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Exploring Mosquito Hazards in Bangladesh: Challenges and Sustainable Solutions

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Abstract

Mosquito-borne diseases remain a persistent public health challenge in Bangladesh, posing significant burdens on individuals, healthcare systems, and socio-economic development. This review explores the multifaceted dimensions of the mosquito problem, encompassing epidemiology, vector ecology, environmental factors, and socioeconomic determinants of mosquito proliferation. To understand the disease burden, we explore the transmission dynamics and public health impact of prevalent mosquito-borne diseases like dengue, malaria, and chikungunya. Furthermore, we scrutinize the efficacy and limitations of existing vector control strategies, including their environmental implications and sustainability. The role of urbanization, climate change, and water management practices in exacerbating mosquito-breeding habitats is critically examined. This research aligns with Sustainable Development Goal (SDG) point 3 and 11. By analyzing successful mosquito control programs implemented in other countries, we aim to inform the development of evidence-based, integrated vector management strategies for Bangladesh. This approach aligns with the principles of Happy Bangladesh, emphasizing innovation, data-driven decision-making, and sustainable development. Ultimately, this review seeks to provide actionable insights for policymakers and public health practitioners to combat mosquito-borne diseases and improve the health and well-being of the Bangladeshi population.

1. Introduction

Technological advancements have remarkably improved human life, but persistent challenges remain. While we enjoy increased comfort and convenience (Brynjolfsson & McAfee, 2011), issues such as mosquito-borne diseases continue to hinder progress, especially in developing nations like Bangladesh (World Health Organization, 2019). To achieve the Sustainable Development Goals (SDGs) and

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realize the vision of a Happy Bangladesh, it is imperative to address the mosquito problem effectively. Implementing robust mosquito control strategies is crucial not only for public health but also for stimulating economic growth and enhancing overall quality of life (Gates, 2022).

Mosquitoes have long plagued human populations, serving as vectors for deadly diseases and inflicting immense suffering on communities worldwide (World Health Organization, 2023b). In urban centers like Dhaka, Bangladesh, where dense populations, inadequate infrastructure, and environmental challenges converge, the mosquito menace presents an ever-escalating public health crisis (Bonna *et al*., 2023). With a history of recurring outbreaks of mosquito-borne illnesses, including dengue fever, malaria, and chikungunya, Dhaka epitomizes the relentless struggle against these tiny yet formidable adversaries (World Health Organization, 2009a, 2022a).

The burgeoning urbanization of Dhaka, fueled by rapid population growth and rural-to-urban migration, has created a fertile breeding ground for mosquitoes. The proliferation of slums and informal settlements, characterized by poor sanitation, overcrowding, and inadequate waste management, further exacerbates the problem by providing abundant breeding sites for mosquitoes (Ferdousi *et al.*, 2015; Rahaman *et al.*, 2023). Moreover, the city's geographical location and subtropical climate create favorable conditions for mosquito breeding and the transmission of vector-borne diseases throughout the year (Sharower *et al.*, 2021).

The impact of mosquito-borne diseases on public health in Bangladesh is profound and far-reaching. Dengue fever, a viral illness transmitted primarily by the *Aedes aegypti* mosquito, has emerged as a significant threat, with recurrent outbreaks causing widespread morbidity and mortality (World Health Organization, 2009a). Malaria, although traditionally associated with rural areas, continues to pose a threat in peri-urban and urban settings, contributing to the burden of febrile illness in Dhaka (World Health Organization, 2019). Chikungunya, another mosquito-borne viral infection transmitted by the Aedes mosquitoes, has also been reported in the city, adding to the complexity of the public health challenge (World Health Organization, 2022a).

The control of mosquito vectors and the prevention of mosquito-borne diseases in Bangladesh require a multifaceted approach that addresses the complex interplay of biological, environmental, and socio-economic factors. Traditional vector control measures, such as insecticide spraying and larviciding, have been implemented sporadically but often prove insufficient in the face of rapid urbanization and environmental degradation. Moreover, the emergence of insecticide resistance among mosquito populations poses a significant obstacle to

the effectiveness of conventional control strategies (Richards *et al*., 2020; Suh *et al.*, 2023).

Beyond biological factors, socio-economic determinants play a crucial role in shaping the dynamics of mosquito-borne disease transmission in Dhaka. Poverty, inadequate housing, and limited access to healthcare exacerbate vulnerability to mosquito-borne illnesses, particularly among marginalized populations residing in urban slums (Cousins, 2019). Furthermore, issues of governance, urban planning, and environmental management intersect with public health concerns, influencing the distribution of mosquito breeding habitats and the efficacy of vector control interventions (Lowe *et al.*, 2022).

Addressing the mosquito problem in Bangladesh aligns with several Sustainable Development Goals (SDGs). SDG 3, which aims to ensure healthy lives and promote well-being for all at all ages, is directly relevant as mosquito-borne diseases pose significant health risks to the population. Additionally, SDG 11, focused on sustainable cities and communities, is applicable as effective mosquito control contributes to improved living conditions and public health (United Nations, 2015).

Since, mosquito-borne diseases pose a significant public health challenge in Bangladesh, it is drawing attention to many researchers now a days. Recent studies have highlighted the increasing prevalence of dengue, chikungunya, and malaria in the country. Rahman *et al.* (2023) reported knowledge, attitude, and practices of general people regarding dengue prevention in Bangladesh. The complex interplay of factors such as climate change, urbanization, and population growth has contributed to the resurgence of these diseases (World Health Organization, 2020). To address this issue, comprehensive vector control strategies, including the use of insecticides, larvicides, and environmental management, are being implemented (Wilson *et al.*, 2020). Additionally, the emergence of insecticide resistance among mosquito populations necessitates the development of innovative control measures and a deeper understanding of mosquito behavior and ecology which were demonstrated by Bhatt *et al.* (2013).

This review aims to comprehensively examine the enduring problem of mosquitoes in Bangladesh, realizing current knowledge on mosquito biology, disease epidemiology, vector control strategies, and socio-economic determinants. By critically analyzing existing evidence and identifying gaps in knowledge, this review seeks to inform future research directions and guide the development of effective interventions to mitigate the mosquito jeopardy in Bangladesh. Through collaborative efforts and evidence-based action, it is possible to counter this persistent public health challenge and safeguard the health and well-being of Bangladesh's citizens.

