Social and Climatic Factors Contributing to the Persistence of Malaria in The Chittagong Hills Tracts of Bangladesh

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Abstract

Malaria persists in 13 of Bangladesh's 64 districts, notably in the Chittagong Hill Tract (CHT) districts consisting of Bandarban, Rangamati, and Khagrachhari. While prior studies have explored malaria in Bangladesh, none have delved into the behavioral and climatic factors that simultaneously contribute to its persistence in the CHT districts. This study aims to fill this gap by investigating behaviors influencing malaria persistence in Bangladesh's endemic region, focusing on the Lama, Alikodom, and Naikhongchhari subdistricts of Bandarban district. Data were collected through surveys and key informant interviews (KIIs) in Lama and Alikodom, revealing tribal villages as having the highest concentration of cases, with inhabitants lacking essential knowledge about malaria and prevention methods. Socio-economic dynamics between tribal and Bengali communities emerged as a barrier to accepting information provided by NGOs. Additionally, occupation (employment) was found to be closely linked to malarial sickness. These findings can inform policies to eradicate malaria and protect tribal minorities. Meanwhile, in Naikhongchhari, this study analyzes the relationship between malaria incidence and climatic variables such as rainfall and temperature from 2013 to 2022. Utilizing NGO malaria registry data and meteorological data, significant correlations between rainfall, temperature, and malaria incidence were identified, with temperature and rainfall spikes preceding increases in cases. Despite limitations such as retrospective data collection inaccuracies and omitted determinants, these findings underscore the importance of considering climatic factors in malaria control efforts, necessitating further research for a comprehensive understanding of malaria dynamics. Combined, the overall findings suggest the need for greater education measures using improved communication devoted to preventative efforts among the ethnic minority residents of the CHTs, particularly during the time periods immediately after high rainfall and temperature. Such efforts could contribute greatly to Bangladesh’s attempt to eliminate malaria within its borders.

Social and Climatic Factors Contributing to the Persistence of Malaria in The Chittagong Hills Tracts of Bangladesh

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General Audience Abstract

Malaria remains a persistent issue in 13 out of Bangladesh's 64 districts, particularly prevalent in the Chittagong Hill Tract (CHT) districts like Khagrachhari, Bandarban, and Rangamati. Previous studies have overlooked the behavioral and climatic factors contributing to malaria's endurance in the CHT districts. This study fills this gap by investigating behavioral influences on malaria persistence, focusing on subdistricts like Lama, Alikodom, and Naikhongchhari in Bandarban district. Surveys and key informant interviews in Lama and Alikodom revealed tribal villages as hotspots for malaria, with inhabitants lacking crucial knowledge about prevention methods. Socio-economic disparities between tribal and Bengali communities hinder the acceptance of information provided by NGOs. Occupation was identified as closely linked to malarial sickness. In Naikhongchhari, the study explores the correlation between climatic variables and malaria incidence from 2013 to 2022, finding significant relationships between rainfall, temperature, and malaria cases. Temperature and rainfall spikes preceded increases in malaria cases. Despite limitations like retrospective data collection issues, the findings stress the importance of considering climatic factors in malaria control strategies. Enhanced education and communication efforts, particularly targeting ethnic minority residents of the CHTs, could significantly aid Bangladesh's malaria elimination efforts.

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Attribution

Korine Kolivras, PhD serves as my academic advisor and thesis committee chair. She has provided valuable input by proposing potential analysis methods and offering editorial feedback for improvement.

Dr. Tom Crawford, PhD, department chair and committee member, has contributed by recommending additional variables for analysis and providing editorial comments.

Similarly, Dr. Eranga Galappaththi, PhD, my other committee member, has suggested the sampling method for the KAP survey and shared his insights about personal interview methods and analysis.

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Chapter 1: Introduction

1.1 Background

Malaria is estimated to have been directly responsible for around 619,000 deaths worldwide in 2021 (WHO, 2023). In 1991, malaria morbidity and mortality were responsible for nearly 3% of the world's DALYs (Disability-adjusted life years) (Benet et al., 1991) and with recent reductions in malaria cases and deaths, the DALY was reduced to 0% in 2000 and remained 0% as of 2019 (WHO, 2020). In their pursuit of a world free from disease, the World Health Organization (WHO) has aims to eventually eradicate malaria, with current efforts going toward elimination of the disease within individual countries (WHO, 2024). Global efforts have yielded promising results, with a number of countries successfully eliminating the disease within their borders. Over the past two decades, 11 nations have earned the WHO's certification as malaria-free, signifying the interruption of indigenous malaria transmission for a minimum of three consecutive years, resulting in a total of 43 nations and one territory that have eliminated malaria (WHO, 2024). Although Africa bears 90% of the malaria mortality burden, Southeast Asia also faces significant mortality and morbidity from the disease. Within the Southeast Asian Regional Office of the WHO, nine countries, including Bangladesh, remain malaria-endemic. Since 2000, the number of countries in the region reporting fewer than 100 malaria cases, increased from six to 27 in 2021; however, while Bangladesh as a whole saw reduced malaria incidence during that period, the eastern part of the country experienced a surge in indigenous cases- “Malaria cases contracted locally with no evidence of importation or no direct link to an imported case” (WHO, 2022).

Transmitted by a particular species of mosquito, *Anopheles* spp., that feeds on humans, malaria is a potentially dangerous and occasionally fatal disease brought on by a parasite. Thirty-four mosquito vectors out of 41 dominant vectors for malaria have been found in Bangladesh (Islam et al., 2013). *Anopheles* mosquitoes do not bite during the day; they are only active during late evening and at night (Aubourg et al., 2022). The most prevalent *Anopheles* mosquito species found in Bangladesh are those that thrive in forested and rural areas (Islam et al., 2013). For example, one of the most prominent species, *An. dirus*, thrives in forested mountainous areas and foothills (Sriwichai et al., 2016). *An. minus* is common in vegetated areas near running water (Dev & Manguin, 2016), and *An. vagus* is found in rice fields, muddy ponds, and forested areas (Alam et al., 2020). Humans can be infected by *Plasmodium falciparum, P. malariae, P. ovale,* and *P. vivax* four different types of malaria parasites, resulting in human-to-human transmission with mosquitoes as the vector. The *Plasmodium* parasite is transmitted by bites from the female *Anopheles’* mosquito, entering the bloodstream and eventually arriving in the liver, where it then reenters the

bloodstream and causes inflammation and infection. The parasite continues to multiply, damaging red blood cells. The infected person will have fevers, chills, and increased sweat throughout each cycle of multiplication, where blood cells burst releasing additional parasites (48–72-hour development cycle). Malaria infections caused by *P. falciparum* are the most likely to be severe and, if left untreated, may be fatal (CDC, 2009). The specific malarial parasite responsible for most malaria cases in Bangladesh is *P. falciparum*, followed in importance by *P. vivax*.

