October, when mosquito breeding is most prevalent. Urbanization, unplanned construction, temporary settlements, and lack of sanitation facilities contribute to the spread of the disease. Additionally, climate change may be causing an increase in the incidence of dengue cases, as warmer temperatures and increased rainfall create a more favorable environment for the *Aedes* mosquito breeding (Dhara et al. 2013, Pramanik et al. 2020).

3. Chikungunya: Chikungunya poses a significant public health threat in India, with multiple outbreaks documented over the past two decades (Tyagi 2007). This mosquito-borne viral disease is transmitted to humans through the bites of infected *Aedes* mosquitoes, specifically *Ae. aegypti* and *Ae. albopictus* (Das et al. 2007). Notably, it has been reported for the first time that *Ae. albopictus* has emerged as the primary vector for chikungunya in

Kerala, independently driving the epidemic without reliance on *Ae. aegypti* in 2007 (Thenmozhi et al. 2007, Kumar et al. 2011). Chikungunya can cause high fever, joint pain, muscle pain, headache, fatigue, and rash, among other symptoms. Although the disease is not usually fatal, it can be debilitating and may cause long-term joint pain and secondary complications in some patients (WHO 2022a).

Chikungunya has been reported in many states of the country, including Karnataka, Maharashtra, Andhra Pradesh, and Tamil Nadu (Yergolkar et al. 2006, Cecilia 2014), and also from Andaman and Nicobar and Lakshadweep islands (Paramasivan et al. 2009). As per the data depicted in Fig. 1, chikungunya outbreaks have been a recurring phenomenon in India over the past few decades (NCVBDC 2023). The graph illustrates significant spikes in reported cases, with a major outbreak in 2006 recording a staggering 1.39 million cases (Kalantri et al. 2006, Krishnamoorthy et al. 2009). Another notable surge occurred in 2016, with more than 58,000 confirmed cases across the country, particularly affecting Delhi. These statistics clearly demonstrate the recurrent nature and impact of chikungunya outbreaks in India, emphasizing the urgency of ongoing efforts to effectively address and manage the disease.

The significance of chikungunya in the Indian context is that it affects a large number of people, generally during the monsoon and postmonsoon seasons when mosquito populations are at their highest. The disease can have a significant impact on public health, leading to increased health care costs and lost productivity due to illness (Singh et al. 2012). Additionally, chikungunya outbreaks can place a significant burden on health care systems, particularly in areas where resources are limited. According to the World Health Organization, chikungunya has been given low priority compared to other diseases in line with country's limited resource allocation (WHO 2008).

4. Japanese encephalitis: Japanese encephalitis (JE) is a mosquito-borne zoonotic viral diseases caused by the Japanese encephalitis virus (JEV), belonging to the genus *Flavivirus* in the family Flaviviridae. The history of JE goes back to the so-called "Yoshiwara cold" in 1904, and this was followed by encephalitis epidemics in 1924, 1935, and 1948 (Miyake 1964). But the first recognition of JE based on serological surveys was made in 1955, in Tamil Nadu, India (Carey et al. 1968, Namachivayam and Umayal 1982). Subsequently, the disease was identified in other parts of the country, and JE was confirmed as the cause of encephalitis cases. Since then, JE has been recognized endemic and reported in many parts of India, particularly in rural areas, and continues to be a significant public health concern in the country with the highest case fatality rate (Chakravarty et al. 1975, Dhillon and Raina 2008).

Over the last 30 years, JE has had a significant impact on public health in India, particularly in rural areas. A JE epidemic occurred in Andhra Pradesh during October and November 1999 affecting 15 out of 23 districts with 873 cases and 178 deaths (Rao et al. 2000). Later, in 2003 an outbreak occurred in Warangal and Karim Nagar districts of Andhra Pradesh (Das et al. 2004)

India has witnessed multiple sporadic outbreaks of JE, particularly in the northern and southern regions of the country (Fig. 4). The analysis of mosquito-borne diseases as shown in Fig. 2 reveals that JE poses a major stumbling block, characterized by its highest case fatality rate (CFR). The graph highlights the severity of JE compared to other mosquito-borne diseases, indicating a significant impact on public health. These findings underscore the importance of prioritizing efforts to control and prevent JE transmission, as it presents a considerable threat to affected regions. The large-scale outbreak of JE was reported in India in 2005, which resulted in more than 6,727 cases and 1,682 deaths (Parida et al. 2006, Kulkarni et al. 2018). This outbreak was centered around the city of Gorakhpur and its surrounding areas, and it mostly affected children. Another substantial outbreak of JE was recorded in 2011 and 2012, with more than 9,000 cases and 1,350 deaths, and the focal area of disease outbreak mainly reported the state of Assam (Mariappan et al. 2014). In 2016, the country witnessed another outbreak of JE, with more than 1,600 cases and 300 deaths, of which most cases were reported from Odisha state (Sahu et al. 2018). Once again, in 2019, there was a surge in the number of JE cases, with 2,545 cases and 266 deaths reported primarily from Bihar state (Rajaiah and Kumar 2022).