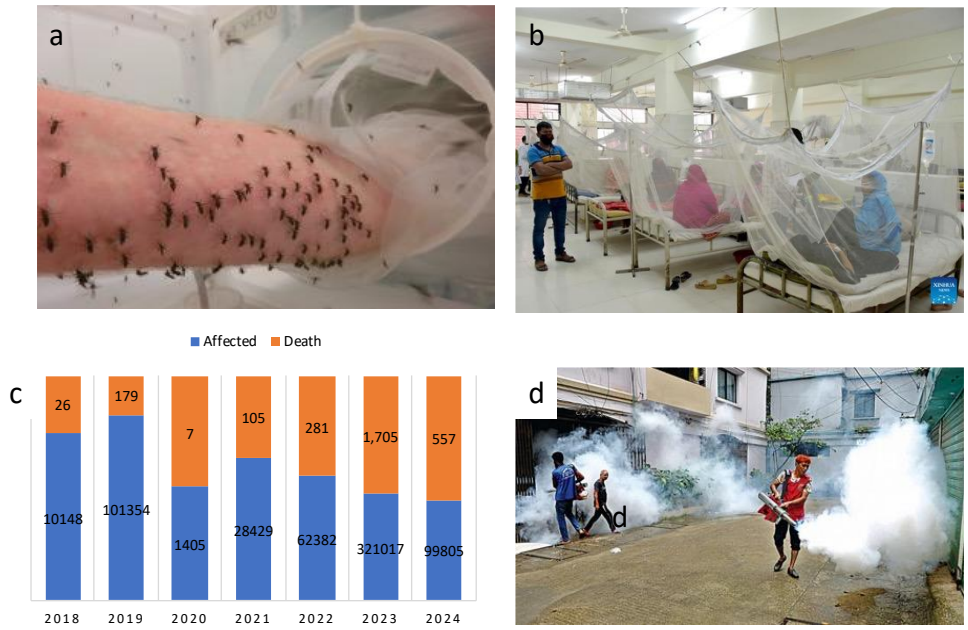

Illustration of Graphical abstract: The scenery of mosquito problems in Bangladesh are presented in graphically (a) Photo of - mosquito biting human finger (b) Mosquito infected people are in hospitalized (c) Tally of mosquito infected number with death toll (Reference – Dengue dashboard) (d) Spreading of smoke to prevent mosquito.

2. Methodology

This study employed a systematic literature review to examine existing research, reports, and epidemiological data pertaining to mosquito-borne diseases in Bangladesh. Sources included national health surveys, publications from international organizations such as the World Health Organization, and relevant news articles and case studies from countries with successful mosquito control initiatives. A comprehensive search of both published and gray literature was conducted across multiple databases. Relevant data were extracted and analyzed to identify contemporary solutions, challenges specific to Bangladesh, and potential sustainable interventions.

Data Sources

This study utilized two primary data sources:

1. Academic Databases:

A systematic search was conducted across databases, including PubMed, Google Scholar, Scopus, DOAJ, and the World Health Organization repository (WHO IRIS)

to gather of published and gray literature including peer-reviewed articles, epidemiological reports, and case studies. This helped in identifying global scenery of mosquito-infected diseases, prevalent mosquito species, disease transmission, spreading mechanism of mosquito-related fever to humans, existing mosquito control strategies, their effectiveness, and challenges related to urbanization, insecticide resistance, and climate change.

Search Strategy

The systematic search focused on identifying literature published between 2010 and 2024, using the following search terms:

- "mosquito control strategies in Bangladesh"
- "dengue outbreaks in South Asia"
- "climate change and mosquito-borne diseases"
- "integrated vector management"

Inclusion criteria

- Peer-reviewed articles that addressed mosquito control, public health, and environmental factors in Bangladesh or similar regions.
- Studies that focused on Aedes aegypti and Aedes albopictus as vectors of dengue and chikungunya.

Exclusion criteria

- Articles not available in English or Bengali.
- Studies published before 2010, unless highly cited.

2. News Articles and Media Reports: To complement the scientific data, news articles were incorporated to provide real-time insights into the magnitude of outbreaks and the public health system's responses. This mixed-methods approach enabled a more comprehensive analysis, combining quantitative data from academic research with qualitative perspectives from media coverage. News articles were selected from both national and international media outlets to offer up-to-date information on the impact of mosquito-borne diseases in Bangladesh. These sources were instrumental in capturing the dynamic nature of outbreaks, public health interventions, and socio-political challenges. Media reports were chosen based on their relevance to dengue and other mosquito borne diseases outbreak and their coverage of mosquito control initiatives in Bangladesh. Data from media reports and news articles were cross-referenced with peer-reviewed studies to ensure accuracy and consistency in reporting.

Data Extraction and Synthesis

Global health reports and academic studies provided a broad overview of mosquito-borne diseases worldwide. News articles focused on the recent dengue outbreak in Bangladesh, highlighting its scale and socio-economic impacts. Peer-reviewed studies were analyzed to identify the prevalent mosquito species (Aedes aegypti,

Aedes albopictus, and Anopheles) and their roles in transmitting diseases like dengue, malaria, and chikungunya. Factors contributing to mosquito abundance, such as urbanization, climate change, and public health infrastructure, were also investigated. Case studies from countries like Malaysia, Thailand, and Singapore were examined to identify successful integrated mosquito control strategies. Finally, limitations in Bangladesh's current strategies were analyzed, and potential sustainable solutions, such as Integrated Vector Management (IVM), were proposed.

3. Results

Following the systematic literature review and analysis of both academic studies and global media reports, this section presents a comprehensive overview of mosquito-borne diseases and their impacts. The findings are structured to present findings on biology of prevalent mosquito species, disease transmission mechanisms, and human immune responses to these pathogens. Additionally, the paper analyzes the environmental and social factors contributing to mosquito abundance, compares control strategies implemented in other countries, and evaluates current and potential mosquito management practices in Bangladesh.

a) Global scenery of mosquito infected diseases

Mosquito-borne diseases pose a significant global health challenge, affecting millions of people annually and resulting in substantial mortality rates. Diseases such as malaria, dengue, Zika, and chikungunya are primarily transmitted through the bites of infected mosquitoes.

Malaria remains a leading cause of death in many developing countries, particularly in sub-Saharan Africa. In 2022, there were an estimated 249 million malaria cases and 608,000 deaths globally (World Health Organization, 2023b). Children under five are disproportionately affected, accounting for a significant portion of malaria-related fatalities.

Dengue is another major concern, with over 3.9 billion people living in areas at risk of infection. The disease burden has increased dramatically in recent decades, with an estimated 96 million symptomatic cases reported annually (World Health Organization, 2024). While fatalities are less common compared to malaria, dengue can lead to severe complications and death in some cases.

Other mosquito-borne diseases, including Zika, chikungunya, and yellow fever, also contribute to the global disease burden, particularly in tropical and subtropical regions. These diseases often cause significant morbidity and impact economic development. Table 1 shows an overview of the epidemiology of dengue fever in the world, including the number of new cases in 2022 and the level of risk of infection.

Table 1. Overview of the epidemiology of dengue fever in the world, including the number of new cases in 2022 and the level of risk of infection (Lessa *et al.*, 2023). The table is reprinted with the permission of the World Health Organization (WHO).