Malaria usually occurs in low-lying areas within warm and humid climates. However, malaria in Bangladesh exists under a unique scenario. Bangladesh throughout has optimum weather for sustaining the *Anopheles* mosquito and malaria parasite. However, the disease is endemic in only 13 districts out of 64, with over 90% of cases reported in the Chittagong Hill Tract districts (CHTs) consisting of Bandarban, Khagrachhari and Rangamati as well as Cox's Bazar district neighboring the CHTs (National Malaria Control Programme, 2015). These districts have hilly topography and are at a higher elevation than the districts that do not experience malaria, which is contradictory to the usual topographic setting of malaria. Although environmental factors including temperature, humidity, and rainfall are optimal in these areas, the same is also true for other rural areas of Bangladesh.

1.2 Problem statement

Malaria has a very long history in southeastern Asia (Poolsuwan 1995), and the disease was firmly entrenched in Bangladesh prior to the independence of the country in 1971. Early malaria control attempts used dichlorodiphenyltrichloroethane (DDT) were thwarted by natural disasters, political upheavals, and the eventual ban on DDT (Rahman, 2013). Until the early 2000s, Bangladesh lacked focused measures to counter the disease, but a turning point came in 2006 when the Global Fund to Fight AIDS, Tuberculosis, and Malaria (the Global Fund hereafter) allocated USD 39.6 million to support Bangladesh's national malaria control program (Haque et al., 2011; Haque et al., 2014). The funds catalyzed initiatives at the community level, including insecticide-treated net (ITN) distribution, the introduction of coartem combination therapy and rapid diagnostic tests (Haque et al., 2011; Haque et al., 2014). In 2007, non-governmental organizations (NGOs) conducted Bangladesh's first malaria prevalence survey, marking the initiation of renewed efforts against the disease (Haque et al. 2009). From 2000 to 2020, Bangladesh achieved a remarkable 93% reduction (Figure 1) in malaria cases through a systematic, phased elimination strategy at the district level (Haldar et al., 2023). Despite this progress, challenges persist in remote, densely forested areas, hindering malaria prevention, detection, and treatment. This peculiar situation underscores the need for deeper research into the persistence of malaria in eastern Bangladesh, where topographic conditions are less favorable and cultural norms differ from the rest of the country.

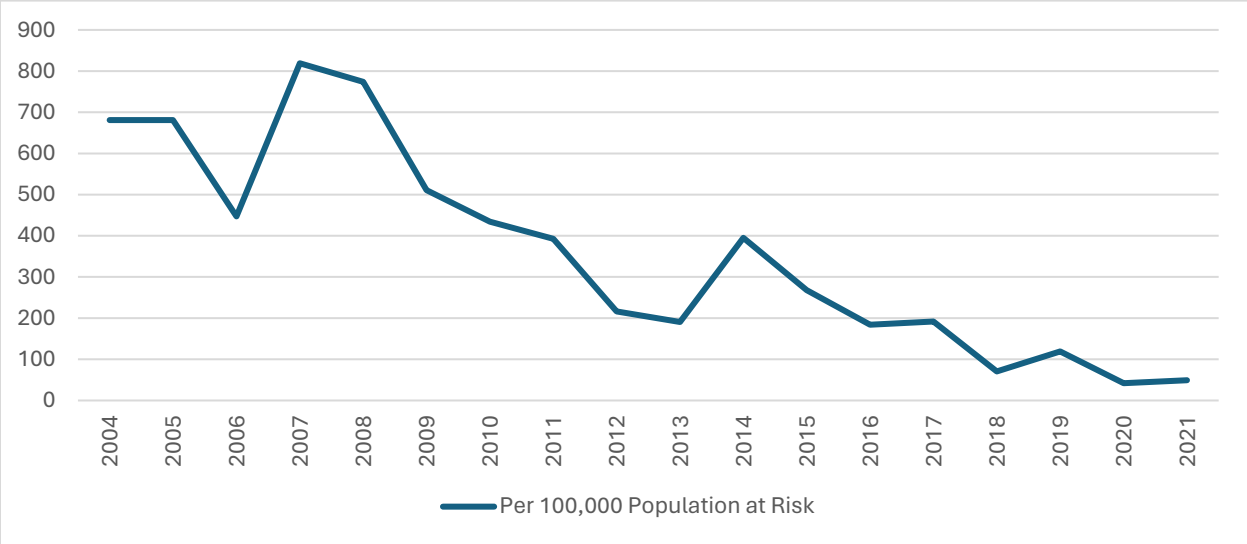

Figure 1 Incidence of malaria in Bangladesh (per 100,000 population at risk) (Data Source: https://data.worldbank.org/indicator/SH.MLR.INCD.P3?locations=BD)

After the consolidation of Bangladeshi nationalism following independence, the CHTs have developed under a unique history that affects current socio-cultural and political conditions, which in turn, contribute to malaria's persistence in the region. While independence marked a significant moment in the nation's history, the subsequent phase of state formation and nation-building revealed challenges for the majority ethnic group, the Bangla, particularly in recognizing the cultural identities of minority ethnic groups residing in the CHT region. One core issue in the region is the perceived lack of recognition by the Bangladeshi state of the unique cultural identities of the original Indigenous inhabitants of the CHT, the tribal communities, a part of the ethnic minority of the country. These communities are a part of the ethnic minority of the country. Despite the distinctiveness of the groups, the central government has been criticized for not affording sufficient acknowledgment, political autonomy, or promotion of the region's culture and languages. This neglect has contributed to a growing sense of grievance among the tribal communities that has affected aspects of malaria control.