Japanese encephalitis outbreaks in India typically occur during the monsoon season, between June and September, when mosquito populations are high. The disease is most prevalent in rural areas, where mosquito control measures may be inadequate and vaccination coverage may be low. Vaccination programs and mosquito control measures remain crucial in preventing and controlling outbreaks of JE in India (Verma 2012). The Government of India has introduced the live attenuated SA-14-14-2 vaccine against JE in routine immunization program under the Universal Immunization Program in 181 endemic districts (Vashishtha and Ramachandran 2015). Nevertheless, the government interventions resulted in significant decline in CFR of JE from 17.6% in 2014 to 11.2% in 2020 (MOHFW 2022).

5. Lymphatic filariasis: Lymphatic filariasis (LF), also known as elephantiasis, is another neglected tropical disease caused by parasitic worms *Wuchereria bancrofti* Cobbold*, Brugia malayi* Brug, and *Brugia timori* Partono that are transmitted to humans through the bite of infected *Culex* and *Anopheles* mosquitoes. Lymphatic filariasis is a debilitating disease that often develops during childhood (WHO 2019). In its early stages, the disease may be asymptomatic or present with nonspecific symptoms. Despite the lack of external symptoms, the lymphatic system suffers damage, which may persist for several years. Individuals who are infected with the disease continue to transmit the disease (Kalyanasundaram et al. 2020). It has severe long-term physical consequences, including painful swelling of the limbs. During episodes of acute attacks, patients may be bedridden for days, and performing

Fig. 4. Distribution of Japanese encephalitis in India. Source: Kulkarni et al. (2018).

regular activities becomes challenging. The severity of these attacks causes not only physical distress but also social stigma and hinders the individual's earning potential (Shukla et al. 2019).

India accounts for approximately 40% of the global disease burden, with 272 lymphatic filariasis endemic districts across 16 states and five union territories (NCVBDC 2023) (Fig. 5). Nearly 670 million people in India are at risk of contracting the disease (Ramaiah et al. 2000, Tripathi et al. 2022). In the 1970s and 1980s, the disease burden was highest in the states of Uttar Pradesh, Bihar, and Orissa, where the prevalence of LF was over 10%. India launched its national program of National Filaria Eradication Program (NFEP) in 2004 with a mass drug administration (MDA) strategy to the at-risk population, and since then, India has made significant progress in reducing the burden of LF. The status of LF condition is improving among the affected people in India due to the disease intervention through MDA (Ramaiah et al. 2001, Molyneux and Zagaria 2002, Molynuex 2003, Ramaiah et al. 2005, MOHFW 2022).

The northwestern states and union territories, namely, Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Chandigarh, Rajasthan, Delhi, and Uttaranchal, and the northeastern states, namely, Sikkim, Arunachal Pradesh, Nagaland, Meghalaya, Mizoram,