Country	New Cases Reported in 2022	Level of Infection Risk
	Asia	
Afghanistan	1266	Sporadic/Uncertain
Bangladesh	82,743	Frequent/Continuous
Cambodia	12,591	Frequent/Continuous
China	537	Risk varies based on region
India	110,473	Risk varies based on region
Indonesia	125,888	Frequent/Continuous
Malaysia	64,078	Frequent/Continuous
Nepal	54,784	Frequent/Continuous
Pakistan	78,554	Risk varies based on region
Philippines	220,705	Frequent/Continuous
Singapore	31,883	Sporadic/Uncertain
Thailand	33,489	Frequent/Continuous
Vietnam	367,729	Frequent/Continuous
	Africa	
Kenya	34	Frequent/Continuous
São Tomé and Príncipe	1161	Sporadic/Uncertain
Somalia	5350	Frequent/Continuous
Sudan	4800	Frequent/Continuous
	American	
Brazil	2,363,490	Frequent/Continuous
Colombia	69,497	Frequent/Continuous
Mexico	59,918	Risk varies based on region
Nicaragua	97,541	Frequent/Continuous
Peru	72,851	Risk varies based on region
	Australia and the Pacific	
Australia	407	Frequent/Continuous
Fiji	1960	Frequent/Continuous
Vanuatu	148	Sporadic/Uncertain
	Europe	
France	272	Sporadic/Uncertain

b) Overview of the recent report in world media about the mosquito disaster in Bangladesh

The dengue outbreak in Bangladesh during 2023 has reached unprecedented proportions, drawing international attention due to the staggering number of cases, hospitalizations, and fatalities. The situation has overwhelmed healthcare facilities, leading to critical shortages of beds and medical resources. This outbreak has highlighted systemic vulnerabilities in the country's healthcare infrastructure and the urgent need for effective vector control measures to prevent future occurrences. Here below we shortly quoted some of them-

Dhaka Tribune, June 11, 2024, Dhaka: Bangladesh is wrestling with a harsh dengue outburst, characterized by a rapid surge in cases and fatalities. As reported by Ahmad (2024), the situation has escalated to crisis levels, overwhelming healthcare facilities. The city has witnessed an alarming increase in new infections and deaths within a short period, underscoring the gravity of the circumstance. The outbreak has placed an immense strain on the healthcare system, with hospitals brawling to accommodate the influx of valetudinarian. This emergency public health issue necessitates immediate and comprehensive measures to curb the proliferation of the dengue and mitigate its devastating impact on the population.

The Daily Star, August 4, 2023, Dhaka: Bangladesh is forthwith confronting its acutest dengue rush since the disease was first officially recorded in 2000. On August 3rd, 2023, the death toll has climbed to 33 due to dengue fever, with a total of 2,581 cases announced. These figures represent a significant increase contrast to the preceding year, which saw 1,705 deaths and 321,179 cases. The situation reached a crisis point in August 2023, with a surpassing 2,192 new occurrences reported in a single day, surpassing the 100,000 marks for the year. This surpasses the previous peak of 101,354 cases recorded in 2019. Fatalities have also reached an alarming level, with 485 deaths reported this year, surpassing the previous highest death toll of 363 in 2019. The months of August as well as September have historically been peak periods for the recorded occurrences in this country of Bangladesh of dengue fever, with September witnessing the highest figure of occurrences in nine out of the past 22 years (Alam, 2023).

BDNEWS24.COM, May 15, 2024, Dhaka: Dengue cases are continuing to rise in Bangladesh. According to the Health Services Directorate General, three more losses of life were reported, bringing the announced entire fatalities for the year to 32. The figure of hospitalized patients reached 2,545, with 21 new cases identified within 24 hours. Dhaka remains the most affected area, followed by Chattogram, Barisal, and Khulna. Currently, 136 patients are undergoing treatment nationwide, including 64 in Dhaka. This year's outbreak follows a severe 2023 dengue season with 321,179 hospitalizations and 1,705 reported deaths (BDNews24, 2024).

Aljazeera, November 21, 2023, Qatar: Bangladesh is currently faced with an unprecedented dengue outbreak, surpassing previous records in both cases and fatalities. The number of dengue cases has surged dramatically, overwhelming healthcare facilities. The situation is particularly alarming as the typical decline in dengue cases associated with the end of the monsoon season has not materialized this year. Health authorities are facing with a crisis as the death toll continues to rise, with children being disproportionately affected (Mahmud, 2023).

Xinhua, November 20, 2023, China: Dengue cases in Bangladesh continue to surge. As of Sunday, the Directorate General of Health Services (DGHS) reported 1,291 new infections, bringing the total to 301,225 since January. The death toll has

climbed to 1,549, with 201 fatalities recorded this month alone. Notably, November witnessed a significant increase of 30,080 cases, following a spike of 67,769 infections in October. Despite 1,522 new recoveries reported on Sunday, the total recoveries stand at 294,757. September remains the deadliest month with 79,598 new cases and 396 deaths (Huaxia, 2023).

Reuters, October 02, 2023, USA: Bangladesh is troubling with its worst dengue outbreak on record, with over 1,000 fatalities reported in 2023. The rapid spread of the disease has overwhelmed hospitals, leading to a critical shortage of beds for patients. This year's outbreak surpasses previous records, eclipsing the 281 deaths reported in 2020. Nearly 209,000 people have contracted the virus so far in 2023, highlighting the severity of the situation (Paul, 2023).

The Telegraph, October 02, 2023, UK: The situation of dengue is in outbreak in Bangladesh which is grappling with an unprecedented record. Since the beginning of 2023, the country has recorded a surge in dengue cases and fatalities, far exceeding previous years. Over one thousand deaths have been reported, with a disproportionate impact on children. Hospitals have been overwhelmed by the influx of patients, underscoring the severity of the situation (Bowman, 2023).

Voice of America, August 26, 2023, USA: Bangladesh is experiencing an unusually severe dengue fever epidemic in 2023. The number of infections and fatalities has surged dramatically compared to previous years. With over 78,000 cases and 364 deaths reported thus far, the country's health system is under immense strain. The situation worsened in August, with a staggering number of cases and deaths exceeding those of the entire previous year (Ahmed, 2023).

World Health organization (WHO), August 11, 2023, Switzerland: Bangladesh witnessed an unprecedented surge in dengue cases between January and August 2023, with a significant increase in both infections and fatalities compared to previous years. The outbreak was characterized by a rapid escalation of cases, particularly from June onwards, culminating in the highest number of cases reported since 2000. The data reveals significant geographical disparities in the outbreak. Dhaka division, particularly Dhaka city, bore the brunt of the epidemic, accounting for the majority of cases and deaths. However, the outbreak was not confined to urban areas, with substantial numbers of cases reported across the country. The case fatality rate (CFR) for the 2023 outbreak was higher than observed in previous years. The overall scenery of distribution of dengue affected (admitted) by division in 2024, distribution of dengue death by division in 2024, dengue affected (admitted) by month in the year of 2023 and 2024, dengue affected (admitted) by year, is illustrated in Figure 1.