Addressing these concerns would support a more inclusive and harmonious relationship between the ethnic minority of the CHT and the broader Bangladeshi state (Panday & Jamil, 2009), including addressing the current high rate of malaria as the government works to eliminate the disease. While significant strides have been made, minimal research has focused on the unique characteristics of eastern Bangladesh, and addressing this gap in the literature is key if Bangladesh hopes to eventually eliminate malaria. Previous studies have provided some explanation for eastern Bangladesh's challenges with respect to malaria control, for example indicating inadequate usage of prevention methods in endemic zones, highlighting the need for

improved education (Ahmed et al., 2011). Bed net distribution did not significantly reduce malaria in the CHT, where ITNs were supplied in the study by Bashar et al. (2012), but in contrast, several African researchers found that when ITNs were extensively distributed, malaria transmission rates and accompanying morbidity were reduced to 50% of previous levels (D'Alessandro et al., 1995; Njama et al., 2003). Another study in Bangladesh found that low bed net coverage per household, penetrable walls made up of mud straw, mud or bamboo and a high density of housing were the biggest risk factors for malaria infection, and the risk of malaria was not significantly correlated with hydrologic or topographic factors (Haque et al., 2013). This previous work along with the CHTs socio-cultural and political setting suggest that malaria's persistence in the region is the result of a complex interplay among different factors.

There has been minimal research to explain this discrepancy in the distribution of endemic malaria in Bangladesh. When there is an outbreak, it usually takes the form of a cluster (Noé et al., 2018); these outbreaks are highly seasonal as well given the seasonality of precipitation. Some studies have shown that the local residents have records of using prevention methods inappropriately (e.g., Ahmed et al., 2011). Prior research focuses singularly on either analyzing spatial patterns correlating environmental factors and malaria cases (S. Ahmed et al., 2013; Annister-Tyrrell et al., 2017; Shannon et al., 2016), or solely based on socio-economic data. Therefore, there is a need to combine the two and examine the interaction and relationship between environmental and socio-economic factors. Furthermore, public health officials require an understanding of the interacting role of public perceptions and environmental factors in order to continue pursuing malaria control and elimination. This study can guide proper policy implementation and help determine appropriate health interventions that are geared toward the factors promoting malaria transmission.

1.3 Research Questions

To effectively combat malaria in the CHTs, public health officials must comprehend this interplay between public perceptions, knowledge, and cultural practices while considering climatic variability, as the country works toward elimination of the disease. Therefore, this research aims to answer the following critical questions, with a focus on Bandarban within the CHTs:

- Are malaria cases temporally associated with climatic factors in the Chittagong Hill Tracts of Bangladesh?
- What is the knowledge, attitudes, and practices related to malaria in the endemic area of Bandarban, Bangladesh?

- What socio-economic and climatic factors should be considered to combat malaria transmission in the Chittagong Hill Tracts of Bangladesh?

Answers to these questions, using a mixed methods approach with qualitative methods to evaluate knowledge, attitudes, and practices and a regression analysis to quantify the relationship between malaria and climate conditions, will not only advance scientific understanding but also guide policy implementation and health interventions crucial for sustained progress in malaria control and eventual elimination.

The thesis is organized as follows: Chapter 2 includes a broad review of the literature associated with malaria transmission and prevention scenarios, Chapter 3 is a manuscript summarizing the Knowledge, Attitude and Practice (KAP) study, Chapter 4 is a manuscript that outlines the malaria-climate (rainfall and temperature) analysis, and finally Chapter 5 concludes the thesis with a broad synthesis of the full study.

1.4 Positionality Statement

I am a citizen of Bangladesh and belong to the part of the ethnic and religious majority of the country (Bengali and Muslim). I have been blessed with many privileges and opportunities such as my education and socio-economic standing that my respondents were not privy to. I understand that I stood out among my respondents even though we were citizens of the same country. Although my respondents spoke Bengali it was not their first language and I, myself was not well versed the language that they spoke in.

For this project I worked with the NMEP, who are affectively serving these communities to treat and eliminate malaria and the NGOs serving the communities in the region. I was escorted to the study areas by community health workers affiliated with the NGOs, they served as guides and translators as required. I was viewed as an outsider by my respondents, and I was asked several questions to prove my intentions.

I recognize that I am listening, analyzing and reporting stories of people who have had a very different life than mine. This situation is something I do not take lightly and have tried my best to convey the stories truthfully as they were told to me.

Chapter 2: Literature review

2.1 Theoretical framework

The research design encompasses the dynamics of medical and health geography. Medical geography focuses on how disease, nutrition, and medical care systems are related to human and natural environments using notions and paradigms from geography, such as maps, GIS, and remote sensing techniques most well-known today (Earickson, 2009). Medical geography is closely related to health geography, which focuses on the differences in healthcare and health that exist geographically. Its main issues are with the social model of health and, more specifically, with the concept of health that prioritizes good health and wellness over adversity and illness (Moon, 2009). Additionally, it has focused a lot of attention on the delivery of healthcare outside of traditional medical facilities as well as health-related habits like nutrition, alcohol consumption, smoking, and exercise, among other factors. Therefore, the distribution and dispersion of the majority of diseases, the availability and demand for healthcare resources and nutrition as a role in sickness and health can all be compared to site, situation, place, location, region, and all spatial notions. Medical geographers are first and foremost problem solvers who address both anthropogenic and environmental issues.

Medical geography equips researchers with a robust toolkit to unravel the intricate web of factors contributing to the presence of malaria in the Chittagong Hill Tracts of Bangladesh. By employing a variety of methods ranging from qualitative techniques to spatial analysis, exploring the interplay between environmental and socio-economic variables, harnessing predictive modeling tools, conducting historical analyses, and fostering community engagement, medical geographers pave the way for targeted, evidence-based interventions that hold the promise of mitigating the burden of malaria in this vulnerable region.