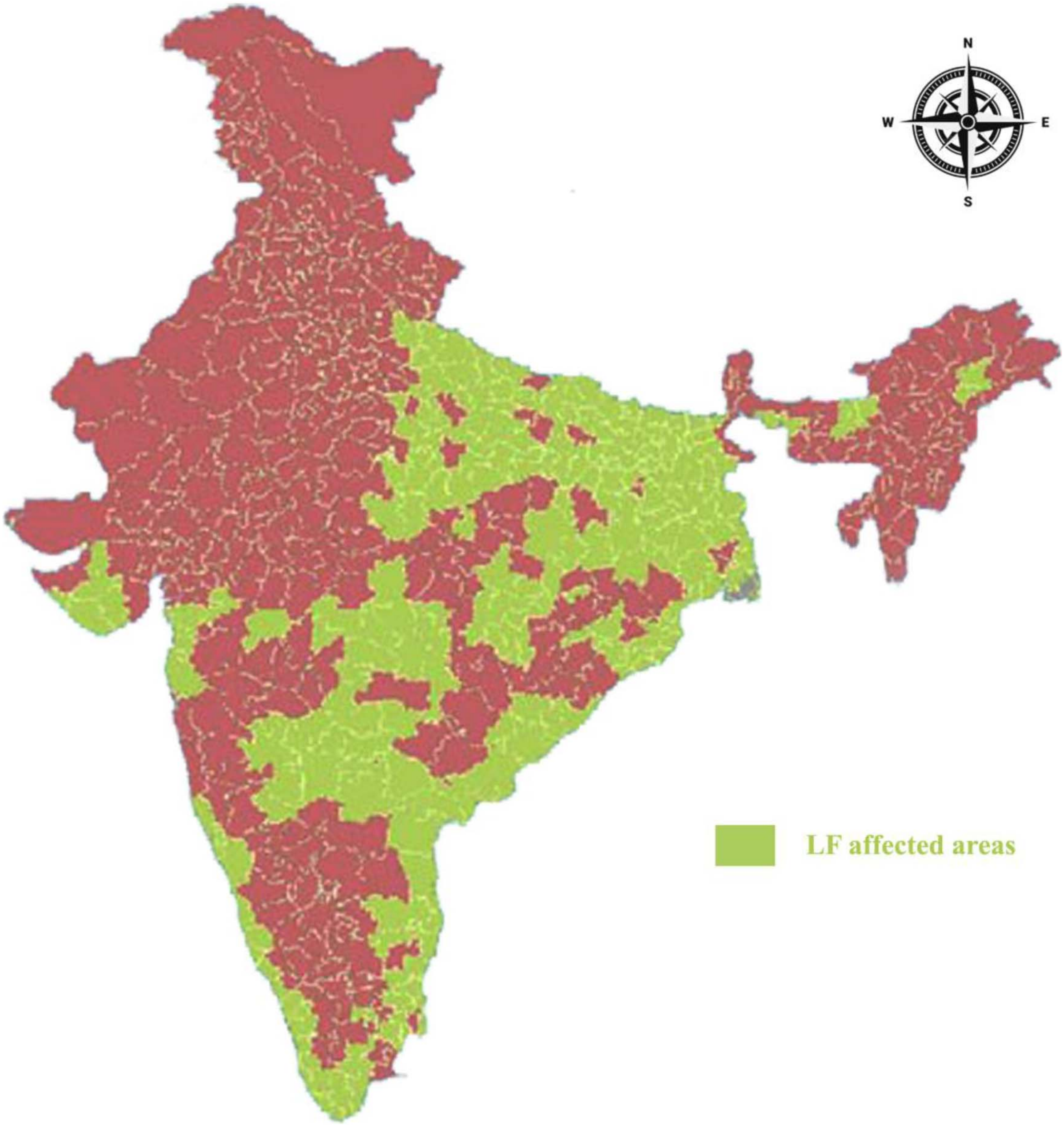


Fig. 5. Distribution of lymphatic filariasis in India. Source: NCVBDC, https://ncvbdc.mohfw.gov.in/index4.php?lang=1&level=0&linkid=453&lid=3733.

Manipur, and Tripura, are known to be free from indigenously acquired filarial infection. Cases of filariasis have been recorded from Andhra Pradesh, Assam, Bihar, Chhattisgarh, Goa, Jharkhand, Karnataka, Gujarat, Kerala, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, Telangana, Uttar Pradesh, West Bengal, Pondicherry, Andaman and Nicobar Islands, Daman and Diu, Dadra and Nagar Haveli, and Lakshadweep (NCVBDC 2023). The latest data from the Ministry of Health and Family Welfare show an overall reduction of 90.4% in the prevalence of microfilaria in the population, and the number of people living in endemic areas has decreased from 650 million in 2004 to 256 million in 2019 (MOHFW 2022). India has eliminated LF in 13 states and union territories, and another 11 states and union territories have achieved the target of bringing the prevalence of LF down to less than 1% (Sabesan et al. 2022). The government has implemented a comprehensive disability prevention and management program to address the disability associated with LF. Despite the achievements, LF remains a significant public health problem in India, particularly in northeastern and southeastern regions of the country. The Government of India prioritized the elimination of LF through the annual MDA program in 2004 and continued with a single dose of diethylcarbamazine citrate (DEC), 6 mg/kg of body weight, plus albendazole annually over a period of 5–6 years. The prevalence of LF in India decreased from 1.24% in 2004 to 0.36% in 2015 (Srivastava and Dhillon 2008, Sabesan et al. 2022). However, the frequent and often predictable outbreaks of acute encephalitis in different parts of the country constitute a huge challenge to public health in India (Narain et al. 2017).