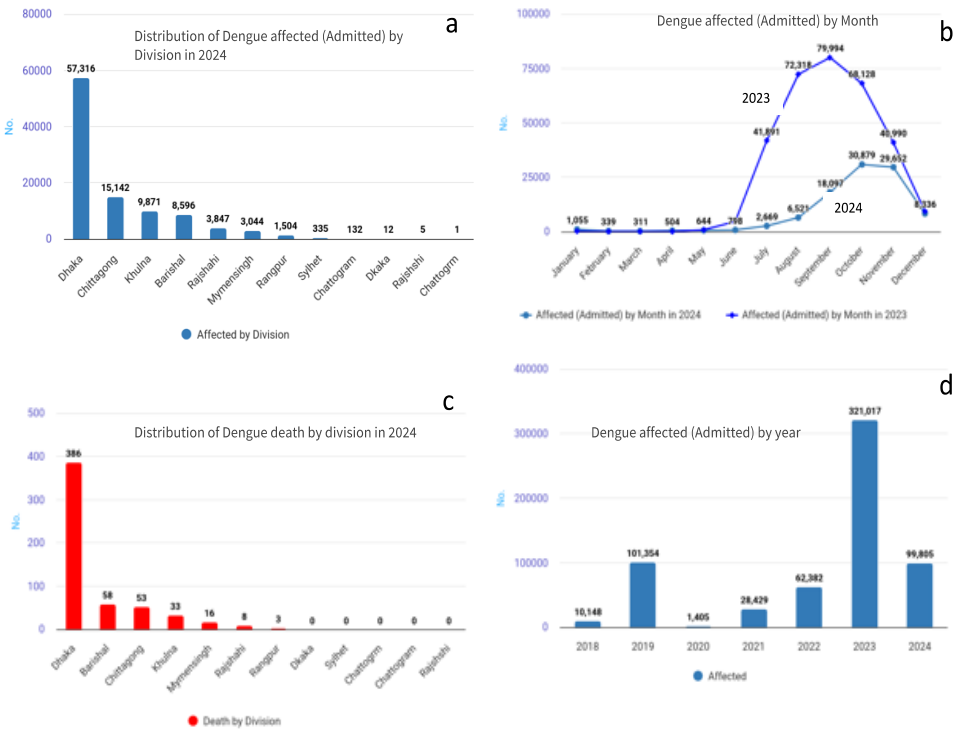

Figure 1. Number of cases reported and death tool due to dengue fever in Bangladesh recorded from 2018 to 2024. Dengue Dashboard, (2024). The figure is reprinted with permission of world health organization (WHO).

In another research by Bhowmik *et al.* (2023) were explained year and month-wise dengue reporting from 2012 to December 15, 2022 which is shown in the ***Figure 2.*** *This* report presents a comprehensive overview of dengue fever cases in Bangladesh from 2012 to December 15, 2022, revealing a distinct seasonal pattern. The data indicates a clear surge in cases during the latter half of the year. August 2019 stands out as the peak month with a staggering 52,636 confirmed cases, marking the highest recorded monthly incidence to date. Following closely behind, October 2022 witnessed a significant outbreak with 21,932 confirmed cases. September and July of 2019 also reported substantial numbers, with 16,856 and 16,253 cases respectively, solidifying their position as the third and fourth highest months in terms of dengue infections during the analyzed period.

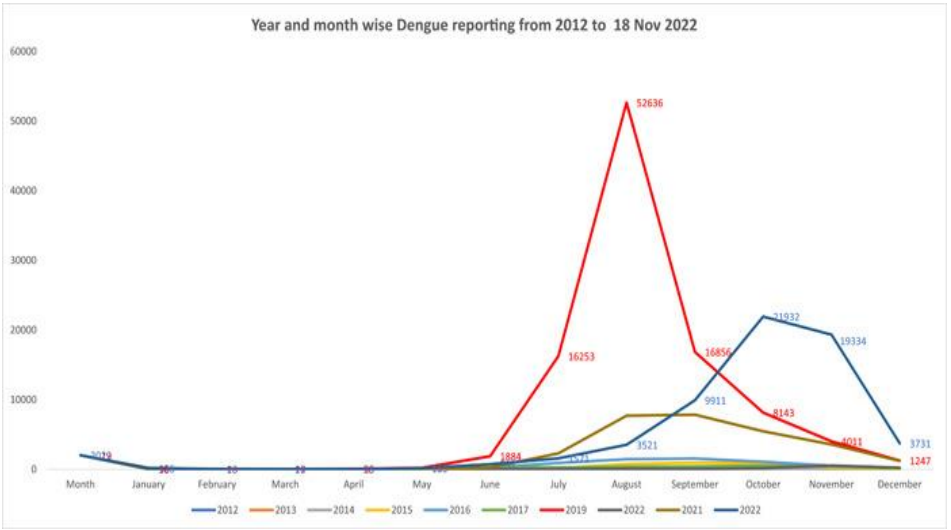

Figure 2. Year and month-wise dengue reporting from 2012 to December 15, 2022 (Bhowmik et al., 2023). The figure is reprinted with permission of Willy Online.

c) Prevalent mosquito species and disease transmission

In Bangladesh, the prevalence of mosquito-borne diseases poses a significant public health challenge, with several mosquito species playing crucial roles in disease transmission. Among the most prevalent species are *Aedes aegypti* and *Aedes albopictus*, both known vectors for diseases like dengue fever, chikungunya, and Zika virus (Messina *et al.*, 2014; Zhang *et al.*, 2021). These mosquitoes have demonstrated remarkable adaptability to urban environments, thriving in areas with stagnant water sources, such as discarded containers and water storage vessels. Their ability to reproduce efficiently in these settings contributes to their status as formidable adversaries in disease control efforts.

Dengue fever remains a major concern in Bangladesh, with seasonal outbreaks causing significant morbidity and mortality (Kamel *et al.*, 2017). The Aedes mosquitoes responsible for transmitting dengue are active throughout the year, but outbreaks typically peak during the monsoon season when rainfall creates ample breeding sites (Messina *et al.*, 2014). The densely populated urban areas of Dhaka, Chittagong, and other major cities are particularly vulnerable to dengue outbreaks due to the abundance of breeding sites and the close proximity of susceptible human hosts (World Health Organization, 2024). Dengue fever symptoms typically include a high fever, severe headache, pain behind the eyes, muscle and joint pain, nausea, vomiting, and a rash. In severe cases, it can progress to dengue hemorrhagic fever, characterized by severe abdominal pain, persistent vomiting, bleeding, and difficulty breathing (Rapp, 2020).

In addition to dengue fever, Aedes mosquitoes are also implicated in the transmission of chikungunya and Zika virus (World Health Organization, 2009a). While outbreaks of these diseases have been less frequent in Bangladesh compared to dengue, the potential for their spread remains a concern. Chikungunya, characterized by fever and severe joint pain, can cause debilitating illness and has the potential to emerge as a significant public health problem during outbreaks (World Health Organization, 2022a). Zika virus, although typically mild in most cases, poses a particular risk to pregnant women due to its association with birth defects such as microcephaly (Johansson *et al.*, 2016; World Health Organization, 2022b). Different types of mosquito spies exist and responsible for different types of fever are shown in the Figure 3.