Environmental factors play a pivotal role in the prevalence of malaria, and medical geographers are equipped to analyze these variables in the context of the Chittagong Hill Tracts. Factors such as temperature, rainfall, altitude, and vegetation cover should be scrutinized to understand their influence on the breeding and survival of malaria vectors, predominantly mosquitoes. By assessing the interplay between environmental conditions and disease transmission dynamics, researchers can effectively pinpoint areas most susceptible to malaria outbreaks. Furthermore, medical and health geographers have the capability to delve into the fabric of human geography within the Chittagong Hill Tracts. By scrutinizing population density, settlement patterns, socio-economic status, and access to healthcare services, the underlying determinants of malaria transmission can be determined. Understanding human-mosquito interactions,

healthcare-seeking behaviors, and the efficacy of malaria control measures necessitates a holistic examination of the socio-demographic and natural landscape.

Medical geography has the means to employ ecological niche modeling techniques to predict the spatial distribution of malaria vectors and the risk of malaria transmission (Caprotti, 2006, Park, 2012). By integrating environmental and socio-economic data, they can identify areas most vulnerable to malaria outbreaks.

The human ecology of disease investigates the intricate relationship between human populations and their environments, recognizing the multifaceted factors that influence the occurrence and spread of diseases within communities (Meade & Emch, 2010). Central to this concept is the understanding that health outcomes are not solely determined by biological factors but are profoundly shaped by socio-cultural, economic, environmental, and behavioral elements. Socio-economic disparities, for instance, significantly impact access to healthcare, nutrition, sanitation, and living conditions, thereby influencing vulnerability to diseases. This acknowledgment underscores the importance of addressing broader social determinants of health to effectively combat diseases and improve overall well-being within populations. Moreover, environmental factors play a pivotal role in disease transmission dynamics, with human ecology of disease examining how various elements of the environment interact with human populations to facilitate or hinder the spread of pathogens. Climatic conditions, land use patterns, water sources, and urbanization profoundly influence disease vectors, reservoirs, and transmission pathways. For instance, changes in temperature and rainfall patterns can impact the distribution of vector-borne diseases like malaria and dengue fever, highlighting the intricate interplay between environmental conditions and disease ecology. Behavioral and cultural practices further shape disease dynamics, as human actions and beliefs influence exposure to pathogens and adherence to preventive measures (Meade & Emch, 2010). Practices related to food preparation, hygiene, sanitation, animal husbandry, and traditional healing can either mitigate or exacerbate disease transmission within communities (Meade & Emch, 2010). Understanding the cultural context and social norms surrounding health behaviors is essential for designing interventions that are culturally sensitive and effectively engage with local populations.

Additionally, globalization and urbanization have profound implications for disease ecology, with rapid population growth, urban migration, and increased mobility facilitating the spread of infectious diseases across geographical boundaries. Urban slums, characterized by overcrowded living conditions and inadequate infrastructure, become fertile grounds for disease transmission. Moreover, ecosystem disturbance driven by human activities, such as deforestation and wildlife trade, can lead to the emergence of zoonotic diseases, where pathogens jump from animals to humans, highlighting the connections between human, animal, and environmental health. The concept of 'One Health' is employed across diverse contexts

and by individuals from various disciplines, encompassing areas such as contagious diseases, infection biology, evolutionary medicine, comparative medicine, zoonotic infections, and translational medicine (Lerner & Berg, 2015).

In response to these complex dynamics, the human ecology of disease emphasizes the importance of adopting a holistic approach to health that integrates insights from multiple disciplines, including public health, ecology, sociology, and anthropology. By addressing the underlying social, environmental, and behavioral determinants of health, researchers, policymakers, and public health practitioners can develop comprehensive strategies for disease prevention and control that promote health equity and resilience within communities. The human ecology of disease examines how environmental factors, social dynamics, and human behavior influence the transmission and distribution of diseases like malaria. For instance, factors such as land use changes, urbanization, population movement, and climate change can alter the ecology of malaria vectors and impact the incidence and spread of the disease among human populations.

2.2 Environmental Factors Associated with Malaria

Vector-borne diseases such as malaria are indeed heavily influenced by climatic factors, which not only impact their transmission rate but also affect their geographic presence (Paaijmans et al., 2009). However, a comprehensive understanding of malaria epidemiology requires consideration of interactions with other factors, including human activities and their impact on local ecology. While temperature plays a crucial role in the survival of mosquitoes and the multiplication of the malaria parasite within the vector, additional environmental factors such as rainfall, humidity, wind patterns, and daylight duration also exert significant influence. In regions with colder climates, mosquitoes and the malaria parasite have evolved strategies to survive during winter months, while in areas with extreme dry seasons, they adapt to persist through periods of reduced moisture. The circadian rhythm further affects mosquito behaviors such as feeding, resting, and oviposition, which are regulated by optimum times rather than ambient temperature alone. These complex interactions highlight the importance of considering the broader ecological context in malaria transmission dynamics.

Human activities profoundly impact local ecosystems, altering climatic conditions and habitat structures in ways that can favor mosquito proliferation (Ortiz et al., 2021; Jones et al., 2018). Forest ecosystems, known to support malaria transmission, are particularly vulnerable to human-induced changes. Forest clearance, for instance, creates favorable conditions for mosquitoes by exposing temporary ground pools to full sunlight, ideal for larval development (Jones et al., 2018). Additionally, the proximity of vegetation to human habitation can increase the population of forest-dwelling malaria vectors, exacerbating disease transmission in nearby communities (Patz et al., 2000).

Understanding the intricate relationship between human activities, environmental changes, and malaria transmission is essential for effective disease control and prevention strategies. Sustainable land use practices, ecosystem conservation efforts, and targeted vector control measures can help mitigate the impact of human activities on local ecology and reduce the burden of malaria in affected regions. By addressing the interplay between climate, ecology, and human behavior, researchers and policymakers can develop holistic approaches to malaria management that prioritize both public health and environmental sustainability.

2.3 Global burden of malaria

Malaria symptoms usually include fevers. It is a flu-like disease with headache, pain in the muscles, chills, and fatigue (WHO, 2023). These symptoms can also be accompanied by vomiting, nausea, and diarrhea. Due to the loss of red blood cells, it may also lead to jaundice (yellow skin and eyes) and anemia. Infections can grow serious and lead to kidney failure, convulsions, mental confusion, comas, and even death if they are not properly treated.