THE SOCIOECONOMIC BURDEN OF MOSQUITO-BORNE DISEASE

It is imperative to observe that the burden of MBDs in India is significant, with malaria, dengue, chikungunya, Japanese encephalitis, lymphatic filariasis, and others like Zika and West Nile virus posing major public health concerns (Brar et al. 2022, Rathod et al. 2022, Valecha 2023). Poor sanitation, inadequate health care infrastructure, and climate change exacerbate mosquito breeding and disease transmission. The exact magnitude of the economic burden is difficult to estimate due to underreporting and inadequate disease surveillance systems (Wilder-Smith and Rupali 2019).

Lymphatic filariasis is considered one of the leading causes of disability worldwide. Eliminating the disease is crucial for alleviating poverty and fostering economic growth. Lymphatic filariasis is a major impediment to socioeconomic development (India has been estimated to lose $1 billion per year as a result of LF) and is responsible for immense psychosocial suffering among the affected people (Das and Shenoy 2017, Krishnasastry and Mackenzie 2021).

The total direct annual medical cost of dengue in India was estimated to be approximately US$548 million. Out of the total cases, 67% were treated in ambulatory settings, accounting for 18% of the costs. On the other hand, 33% of cases required hospitalization, contributing to 82% of the costs. Among the health care facilities, private establishments received many of the expenditures, amounting to 80% of the total costs. When nonmedical and indirect costs are considered, based on other dengue-endemic countries, the total economic cost rises to $1.11 billion, or $0.88 per capita. The actual economic and disease burden of dengue in India is much higher than officially reported, and stronger control measures are necessary (Garg et al. 2008, Shepard et al. 2014).

To evaluate the impact on disease burden, a comprehensive assessment encompasses the examination of various factors, including disease prevalence, incidence, morbidity, mortality, and disability-adjusted life years. This evaluation process entails analyzing disease trends over a specific period, comparing disease burden before and after interventions, and employing mathematical modeling or similar approaches to estimate the effect of interventions on disease outcomes (Murray 2022). By considering these elements, a holistic understanding of the impact on disease burden can be attained.

Mosquito-borne diseases not only cause physical suffering and death, but also result in substantial economic losses due to health care expenses, loss of productivity, and decreased quality of life (Bhavsar et al. 2010). Mosquitoes cause more human suffering than any other organism: not only can mosquitoes carry diseases that afflict humans, they also transmit several diseases and parasites to which dogs and horses are very susceptible (CDC 2020a). The burden of these diseases disproportionately affects the poor, as they are more likely to live in areas with poor sanitation and limited access to health care. In addition, outbreaks of MDBs can lead to significant economic losses in the tourism and agriculture industries and have a far-reaching impact on individuals, families, and communities. These diseases often exhibit an unpredictable pattern, which is influenced by various factors such as climatic conditions, socioeconomic conditions, and poor sanitation practices. Outbreaks of these diseases can lead to panic, fear, and social unrest in affected communities, resulting in a loss of employment and productivity due to illness, disability, and death (Colón-González et al. 2021).

FACTORS INFLUENCING MOSQITOES AND MOSQUITO-BORNE DISEASE

Mosquito-borne disease transmission dynamics are influencing several factors, which can be broadly categorized into environmental, social, biological, human movement, and health infrastructure (Acevedo et al. 2015) as follows:

1. Environmental factors play a crucial role in influencing mosquitoes and MBDs. Temperature, rainfall, humidity, and vegetation affect the distribution, abundance, and behavior of mosquitoes, which are closely linked to providing favorable breeding sites for mosquitoes. Changes in environmental factors due to deforestation, urbanization, and climate change can alter the distribution and abundance of mosquitoes and, subsequently, the transmission dynamics of MBDs (Nosrat et al. 2021). Urbanization and industrialization have a significant impact on land use and land cover, resulting in the creation of artificial mosquito habitat favoring the proliferation, and increasing their breeding sites ultimately leads to the spread of MBDs. Urbanization and industrialization can also increase the exposure of people to mosquito bites due to the expansion of urban and industrial areas, leading to an increase in human population density and more opportunities for mosquitoes to find hosts (Wilke et al. 2021).
2. Socioeconomic factors, such as population density, housing conditions, sanitation practices, access to clean water, and socio-cultural practices, all can influence mosquitoes and MBDs.