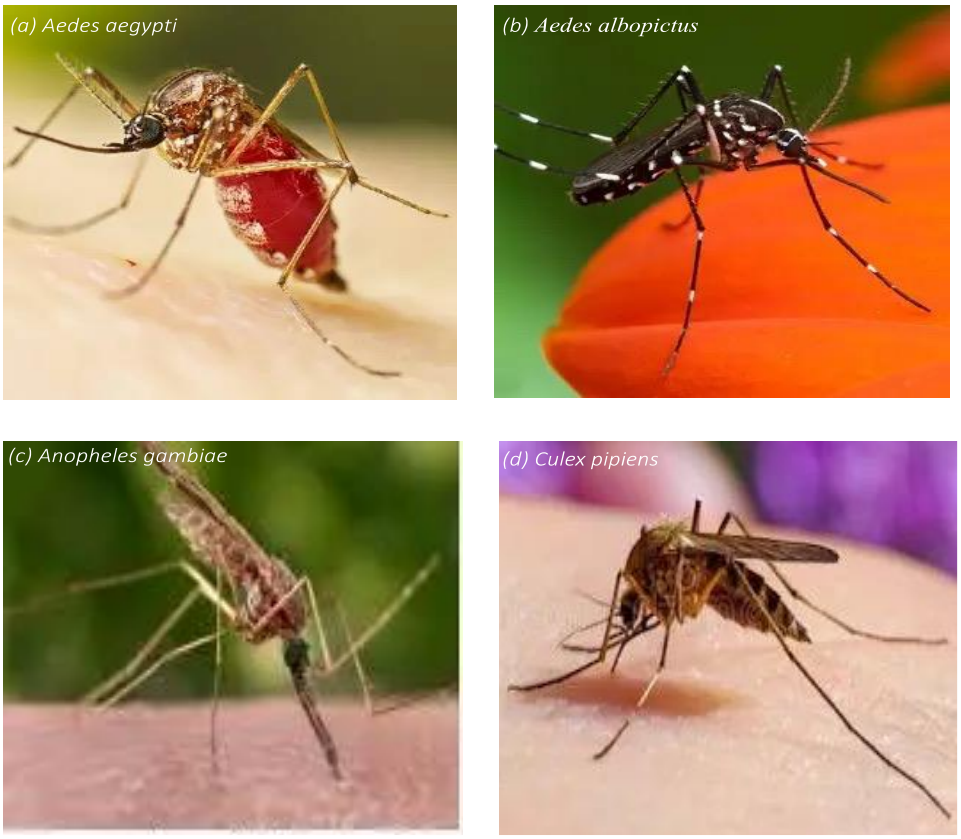

Figure 3. Photo of Mosquitoes - (a) *Aedes aegypti* (b) *Aedes albopictus (c) Anopheles gambiae (d) Culex pipiens* – (a) and (b) are responsible for spreading yellow fever, dengue, chikungunya, Zika fever, Mayaro. (c) responsible for malaria (d) responsible for disfiguration of the human body.

Apart from Aedes mosquitoes, Anopheles mosquitoes are also prevalent in Bangladesh and are responsible for transmitting malaria (World Health Organization, 2023b). While significant progress has been made in malaria control efforts over the past few decades, malaria remains endemic in certain regions of the country, particularly in remote and rural areas. The implementation of insecticide-treated bed nets, indoor residual spraying, and prompt diagnosis and treatment of malaria cases have contributed to a reduction in malaria transmission (Fikadu & Ashenafi, 2023).

Culex mosquitoes, although less studied compared to Aedes and Anopheles species, are also prevalent throughout Bangladesh and are implicated in the transmission of diseases such as lymphatic filariasis and Japanese encephalitis. Lymphatic filariasis, caused by filarial worms transmitted through the bites of infected mosquitoes, can lead to severe disability and disfigurement if left untreated (Gelderblom, 1995). Japanese encephalitis, a viral disease transmitted by Culex mosquitoes, can cause inflammation of the brain and is associated with high mortality rates, particularly among children (World Health Organization, 2013).

d) Spreading mechanism of mosquito related fever to the human

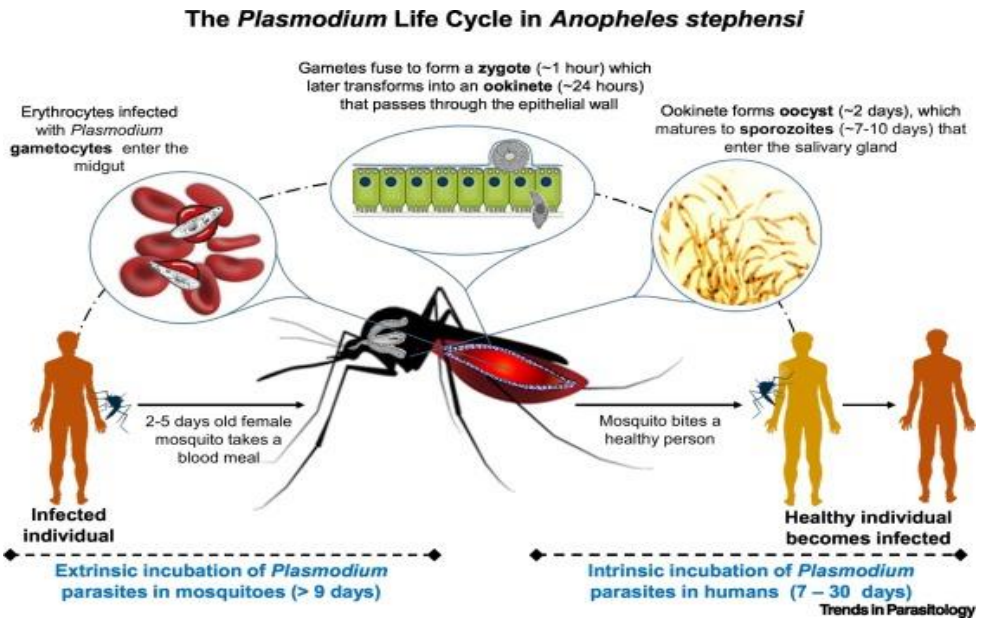

Figure 4. Mosquito diseases transmission in human to human by *Anopheles stephensi* (Hemming-Schroeder & Ahmed, 2023*).* The figure is reprinted with permission of journal of *Trends in Parasitology.*

A comprehensive understanding of the mosquito life cycle is crucial for implementing effective control strategies. Mosquitoes undergo complete metamorphosis, progressing through four distinct stages: egg, larva, pupa, and adult (Hemming-Schroeder & Ahmed, 2023). The first three stages occur entirely in aquatic environments, while the adult is a terrestrial insect (Eckhoff, 2011). The female mosquito, after obtaining a blood meal, deposits her eggs on or near water bodies. These eggs can withstand dry conditions for extended periods, making them resilient to environmental challenges (Acharya, 2016). Upon exposure to water, the eggs hatch into larvae, commonly known as wrigglers, which feed and grow in the aquatic environment (Conlon, 2011). The larval stage is followed by the pupal stage, during which the mosquito undergoes metamorphosis without feeding (Nureye, 2021). Finally, the adult mosquito emerges from the pupal case, dries its wings, and takes flight. The duration of the mosquito life cycle varies depending on environmental conditions, primarily temperature. While it typically takes about two weeks, under optimal conditions, the cycle can be completed in as little as four days (Naik *et al.*, 2023). By comprehending these distinct stages, targeted control measures can be implemented to disrupt the mosquito life cycle at vulnerable points. This knowledge is essential for public health officials, researchers, and individuals seeking to protect themselves and their communities from mosquito-borne diseases (Cloherty *et al.*, 2023). Figure 4. demonstrate the Mosquito diseases transmission in human to human by *Anopheles stephensi* (Hemming-Schroeder & Ahmed, 2023).