Most patients develop symptoms between 10 days and four weeks after infection, though symptoms can appear as soon as seven days or as late as one year after infection. Infections caused by *P. vivax* and P. *ovale* can remain dormant in the liver for a few months up to about four years after the initial mosquito bite. The individual falls ill when these parasites emerge from dormancy and begin infecting red blood cells, a condition known as a "relapse." Infants, children under five, pregnant women, people with HIV/AIDS, and those with low immunity traveling to regions with high malaria transmission, such as migrant workers, mobile communities, and travelers, are at significantly higher risk of contracting malaria and developing severe illness (WHO, 2022). Due to these factors, sub-Saharan Africa is believed to account for 90% of malaria-related deaths (CDC, 2022).

According to reports from the World Health Organization, despite only small changes in malaria incidence, mortality has steadily decreased since 2000 (Figure 1), from 896,000 to 562,000 in 2015 and to 558,000 in 2019 (CDC, 2022). However, the number of malaria deaths rose to an anticipated 627,000 in 2020, an increase of 12% from 2019 (WHO, 2021). Of the additional 69 000 malaria deaths, an estimated 47,000 (68%) were attributed to COVID-19 pandemic-related disruptions (CDC, 2022). Between 2000 and 2015, the malaria fatality rate was reduced by half, dropping from about 30 to 15 deaths per 100,000 at risk. It further decreased to 14 in 2019 before rising again to 15 in 2020 (CDC, 2022). Over the past 20 years, the proportion of malaria deaths among children under five years old has decreased from 87% in 2000 to 76% in 2019, with a slight increase to 77% in 2020 (CDC, 2022). In 2020, around 96% of malaria cases and fatalities occurred in 29 of the 85 countries where the disease is endemic (CDC, 2022).

While malaria incidence has decreased since 2000, there was a reversal of this trend in 2020, during with the WHO African Region home to the majority of the increase in case numbers. The at-risk population in sub-Saharan Africa has grown quickly, nearly doubling since the turn of the century, which underscores the effects of even mild service interruptions in treatment and prevention efforts. In the 108 countries where malaria is prevalent, there were almost the same number of cases in 2020 as there were in 2000, although there are significant uncertainties in data from 2020 due to the pandemic according to the World Malaria Report from the World Health Organization (WHO, 2021). The patterns in malaria case incidence, which decreased from 81 per 1000 at-risk population in 2000 to 56 in 2019, before rising slightly to 59 in 2020 (a 5% rise), may best illustrate this for Africa. Despite the rise in cases, the findings imply that global efforts have prevented the worst-case scenario envisioned at the beginning of the COVID- 19 pandemic, assuming that malaria cases would double as the World Health Organization warned.

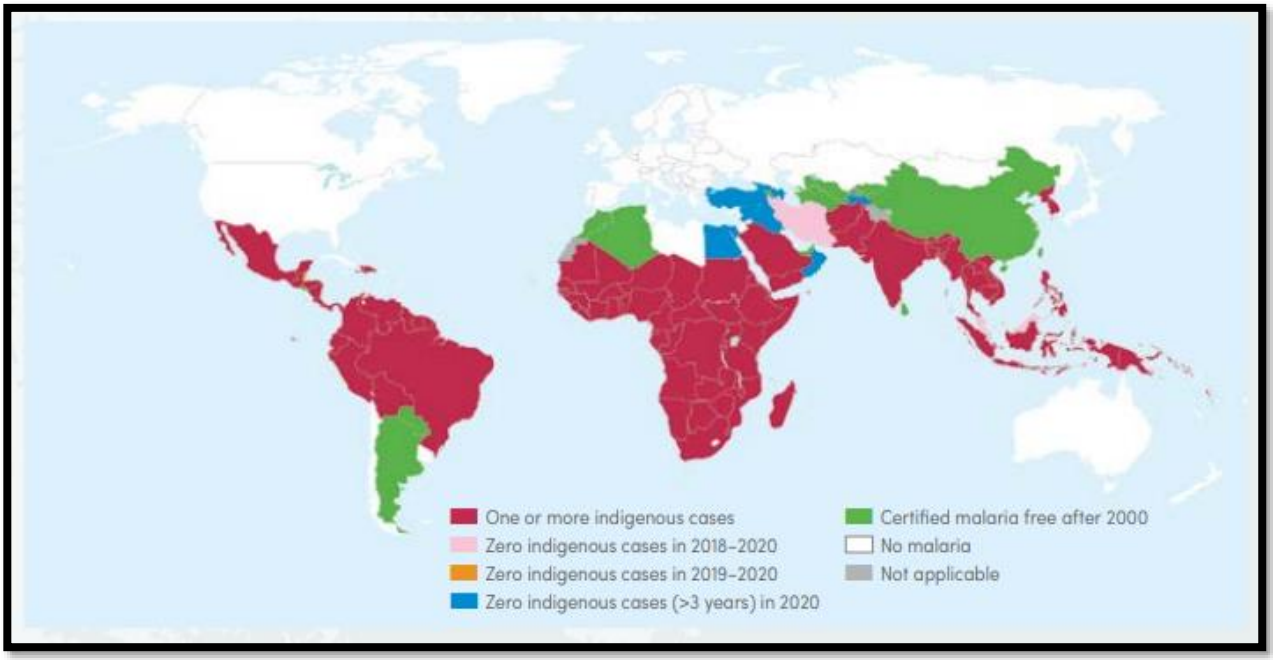

Figure 2 Countries with cases in 2000 and their status by 2020 (WHO, 2020)

2.4 Malaria in Southeast Asia

The burden of malaria is significant in Southeast Asia, second only to Africa in terms of reported cases; nearly 70% of the 1.8 billion people in this region are at risk of contracting malaria (Hay et al., 2004; Maude et al., 2008). The WHO Southeast Asia Region includes 11 countries: Bangladesh, Bhutan, the Democratic People's Republic of Korea, India, Indonesia, Maldives, Myanmar, Nepal, Sri Lanka, Thailand, and Timor-Leste. Except for the Maldives and Sri Lanka, malaria is endemic in all these countries. Malaria intensity varies greatly within most of these nations (World Malaria Report, 2022).