For instance, overcrowded urban areas with inadequate sanitation facilities can create favorable conditions for the breeding of mosquitoes, leading to increased transmission of diseases like dengue and chikungunya. These factors also influence the ability of communities to adopt and sustain mosquito control measures, such as the use of bed nets, insecticide spraying, and environmental management practices (Whiteman et al. 2020).

3. Biological factors related to mosquitoes, such as their biology, behavior, and genetics, can also impact the disease transmission. For example, the presence of insecticide resistance in mosquitoes can reduce the effectiveness of mosquito control measures. Mosquito species composition and their ability to adapt to changing environments can also influence the transmission dynamics of MBDs (Karthikeyan et al. 2020).
4. Human movement and travel, including migration, urbanization, and international travel, can also influence mosquitoes and MBDS. Movement of people from endemic to nonendemic areas or across borders can introduce new vectors or causal agents of disease to previously unaffected areas, leading to changes in disease patterns and dynamics (WHO 2012). India shares long international borders with China, Bhutan, and Nepal in the north, Myanmar and Bangladesh in the east, and Pakistan in the west; these borders are porous and people move across freely for livelihood and other purposes (Pathak and Mohan 2019).
5. Availability and accessibility of health care infrastructure, mosquito control interventions, and disease surveillance systems can also impact mosquitoes and MBDs. Adequate health care infrastructure, trained health care professionals, and well-implemented mosquito control interventions can significantly reduce the burden of mosquito-borne diseases by early diagnosis, treatment, and management (Priya and Chikersal 2013, Penhollow and Torres 2021).

A comprehensive understanding of these factors is crucial for designing effective strategies for the prevention, control, and management of mosquito-borne diseases in the country. Incorporating these contents in the high school curriculum may yield positive results. By addressing these factors, we can reduce the burden of MBDs and improve the health outcomes of communities.

CHALLENGE AND PERSPECTIVE IN TACKLING THE MOSQUITO MENACE

India faces numerous challenges in tackling MBDs due to the diverse burden of diseases and the need for tailored strategies for vector control, diagnosis, and treatment. Climate-based disease forecasting models in India should be refined and tailored for different climatic zones, instead of use of a standard model (Mutheneni et al. 2017).

Challenges:

1. Mosquito resistance: Vector mosquitoes, such as *An. stephensi*, developed resistance to commonly used insecticides. India has a diverse range of vectors and vector-borne diseases, with different transmission dynamics and ecological requirements. This makes vector control efforts complex and challenging, as strategies may need to be tailored to different vectors and diseases based on their specific characteristics. The limited availability of alternative insecticides further complicates the situation (Dev and Manguin 2016, Dykes et al. 2016).
2. Drug resistance: Malaria parasites, particularly *Plasmodium falciparum* Welch, became resistant to commonly used drugs like chloroquine. The spread of drug-resistant strains to remote areas, including the northeastern states of India, posed a significant challenge. Additionally, the unavailability of effective alternative antimalarials exacerbated the situation (Shah et al. 2011).
3. Urbanization: Urbanization may create environmental conditions that favor mosquito breeding, and the rapid growth of the urban population in Indian towns and cities, which increased from 17% in 1951 to 34% in 2018, contributed to the spread of malaria. The urban malaria vector, *An. stephensi*, thrived in these urban areas, leading to malaria transmission in new regions (Brieger et al. 2001, WUP 2018). India's diverse burden of vector-borne diseases, each with unique epidemiology, transmission dynamics, and ecological context, poses a challenge for global health efforts that require tailored strategies for vector control, diagnosis, and treatment (Gubler 2011, Ananya and Miller 2021, Athni et al. 2021).
4. Availability of health care and resources are limited, which presents challenges for diagnosing and treating vector-borne diseases. Addressing the socioeconomic determinants of health is essential in adopting a comprehensive approach. It is important to note that the surveillance system fails to capture patients who seek health care from sources other than designated health centers, including public or private sector facilities (Narain and Nath 2018). Insufficient resources and infrastructure, especially in rural and remote areas, impede effective efforts in vector control. Moreover, there may be limitations in terms of trained personnel, equipment, and funding for sustaining vector control programs in certain areas (Priya and Chikersal 2013, Jagannathan and Kakuru 2022).