e) The mechanism of fever induction by mosquito-borne pathogens in human body

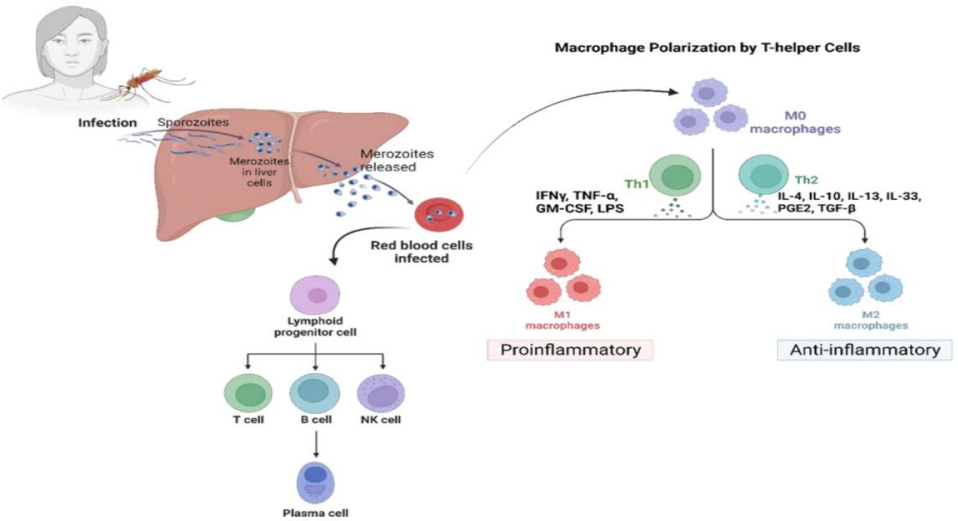

Figure 5. *Plasmodium* and infected red blood cells activate dendritic cells through parathyroid hormone (PTH)/PTH-related peptide receptor (PPR) and are phagocytosed, and their antigens are presented to T cells. PRR signaling leads to the secretion of cytokines that initiate inflammation via Th1 and Th2 cell differentiation and macrophage polarization. Macrophages are responsible for the regulation of inflammation during the infection phase. T cells help with B cell differentiation and antibody secretion and secrete IFN-γ, which activates macrophages. IFN-γ-activated macrophages engulf opsonized cells (Bhattacharjee *et al.*, 2023). The figure is reprinted with permission of journal of *Pathogens*.

Mosquitoes, as vectors for numerous diseases, transmit pathogens into the human bloodstream through their saliva during feeding. These pathogens, including viruses, bacteria, and parasites, can induce fever as part of the host's immune response. Upon entering the bloodstream, the pathogen replicates and spreads throughout the body. This invasion triggers an immune response characterized by the release of inflammatory cytokines, such as interleukin-1 (IL-1), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-α) (Bhattacharjee *et al.*, 2023). These cytokines act as signaling molecules, initiating a cascade of events that ultimately lead to fever. One of the primary mechanisms of fever induction involves the hypothalamus, often referred to as the body's thermostat. Cytokines stimulate the hypothalamus to reset its temperature set point to a higher level. The body then initiates processes to elevate its core temperature, including shivering, vasoconstriction, and increased metabolism (Evans *et al.*, 2015). The elevated body temperature, or fever, is a complex physiological response aimed at creating an inhospitable environment for the invading pathogen while enhancing the immune system's ability to combat the infection. However, in severe cases, the fever can become dangerously high, leading to complications. Arising of fever by mosquito infection in human body is illustrated in Figure 5.

f) Factors Contributing to Mosquito Abundance

Dhaka's urban landscape presents ideal breeding grounds for mosquitoes. Here are some key contributing factors:

Unmanaged Waste: Unmanaged waste significantly contributes to mosquito abundance in Bangladesh, exacerbating public health challenges. The country's rapid urbanization and population growth have led to increased waste generation, often outpacing the capacity for proper disposal and management. Piles of garbage, discarded containers, and stagnant water from uncollected waste provide ideal breeding grounds for mosquitoes (Tuhkanen *et al.*, 2022). These environments offer abundant sites for mosquitoes to lay eggs and for larvae to develop, particularly in stagnant water, which is commonly found in neglected waste areas (Gubler, 1998). Organic waste attracts mosquitoes seeking food and suitable places to lay eggs, further increasing their population. The situation is worsened by inadequate waste management infrastructure and public awareness, allowing waste to accumulate

unchecked in urban and rural areas alike. This unmanaged waste not only promotes mosquito proliferation but also hampers control measures, making it difficult to mitigate mosquito-borne diseases such as dengue and malaria (World Health Organization, 2009b).

Poor Drainage Systems: Poor drainage systems significantly contribute to mosquito abundance in Bangladesh. Inadequate and poorly maintained drainage infrastructure leads to water stagnation, creating ideal breeding grounds for mosquitoes. During the monsoon season, the situation worsens as heavy rainfall overwhelms the drainage capacity, resulting in widespread waterlogging. These stagnant pools of water provide a perfect habitat for mosquito larvae to thrive and multiply (Alom & Khan, 2014). Additionally, clogged drains filled with debris and organic waste further exacerbate the problem by impeding water flow and creating more breeding sites (Srivastava *et al.*, 2015). Urban areas, in particular, suffer from ineffective drainage systems, where rapid urbanization has outpaced infrastructure development. Consequently, the high mosquito population not only increases the incidence of mosquito-borne diseases such as dengue, malaria, and chikungunya but also poses a significant public health challenge.

Lack of Public Awareness: In Bangladesh, the lack of public awareness significantly contributes to the abundance of mosquitoes. Many residents are not fully informed about the importance of preventing mosquito breeding or the health risks associated with mosquito-borne diseases like dengue, malaria, and chikungunya. This lack of awareness results in inadequate measures to eliminate standing water, improper waste disposal, and insufficient use of mosquito repellents or nets. Educational campaigns are often insufficient or fail to reach all communities, particularly in rural or densely populated urban areas (Rahman *et al.*, 2023). Consequently, people may inadvertently create breeding sites by leaving containers filled with water or not maintaining cleanliness in their surroundings. Additionally, misconceptions about mosquito control and prevention further hinder effective community action.