There were only 1037 reported cases of malaria in this region after the national malaria eradication efforts of 1957–1959, and no deaths (Kumar et al., 2012). Malaria experienced a significant resurgence in Southeast Asia during the 1960s and 1970s, which continued in the following decades (Kumar et al., 2012). At its peak in the 1990s, there were 7.2 million cases, with a Slide Positivity Rate (SPR) of 9.7% and an Annual Parasite Incidence (API) of 8.8. *P. falciparum* accounted for 14% of these cases (Kumar et al., 2012). The SPR represents the proportion of positive malaria treatments based on blood smears among patients with fever, while the API indicates the number of positive slides per 1,000 people annually. The estimated frequency of malaria stabilized to between 2 and 3 million cases during the 1990s, and the number of recorded deaths owing to malaria rose to 8061 in 1996 (Kumar et al., 2012). The progressive increase in *P. falciparum*, which accounts for around 60% of malaria infections, coincided with this spike in death (Kumar et al., 2012). However, the actual mortality rate might be higher than what the National Malaria Control Programs of the participating nations reported due to underreporting.

Southeast Asia saw a total of 2.7 million cases of malaria in 2009 (Kumar et al., 2012). Around 15% of the world's malaria cases were found in Southeast Asia, and 38,000 people died from the disease in 2010 (WHO, 2011). These figures may even be higher because current surveillance systems significantly underreported cases (Maude et al., 2008). On the other hand, over the past few years, there have been hints of a decline in both malaria infections and deaths. One of the four main malaria-endemic nations is Bangladesh, where 34% of the population is at risk of contracting the disease as of 2011 (WHO, 2011; Alam et al., 2010)

2.5 Malaria in Bangladesh: Historical background

In Bangladesh, with a population of over 160 million people, more than 10 million individuals were at high risk of contracting malaria in 2011 (WHO, 2011). The cessation of the malaria eradication campaign, widespread population movements during the war of independence in 1971, and the 1985 prohibition on the use of dichlorodiphenyltrichloroethane (DDT) have all been blamed for the continuous increase in the frequency of malaria in Bangladesh. Malaria prevalence does not follow a uniform pattern throughout Bangladesh (Factor et al., 2001; Faruque et al., 2012); some parts of the nation are more impacted than others (Narayanasamy et al., 2012). The eastern and southeastern districts of Bangladesh account for 95–98% of all malaria cases, with weighted prevalence rates ranging from 3.10% to 3.97% in the studies performed in different locations. (WHO, 2011; Alam et al., 2010; Haque et al., 2009; Ahmed et al., 2009). Particularly hyperendemic, the Chittagong Hill Tracts (CHTs) region in which this study focuses has a prevalence of 11% or possibly higher depending on accuracy of surveillance and reporting (Alam et al., 2011; Haque et al., 2011).

Prior to 1971, malaria was mostly under control thanks to the Malaria Eradication Program of the then-Government of East Pakistan's frequent use of DDT. DDT was outlawed in 1985, following Bangladesh's separation from Pakistan, and a rise in malaria incidence followed (Sharma, 1996). The eastern regions of Bangladesh did not continue any control efforts because the incidence of malaria was low there, and there were few financial resources and related programs. Malaria cases started to rise and spread to epidemic levels in the 1990s (Sharma, 1996; WHO, 1999) without these management measures. In Bangladesh in the late 1990s, there were 900,000 clinical cases of malaria, 70,000 laboratory-confirmed cases, and more than 500 recorded deaths (Wijeyaratne et al., 2004).

In 2006, the Global Fund awarded Bangladesh USD 39.6 million to support its national malaria control program (Haque et al., 2011; Haque et al., 2014). This funding enabled the program to initiate community-level advocacy, distribute insecticide-treated nets (ITNs), introduce rapid diagnostic tests (RDTs), and implement combination therapy with Coartem (Haque et al., 2011; Haque et al., 2014). However, due to a lack of baseline data on disease transmission, severity, and mosquito breeding, the resources could not be distributed equitably. These data were also necessary for future assessments of the program's effectiveness. Consequently, in 2007, NGOs such as the Bangladesh Rural Advancement Committee (BRAC) and the International Centre for Diarrheal Disease Research, Bangladesh (ICDDR, B), conducted the first-ever malaria prevalence survey in Bangladesh. Using a multi-stage cluster sampling technique, they collected 9,750 blood samples (Haque et al., 2009).

The survey diagnosed malaria using RDTs and found that the weighted average malaria prevalence in the thirteen endemic districts was 3.97%. A subsequent study in five southeastern districts found a weighted average malaria prevalence rate of 6%, compared to 0.40% in eight northeastern districts. The highest prevalence was in the Khagrachhari district in the southeast, with *P. falciparum* responsible for 90.18% of cases. Malaria morbidity rates were 2.94% in the southeastern districts and 0.07% in the northeastern districts. In 2007, the crude prevalence was 4.0%, with 59,857 laboratory-confirmed malaria cases and 228 fatalities in the endemic area (Haque et al., 2010). *P. falciparum* was the primary cause of about 90% of infections (Malaria and Parasite Disease Control Unit, 2011).

2.6 Trend of Malaria Prevalence: Spatio-temporal variation across Bangladesh

Malaria is heterogeneously distributed throughout Bangladesh, according to cross-sectional research (Reid et al., 2010, Reid et al., 2012). Over time, the spatio-temporal pattern of Bangladesh has changed. In 2007, the frequency of malaria in Rajasthali, a single subdistrict of the CHTs, was 36%. In this subdistrict, the

frequency of malaria dropped to 11.5% in 2011 (Wangdi et al., 2016). Using cross-sectional data, a household-based risk map has also been developed in Rajasthali (Syed M., Ahmed et al., 2011), and risk variables associated with greater exposure to malaria have been found (Haque, Hashizume, et al., 2010; Haque, Huda, et al., 2009).