5. Lack of awareness and community engagement, awareness about vector-borne diseases and vector control strategies among communities, health care providers, and policymakers may be inadequate in some areas of India. This can lead to suboptimal implementation of vector control measures, low community participation in vector control programs, and challenges in sustaining vector control efforts (Gopalan et al. 2021).
6. Intersectoral coordination: Vector control efforts require coordination among multiple sectors, including health, environment, agriculture, and urban planning, among others. Lack of coordination among these sectors can result in fragmented and suboptimal vector control strategies (Rajvanshi et al. 2020).
7. Socioeconomic and cultural factors, such as human behavior, mobility, and practices related to housing, sanitation, and livestock management, can influence vector-borne disease transmission. Addressing these factors requires understanding local social and cultural dynamics, which can pose challenges in implementing effective vector control strategies (CDC 2020b, Athni et al. 2021).

Perspectives: Despite the numerous challenges posed by MBDs, there exist various promising perspectives for global health endeavors to effectively combat and address these diseases.

1. Achieving national health goals requires a well-trained and skilled health workforce, as well as active participation from the community and public. To ensure high-quality health services at all levels of the health care delivery system in India, it is essential to establish a public health cadre in every state and ensure that the workforce has the necessary skills and expertise. By doing so, India can make progress toward meeting the Sustainable Development Goals (Priya and Chikersal 2013, Tiwari et al. 2022).
2. It is important to continuously monitor and adapt vector control efforts to address changing ecological, social, and environmental conditions for effective control of vector-borne diseases. The Government of India has established the Virus Research and Diagnostic Laboratory Network (VRDLN) to strengthen the laboratory capacity in the country for providing timely diagnosis of disease outbreaks. The network is providing additional data on dengue epidemiology (Murhekar et al. 2019, Joshua et al. 2020).
3. Innovations in vector control strategies can play a crucial role in addressing the challenges of MBDs. This may include the development of new biodegradable insecticide formulations such as plant-based silver nanoparticles to replace the chemical pesticides and delivery mechanisms that are effective against insecticide-resistant mosquitoes (Naik et al. 2014, Siddaiah and Reddya 2021). Genetic technologies, such as gene-editing techniques like CRISPR-Cas9, can also offer innovative approaches for vector control by disrupting mosquito populations or making them resistant to disease transmission (Veerakumar et al. 2014).
4. Technological advancements in disease surveillance and diagnosis can improve early detection, monitoring, and response to MBDs. This may include the use of remote sensing, geospatial technologies, and big data analytics for mapping disease transmission patterns and identifying high-risk areas (Gujju et al. 2013). Rapid diagnostic tests, point-of-care diagnostics, and mobile health technologies can enhance the speed and accuracy of disease diagnosis, enabling timely interventions and targeted control measures (Hong et al. 2022).
5. Interdisciplinary approaches that involve collaborations between researchers, policymakers, public health practitioners, and communities can help address the complex challenges of MBDs. Integrating knowledge and expertise from fields such as entomology, epidemiology, climatology, social sciences, and health systems can provide holistic insights into disease dynamics and inform evidence-based strategies. Interdisciplinary approaches can also foster community engagement, behavior change, and participatory decision making, promoting sustainable and locally adapted interventions (Jones et al. 2021).
6. Empowering communities through education, awareness, and capacity building can be a potent tool for addressing MBDs. This may involve community-led initiatives for vector control, such as source reduction, proper waste management, and improving water storage practices. Education and awareness campaigns can promote behavior change, including the use of personal protective measures, such as insecticide-treated bed nets, repellents, and clothing, to reduce exposure to mosquito bites and limit the contact opportunity between humans and vector mosquitoes. Empowered communities can also actively participate in disease surveillance and reporting, contributing to early warning systems and response efforts (Rajvanshi et al. 2020).
7. A potential solution to mitigate the issue of MBDs is through the establishment of a public-private partnership, and a coordinated effort between the public and private sectors is crucial in effectively addressing the problem of mosquito-borne diseases (Kamat 2001, Jones et al. 2021, Yassanye et al. 2021).
8. Adopting a One-Health approach that recognizes the interconnectedness of human health, animal health, and environmental health can help address the challenges of mosquito-borne

diseases. This may involve integrated surveillance systems that monitor disease in humans, animals, and vectors, and identify potential spillover events. Collaborations between human health, veterinary, and environmental agencies can facilitate coordinated responses to disease outbreaks and address the underlying drivers of disease transmission (Prata et al. 2022).

9. Strong policy and governance frameworks are essential for addressing the challenges of mosquito-borne diseases. This may include policies that promote environmental management, urban planning, and sustainable development practices to reduce mosquito breeding habitats. Policies to improve health care access, including diagnostics, treatment, and preventive measures, can be crucial (Rahi and Sharma 2022). Effective governance mechanisms that promote coordination, resource allocation, and accountability among relevant stakeholders can facilitate the implementation of integrated strategies (Sinha et al. 2014).