Climate Change: Climate change is a critical factor contributing to the increased abundance of mosquitoes in Bangladesh. Rising temperatures and altered precipitation patterns, hallmarks of climate change, create ideal conditions for mosquito breeding and survival (Campbell-Lendrum *et al.*, 2015; Githeko *et al.*, 2000). Warmer temperatures accelerate the mosquito life cycle, leading to larger and more frequent populations (Caminade *et al.*, 2019). Simultaneously, increased rainfall and flooding, associated with climate change, provide abundant breeding sites (Rahman, 2014). Bangladesh's monsoon season, intensified by climate change, exacerbates this issue (Ritu *et al.*, 2024). These combined factors not only boost mosquito populations but also extend their active season, heightening the risk of vector-borne diseases. The country's dense population and limited infrastructure further compound the problem, hindering effective mosquito control efforts (World

Health Organization, 2023b). Addressing the interplay between climate change and mosquito proliferation is crucial for public health in Bangladesh. Figure 6 demonstrate the number of most productive containers (in terms of their relative contribution to total immature *Aedes* mosquitoes) by type of containers and total pupae counted in each type of most productive containers (Dhar-Chowdhury *et al.*, 2016).

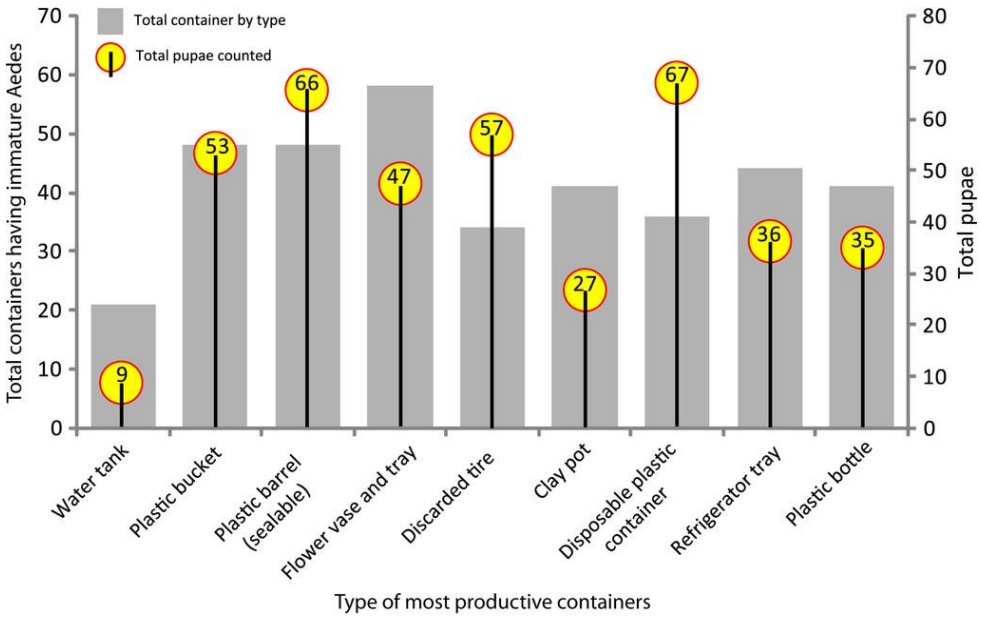

Figure 6. Number of most productive containers (in terms of their relative contribution to total immature *Aedes* mosquitoes) by type of containers and total pupae counted in each type of most productive containers (Dhar-Chowdhury *et al.*, 2016). The figure is reprinted with permission of -*The American Journal of Tropical Medicine and Hygiene (ajtmh)*.

g) Mosquito controlling management in Bangladesh- lesson from ally countries

Countries like Singapore, Malaysia, and Thailand have implemented successful strategies to combat mosquito-borne diseases, such as dengue, malaria, and Zika (World Health Organization, 2012a). These nations have adopted a multi-faceted approach, encompassing vector control, public awareness, and early warning systems. For instance, Singapore's rigorous sanitation practices, coupled with the use of innovative technologies like drone-based surveillance, have been instrumental in controlling mosquito populations (Ho *et al.*, 2023).

Malaysia has implemented a comprehensive approach to mosquito management that Bangladesh can potentially adapt and implement to address its

own mosquito-borne disease challenges. Key strategies employed by Malaysia include integrated vector management (IVM), which encompasses a multi-faceted approach targeting various stages of the mosquito life cycle (Ong, 2016). This involves a combination of larval control measures such as larviciding and source reduction, along with adult control methods like insecticide-treated nets (ITNs), indoor residual spraying (IRS), and targeted insecticide applications. Additionally, Malaysia has invested in robust surveillance systems to monitor mosquito populations and disease outbreaks, enabling timely interventions (Zhang *et al.*, 2024).

Thailand has implemented comprehensive strategies to combat mosquito-borne diseases, making it a valuable case study for Bangladesh. The country has successfully integrated various approaches, including environmental management, biological control, and community engagement, to reduce mosquito populations and the transmission of diseases like dengue, malaria, and chikungunya (Kamtchum-Tatuene *et al.*, 2017). Thailand's emphasis on early warning systems, rapid response mechanisms, and public awareness campaigns has been used in mitigating the impact of mosquito-borne outbreaks (Simmons *et al.*, 2012). Additionally, the country has invested in research and development to explore innovative solutions, such as the use of sterile male mosquitoes and genetically modified mosquitoes, to disrupt the mosquito life cycle (Kittayapong *et al.*, 2019).

Japan has demonstrated remarkable success in controlling mosquito populations, making it a potential model for countries like Bangladesh facing with similar challenges. The nation has implemented comprehensive and integrated vector management strategies that have yielded significant reductions in mosquito-borne diseases (Auerswald *et al.*, 2021). Key elements of Japan's success include robust surveillance systems, effective public awareness campaigns, and the strategic use of larvicides and adulticides. Additionally, Japan's emphasis on environmental management, including proper waste disposal and water management, has contributed significantly to mosquito control efforts (JICA, 2022).

India, facing with similar climatic and geographical conditions as Bangladesh, has made significant strides in mosquito management. The country's experiences in combating vector-borne diseases like malaria, dengue, and chikungunya offer valuable insights for Bangladesh. India's integrated vector management (IVM) approach, encompassing a combination of strategies such as larviciding, adulticiding, environmental management, and public awareness campaigns, has yielded notable results (Bordoloi & Saharia).

Key lessons from India include the effective implementation of early warning systems, rapid response mechanisms, and community engagement. India's success in scaling up interventions like insecticide-treated mosquito nets and indoor residual spraying has been useful in reducing vector populations and disease burden (Dhopte & Hari, 2020). Additionally, India's focus on research and development to

understand mosquito behavior and resistance patterns has contributed to the development of innovative control strategies.

Bangladesh can adapt these strategies to its specific context by incorporating local knowledge and resources. Additionally, international collaborations and knowledge exchange can foster innovation and improve the effectiveness of mosquito management programs in the country (Breman *et al.*, 2004).

h) Mosquito Control Strategies in Bangladesh

Controlling the mosquito problem in Bangladesh requires a multifaceted approach, combining environmental management, community engagement, and technological innovation (World Health Organization, 2012a). One of the most effective strategies is source reduction, which involves eliminating mosquito breeding sites. This can be achieved by improving waste management systems to ensure proper disposal and prevent the accumulation of stagnant water in urban and rural areas (World Health Organization, 2012b). Public education campaigns are crucial for raising awareness about the importance of keeping the environment clean and using personal protective measures, such as mosquito nets and repellents (Guzman *et al.*, 2010). Community participation in these efforts is vital, as collective action can significantly reduce mosquito populations.