By 2011, there were only 51,773 cases and 36 fatalities nationwide, which translates to a 13.5% decrease in morbidity and an 84% decrease in fatalities (Figure 2). Still, Southeast Bangladesh (Bandarban, Chittagong, Cox's Bazar, Khagrachhari, and Rangamati) had a significantly higher incidence of malaria than the northeast of Bangladesh (Kurigram, Mymesingh, Netrakona, Sherpur, Habiganj, Maulvibazar, Sunamganj and Sylhet) (Global Malaria Programme, 2017; Mogeni et al., 2017; Islam et al., 2013; Alam et al., 2016).

Between 2013 and 2016, a small segment of the population at risk experienced the majority of malaria cases. Around 11% of the population were at risk in the in the southeastern area. However, they accounted for 80% percent of the malaria cases in that region. This ratio in the northeastern region was 32/80%. The data are strikingly close to the 20/80 association established by Woolhouse et al. (1997) to describe districts with stable hotspots. Two hypo-endemic unions of Bandarban also had a similar scenario, according to Ahmed et al (2013). In India, Wangdi et al. (2016) also noted this correlation, noting that malaria is more prevalent in remote, tribal, and mountainous locations similar to Bandarban. Since there is spatial malaria variability in Bangladesh, it is also crucial to take the temporal clustering of cases into account.

In Bangladesh, three districts in the southeast-located Chittagong Hill Tracts (CHT) continue to be the site of almost 80% of all malaria cases that are reported. A high frequency (36%) has been noted in a sub-district of Bandarban, one of the three Hill Tract districts (Haque et al., 2011). There have been 55,873 probable and confirmed cases of malaria reported in 2010 in this district.

The boundaries of Bangladesh with Myanmar and India in the south and east, where malaria prevalence is substantially higher, can be used to explain the expansion of the parasite (Islam et al., 2013). In reality, the Annual Parasite Incidence (API) in regions adjacent to the Indian boarder is greater than 5, while in Myanmar, about 50% of the population is at high risk of developing malaria (Maude et al., 2008; Narayanasamy et al., 2012).

Many investigators have documented the highly seasonal nature of malaria in the southeastern region of Bangladesh (Woolhouse et al., 1997; Wangdi et al., 2016). The classical high transmission season in the southeast, from May to October (Islam et al., 2013), is not evident in the northeastern region, likely due to the rapidly declining incidence throughout the area. Hu et al. (2016) demonstrated significant differences in malaria incidence among five closely located villages in the southeastern region, with lower-incidence

villages showing a more erratic temporal distribution of cases. Similarly, Zhang et al. (2014) found that southeastern seasonal peaks diminished or disappeared as incidence declined, based on China's nationwide case data from 2004 to 2012. In the northeastern region, heterogeneity in transmission is believed to be increasing; while there is clear spatial heterogeneity, temporal heterogeneity does not appear to be significant (Zhang et al., 2014).

2.7 The endemic nature of malaria in Bangladesh: hotspot stability

The term "hotspot" is widely used in infectious disease epidemiology to describe regions with a high disease burden or high transmission efficiency. From 2013 to 2016, hotspot stability in both space and time was observed throughout Bangladesh. Within the southeastern region, there was notable consistency in hotspot locations over time, with a hotspot in one period often predicting a future hotspot in the same area accurately (Noé et al., 2018).

The unique topography of the southeastern region plays a significant role in malaria transmission dynamics compared to the rest of the country. The highest and steepest areas, particularly southeast of the Chittagong Hill Tracts (CHTs), host stable hotspots. These regions are characterized by dense forest cover and numerous streams, which are conducive to malaria transmission. Proximity to water bodies and forests, especially in the CHTs, is recognized as a risk factor for malaria (S. Ahmed et al., 2013; Annister-Tyrrell et al., 2017; Shannon et al., 2016).

In the northeastern region, stable hotspots are located in sparsely vegetated plains south of the Indian border and in the West Khasi Hills. Notably, one hotspot is situated in Tanguar Haor, a wetland vital to the livelihoods of many local residents (Yousuf Haroon & Kibria, 2017). The origins of imported and introduced cases in these hotspots have been attributed to the introduction of the pathogen by southeastern regional agricultural laborers and coal miners stationed in transmission hotspots. In light of the fact that social and demographic traits may affect estimates of environmental risk factors (Annister-Tyrrell et al., 2017), additional in-depth research on these topics would be a welcome contribution to the body of knowledge on malaria risk in Bangladesh. Compared to the southeastern region, the northeastern region featured fewer stable hotspots for any given time period. Similar outcomes were described by Mogeni et al. (2017) in several contexts. The fact that regional variability increases as malaria transmission falls may account for poorer hotspot stability. Hotspots eventually lose some of their statistical significance when there are fewer cases, which results in less power. This may explain the relative instability of hotspots in the northeastern region.

2.8 The socio-economic scenario of Malaria in Bangladesh

Despite Bangladesh achieving independence in 1971, subsequent state-building endeavors failed to adequately acknowledge the unique cultural identities of minority groups in the CHTs. The central Bangladeshi government's reluctance to grant political autonomy or promote the region's cultural diversity, coupled with inadequate economic development, has resulted in significant grievances among the Indigenous population of the CHTs (Panday & Jamil, 2009).. The rise in challenges within the CHTs can be traced back to the Bangladeshi government's efforts to impose a singular and dominant notion of national identity across its diverse population. This phenomenon is notably conspicuous in the culturally varied CHTs region.

There is inequality in treatment towards the ethnic minority of the CHTs, from law enforcement agencies and government-backed settlers, leading to systematic violations of their human rights. Consequently, there has been a reactive consolidation of the identity of the ethnic minority that resulted in continuing conflict. The primary objectives of the armed conflict and ongoing insurgency in the CHTs have been to assert cultural and ethnic identities and safeguard against perceived exploitation and suffering endured over decades.

The marginalization of ethnic minority communities in the region, also referred to as hill tribe populations, from mainstream society, stemming from historical socio-political manipulations and continued governmental policies, has perpetuated a sense of “otherness” in political, cultural, and social spheres. Policies aimed at establishing a homogeneous Bengali society by eroding the ethnic identity of the Indigenous people have contributed to the ongoing conflict in the CHTs. Jhum cultivation is subsistence agricultural slash and burn farming practice performed by the ethnic minority up in the hill. Since the ethnic minority perform this, they are often referred to as the Jumma.