MOSQUITO CONTROL AND MANAGEMENT STRATEGY

Mosquito-borne illnesses present a significant global health challenge, affecting more than 40% of the world's population. While progress has been made in controlling malaria since 2000, advancements in tackling other MBDs have been limited. Furthermore, there is a rapid rise in the risk posed by *Aedes*-borne arboviruses like dengue and chikungunya. These diseases have experienced a notable increase in their occurrence and now pose an escalating threat to public health. Efforts to address and combat these diseases are of utmost importance to protect global populations. To address this growing issue, various and innovative mosquito control technologies are currently being developed, spanning a broad range of approaches, from the sterile insect technique that may reduce mosquito populations to low-cost alterations in housing design that restrict mosquito entry (Jones et al. 2021, Wang et al. 2021). Successful mosquito management requires intervening at some point during the mosquito life cycle before they bite and infect a human (CDC 2020a, EPA 2022). The following strategies need to be practiced to get rid of the mosquito menace.

1. Integrated vector management (IVM) is a comprehensive approach that involves multiple interventions for controlling mosquito vectors and reducing disease transmission. It includes a combination of vector control measures such as indoor residual spray (IRS), larval source management (LSM), and use of insecticide-treated bed nets, along with environmental management, community engagement, and surveillance. IVM promotes an evidence-based and holistic approach to vector control (Tusting et al. 2013).
2. Vaccination is an important strategy for controlling MBDs. In India, vaccination programs have been implemented for Japanese encephalitis. Vaccination aims to prevent disease transmission by providing immunity to individuals and reducing the susceptible population (Aggarwal and Garg 2018). Vaccines for malaria and dengue still need to be addressed.
3. Health education and behavior change strategies are critical in raising awareness about MBDs, their transmission, and preventive measures. This includes educating communities about the importance of using bed nets, eliminating mosquito breeding sites, and seeking timely medical care. Behavior change interventions may also focus on modifying human behaviors that increase exposure to mosquitoes and disease transmission (Kusuma et al. 2019).
4. Surveillance and monitoring of mosquito-borne diseases are crucial for understanding disease trends, detecting outbreaks, and evaluating the effectiveness of control strategies. This includes monitoring mosquito populations, disease prevalence, and vector resistance to insecticides. Early warning systems and rapid response mechanisms are also important for timely intervention and control (Lahariya and Pradhan 2006, Murray and Cohen 2017, Rao et al. 2019). Mosquito surveillance and control should be maintained by state and local mosquito control organizations to the extent that local conditions and resources will allow during public health emergencies and natural disasters (Connelly et al. 2020).
5. Environmental management strategies aim to modify the environment to reduce mosquito breeding sites. This may include proper waste management, clearing stagnant water, and modifying water storage practices to prevent mosquito breeding (Ensink et al. 2007). To effectively manage vectors, it is crucial to prioritize measures that primarily target the reduction of water storage containers (Reddya 2018). To achieve a successful vector control, it is necessary to implement a public health response that goes beyond regular larviciding or focal spraying, and this response should be maintained throughout the year (Tyagi et al. 2006, Samuel et al. 2014). During the monsoon periods, breeding in cocoa pods serves as an opportunistic and adaptive behavior of mosquitoes to sustain their population density when typical breeding sites, such as latex-collecting cups in rubber plantations, are unavailable. Mosquitoes were found to breed in cocoa pods located up to 8 m above the ground level (Hiriyan et al. 2003, Hiriyan and Tyagi 2004).
6. Community engagement and participation are essential for sustainable mosquito-borne disease control efforts. This includes involving

communities in planning, implementing, and evaluating control strategies. Engaging citizens and communities in disease surveillance, vector control, and health education can enhance the effectiveness of control measures (Bartumeus et al. 2019).
7. Capacity building and research are critical for improving the knowledge, skills, and resources for mosquito-borne disease control in India. This includes training health care workers, vector control personnel, and other stakeholders involved in disease management. Research efforts focus on understanding the local epidemiology, vector ecology, and impact of interventions to inform evidence-based control strategies (Chanda et al. 2017).
8. Adoptions of innovation and new technology are critical for the improvement of surveillance, prevention, and control of MBDs. Biological control agents are important alternatives or complements to chemical insecticides (Deng et al. 2023)

These are some of the common control and management strategies; however, the choice of strategies may vary depending on the specific disease, local epidemiological situation, and available resources. Integrated and multipronged approaches that combine multiple strategies have been shown to be effective in reducing the burden of mosquito-borne diseases (Hyland-Wood 2021).