In addition to environmental management, the implementation of biological control methods, such as the introduction of natural predators like fish and bacteria that target mosquito larvae, has shown promise (Fouet & Kamdem, 2019). These methods are environmentally friendly and sustainable, offering long-term solutions to the mosquito problem. Chemical control, including the use of insecticides, remains a common practice in Bangladesh. However, it must be carefully managed to avoid adverse health effects and the development of insecticide resistance in mosquito populations (World Health Organization, 2015). Rotational use of different classes of insecticides and the application of larvicides in targeted areas can enhance effectiveness while minimizing risks.

Technological innovations, such as the use of genetically modified mosquitoes, offer new avenues for control. These genetically engineered mosquitoes are designed to reduce populations by introducing genes that inhibit reproduction or produce sterile offspring (Ranathunge *et al.*, 2022). While promising, rigorous testing and monitoring are essential to ensure their long-term safety and efficacy (Gloria-Soria *et al.*, 2016). Additionally, advancements in remote sensing and geographic information systems (GIS) can aid in mapping mosquito breeding sites and predicting outbreaks, enabling more targeted and efficient interventions (Rano *et al.*, 2022).

Government and international collaboration are essential for addressing the mosquito problem in Bangladesh. Strengthening the capacity of local health departments through training and resources can improve the implementation of

control strategies. International organizations can provide technical assistance, funding, and research support to develop and deploy innovative solutions (Hossain *et al.*, 2023). Policies that promote urban planning and infrastructure development, such as improved drainage systems and housing conditions, can reduce mosquito habitats and enhance the overall quality of life (Jing & Wang, 2019).

Monitoring and evaluation are critical components of any control strategy. Regular surveillance of mosquito populations and disease incidence can help assess the effectiveness of interventions and guide adjustment. Community-based monitoring, where local residents participate in data collection and reporting, can enhance the accuracy and timeliness of information. This participatory approach also fosters a sense of ownership and responsibility among community members, leading to more sustainable control efforts.

4. Limitations and the need for a multi-pronged approach

Addressing the mosquito problem in Bangladesh necessitates a multi-dimensional approach due to the limitations of relying on a single strategy. One significant limitation is the adaptability of mosquitoes to various control measures, including insecticides. Over time, mosquitoes can develop resistance to commonly used chemicals, rendering them less effective and necessitating the use of higher doses or alternative substances (Weill *et al.*, 2003). Additionally, environmental concerns arise from the extensive use of insecticides, which can harm non-target species and disrupt ecosystems. This highlights the need for integrated pest management (IPM) strategies that combine chemical, biological, and environmental control methods (Stenberg, 2017).

The geographic and climatic conditions in Bangladesh further complicate mosquito control efforts. The country's tropical and subtropical climate, coupled with heavy monsoon rains, creates an ideal environment for mosquito breeding. Frequent flooding and poor drainage systems exacerbate the problem by creating numerous stagnant water bodies, which serve as breeding sites (Gizaw *et al.*, 2024). These environmental factors are difficult to control through chemical means alone, underscoring the necessity for habitat management and engineering solutions, such as improving drainage systems and ensuring proper waste disposal to eliminate breeding grounds (World Health Organization, 2012a).

Public health education is another crucial component of a multi-dimensional approach to combating mosquito-borne diseases. Community engagement and awareness programs can significantly enhance the effectiveness of mosquito control initiatives (World Health Organization, 2020). Educating the public about the importance of eliminating stagnant water, using mosquito nets, and practicing personal protective measures can reduce mosquito-human contact and lower the incidence of mosquito-borne diseases (Castaneda Aguilar *et al.*, 2020). However, the success of such programs is often limited by socioeconomic factors. In densely

populated urban areas and impoverished communities, access to resources like mosquito nets and repellents may be limited, and sanitation infrastructure may be inadequate. Thus, government and non-governmental organizations need to collaborate to ensure that educational campaigns are accompanied by the provision of necessary resources and improvements in living conditions (Benelli, 2015).

Biological control methods, such as introducing natural predators of mosquitoes or utilizing genetically modified mosquitoes, offer promising avenues for mosquito population management (Jones, 2023). However, these approaches come with their own set of challenges. The implementation of biological controls requires careful consideration of ecological impacts and long-term sustainability. Additionally, the technical and financial resources required for such interventions may be beyond the reach of local authorities without external support and investment (Breman *et al.*, 2004).

So, the mosquito problem in Bangladesh is a complex issue that cannot be effectively addressed through a single approach. The limitations of chemical control methods, coupled with environmental and socioeconomic challenges, necessitate a multi-faceted strategy. Integrated pest management, habitat modification, public health education, and biological controls must be combined to form a comprehensive and sustainable solution.

5. Conclusion

Mosquito-borne diseases remain a significant public health challenge in Bangladesh, imposing substantial burdens on individuals, communities, and the nation's economy. The complex relation of environmental, socio-economic, and ecological factors contributes to the persistence of these diseases. This review has highlighted the critical need for comprehensive and integrated vector control strategies to effectively address the mosquito problem. Existing control measures, including insecticide-treated nets, indoor residual spraying, and larvicides, have yielded some success but face limitations due to the evolving nature of mosquito resistance and the complex ecological context. Therefore, there is an urgent need to explore innovative and sustainable approaches to vector control. This includes developing novel insecticides with alternative modes of action, exploring the potential of biological control agents, and promoting community-based initiatives for change in behavior and environmental management. Future research should focus on understanding the underlying mechanisms of mosquito resistance to current control measures and developing strategies to overcome these challenges. Additionally, there is a need for more in-depth studies on the impact of climate change on mosquito populations and disease transmission. The integration of advanced technologies, such as artificial intelligence and remote sensing, can enhance surveillance and response efforts. International collaboration is essential for addressing the mosquito problem in Bangladesh. Sharing knowledge, expertise, and resources among countries can facilitate the development and implementation

of effective control strategies. Joint research initiatives, capacity building programs, and technology transfer can contribute to building a global network for combating mosquito-borne diseases. By working together, the international community can support Bangladesh in its efforts to create a healthier and more sustainable future for its population. Ultimately, a multi-faceted approach that combines vector control, early warning systems, access to healthcare, and social empowerment is required to achieve significant and lasting reductions in mosquito-borne diseases in Bangladesh. By addressing the root causes of the problem and investing in longer lasting solutions, it is possible to build a resilient and mosquito-free future for the country. By implementing comprehensive strategic steps, Bangladesh can set aims to achieve its sustainable development goals and transition into a smart nation, aligning with the current government's agenda. This strategic approach is necessary for the country's commitment to progress and innovation.

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Conflict of interest

Authors deny any kind of conflict of interest in this research.

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