It is important to note that evaluating the effectiveness of these interventions can be complex due to various factors such as confounding variables, contextual factors, and limitations of data and methods. Robust study designs, appropriate data collection and analysis methods, and careful consideration of potential bias are important in evaluating the effectiveness of mosquito control measures, disease surveillance, health policies, and public health campaigns (Benelli and Beier 2017).

GLOBAL PUBLIC HEALTH IMPLICATIONS

Mosquito-borne diseases are a significant public health concern globally, and India has a high burden of such diseases. Mosquitoes do not require passports to cross borders and can easily spread beyond the geographical territories of countries, affecting global health security. Therefore, understanding the vectors and diseases in India is crucial to prevent their spread to other countries and regions or vice versa and to develop effective global health strategies for vector-borne disease control and prevention. India has been actively engaged in national and international collaborations, including partnerships with global health organizations, research institutions, and other countries, to combat MBDs (Kumar et al. 2020).

The World Health Organization (WHO) plays a crucial role in coordinating mosquito control and preventing the transmission of mosquito-borne diseases across borders. The WHO provides technical guidance and support to member countries in developing and implementing mosquito control strategies. It supports member countries in establishing surveillance systems to detect and respond disease outbreaks, promotes research and development of new mosquito control tools, and facilitates international collaboration and coordination among member countries and partners to control MBDs and prevent their spread across borders (WHO 2021).

Mosquito-borne diseases in India can have implications for regional and global health security. India can collaborate with other countries, international organizations, and global health partners to foster joint research, knowledge sharing, and capacity building initiatives for addressing. India can also develop health policies and strategies that focus on disease prevention and control, strengthen health systems, promote disease surveillance and response, and foster research and innovation for effective disease control measures.

In India, there's an old saying that the entire world is like a family, "Vasudhaiva Kutumbakam." Due to the globalization of the economy and the formation of unions between countries, people are able to move between different countries and mix their cultures. This has also resulted in an increase in exposure to exotic illnesses for people. International travel is on the rise, as millions of people travel for professional, social, recreational, and humanitarian purposes each year (WHO 2012). Moreover, the ease of international travel has made it possible for people to reach any part of the world within 24 h, making tropical diseases a global concern for medical professionals worldwide. Malaria imported from endemic areas continues to pose a growing medical challenge in the USA, due to the increase in travel and trade to and from the endemic areas (Mathai et al. 2010).

The review shows compelling evidence of the evolving landscape of MBDs in India over the past 50 years. These figures offer a standardized assessment of disease patterns and severity, revealing invaluable insights into MBD trends. Notably, the review demonstrates a remarkable decrease in malaria cases and deaths, signifying commendable progress in disease control efforts. However, the escalating number of reported cases and deaths for dengue and Japanese encephalitis serves as a stark reminder of the persistent threat these diseases pose. This reality not only necessitates urgent action at a national level, but also highlights the global burden of MBDs. Given their potential to spread across borders, addressing MBDs becomes imperative on a global scale. Leveraging the distilled knowledge from the analysis, policymakers, public health practitioners, and researchers can make informed decisions and collaborate on effective strategies to combat and eliminate MBDs in India and other countries. Strengthening surveillance systems, enhancing vector control strategies, raising public awareness, and ensuring timely access to health care services are critical measures to tackle these challenges. The insights derived from the analysis visualized in Figs. 1 and 2 shed light on the progress made in reducing malaria cases, while emphasizing ongoing concerns regarding dengue and Japanese encephalitis. These figures serve as essential references, empowering stakeholders to design targeted interventions and allocate resources efficiently, ultimately mitigating the impact of MBDs in India. Moreover, addressing MBDs collectively on a global scale is essential to safeguard public health and prevent the spread of these diseases across borders. The global burden of MBDs necessitates collaborative efforts, knowledge sharing, and the implementation of comprehensive prevention and control strategies to achieve significant progress in disease elimination worldwide.

ACKNOWLEDGMENTS

The authors express their deepest gratitude to the Anastasia Mosquito Control District, St. Augustine, FL, USA, for providing excellent facilities and allowing access to their laboratory during the course of this research. The senior author acknowledges Osmania University, Hyderabad, India, for granting sabbatical leave to undertake this research; this opportunity would not have been possible without their support. Finally, the authors thank all those who contributed to the research in one way or another; their insights and suggestions have been instrumental in shaping this work to its completion.

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