Moreover, the socio-economic challenges faced by hill tribe populations contribute to their vulnerability to malaria. Labor-intensive work in jhum sites and forests increase exposure to mosquito bites, while limited access to healthcare facilities and knowledge gaps regarding malaria exacerbate the risk. Additionally, cultural practices such as reliance on traditional healers and self-treatment further complicate efforts to combat the disease effectively. The ongoing conflict and insurgency in the CHTs have further exacerbated the challenges in malaria control. Displacement, disruption of healthcare services, and insecurity hinder efforts to provide consistent and comprehensive malaria prevention and treatment interventions. The breakdown of social and healthcare infrastructure due to the conflict compounds the existing vulnerabilities of hill tribe populations, leaving them more susceptible to malaria and its adverse impacts. Addressing the root causes of conflict and socio-economic marginalization in the CHTs is crucial for improving malaria

control efforts. Promoting cultural diversity, acknowledging the rights and identities of indigenous populations, and ensuring equitable access to healthcare and social services are essential steps toward mitigating the burden of malaria in the region. Culturally sensitive approaches to healthcare delivery, community engagement, and capacity-building initiatives can enhance the effectiveness of malaria prevention and control programs and contribute to sustainable improvements in health outcomes among hill tribe populations.

Bangladesh has distributed one insecticide-treated net for every 2.6 individuals across the 13 malaria-endemic districts, a higher rate than many other countries grappling with malaria. Findings from a study conducted in the Bandarban district indicated that over 90% of individuals had slept under nets on the night preceding the survey. Of these nets, approximately 80% were confirmed to be insecticide-treated, and over 95% of children under the age of five utilized insecticide-treated nets. Given the observed association between increased coverage of insecticide-treated nets and a decline in malaria cases, it is anticipated that maintaining high coverage levels of such nets will be imperative going forward.

2.9 Knowledge, Attitude and Practices (KAP) of Malaria

When developing guidelines and recommendations for more effective disease prevention in malaria-endemic areas such as Bangladesh and other parts of Southeast Asia, it's essential to comprehensively understand the social and behavioral risk factors, identify knowledge gaps, and assess exposure to malaria. By gaining insight into these factors, interventions can be tailored to address specific challenges and effectively target communities at the highest risk of malaria transmission. This approach ensures that prevention efforts are contextually relevant, culturally sensitive, and ultimately more successful in reducing malaria incidence and improving public health outcomes. It has not yet been determined how much information people in areas with moderate to high malaria risk levels have about the fundamental dynamics of pathogen transmission, risk factors for malaria, or disease prevention techniques in Bangladesh. However there have been attempts to evaluate the level of knowledge in some areas.

The respondents' knowledge of malaria transmission and symptoms varied between research areas in one study in Bangladesh. The majority of respondents from different zones thought that bed nets were the primary malaria prevention strategy, yet the study revealed no connection between bed net use and malaria prevalence (Bashar et al., 2012). According to the survey’s findings, virtually all of the participants were aware of certain aspects of malaria. Health workers with non-governmental organizations (NGOs) served as one of the primary information sources, demonstrating that NGOs frequently interacted with locals. The majority of respondents were familiar with malaria symptoms. Most people were able to identify “fever with rigor” as the primary malaria symptom, which was likely made possible by the informational messages

given by NGO health professionals. Unfortunately, just a quarter of respondents were aware of the methods of transfer or even the part that mosquitoes play in transmission. Few individuals were aware that mosquitoes can contract malaria by feeding on an infected person, even though most knew that mosquitoes are the disease's primary vector. This lack of knowledge was similar between and across different study areas.

In an additional study in Bangladesh (Haque et al., 2013), the prevalence of malaria was assessed for 1,634 households in 54 communities between 2009 and 2010. All (n = 497) malaria cases identified over the full study period were reported by 21.8% of households, of whom 15.4% had one case and 6.4% had two or more. Low bed net coverage per household, weak walls either thatched or made of mud, straw, and a high density of housing were the biggest risk factors for malaria infection. The risk of malaria was not significantly correlated with hydrologic or topographic factors. This study identifies stable malaria hotspots and associated risk factors, providing valuable insights for cost-effective targeting of malaria interventions in Bangladesh. By focusing resources and efforts on these identified hotspots and addressing the specific risk factors contributing to malaria transmission, targeted interventions can be implemented more efficiently.

There was a notable correlation between malaria frequency and locations where individuals congregated after sundown. In Bangladesh, some malaria vectors bite people outside in the early hours of the night (Bashar, Tuno, et al., 2012). *Anopheles* mosquitoes captured outside have a greater Human Blood Index (HBI) than those collected indoors, indicating a higher feeding rate, according to one survey (Bashar, Tuno, et al., 2012). As a result, those who spend time outside have a higher risk of contracting malaria, in part because mosquitoes may bite more frequently outside. Since other researchers in Bangladesh have also noticed that malaria risk may occur outside as well as indoors, it may be necessary to emphasize the location of acquisition of malaria in prospective educational materials.

Regarding knowledge about malaria prevention, many individuals were found to be unaware of the most effective prevention methods. This lack of awareness is likely due to insufficient information, education, and communication activities in the study area. Improving access to accurate and comprehensive information about malaria prevention through targeted education campaigns and community outreach efforts is crucial for increasing awareness and promoting the adoption of effective prevention measures. According to one study, several participants claimed they had not yet received a bed net of any kind (insecticide treated nets- ITNS, or long-lasting insecticidal nets- LLINS), despite the fact that every family was promised to receive one as part of NGO efforts (Ahmed et al., 2011). A single net would be given to each household, but many respondents said this was insufficient to cover everyone in their family. In fact, the usage of ITNs/LLINs is the key component of Bangladesh's current malaria control plan, and this

method has benefited from a widespread campaign promotion for a number of years (Ahmed et al., 2011). Prior to the introduction of treated mosquito nets, Bangladesh reported 450 malaria fatalities and 50,000 confirmed cases of malaria each year (Ahmed et al., 2011). After ITN/LLIN distribution, mortality decreased from 450 to 37 in 2010. (WHO, 2011). It is interesting to note that bed nets did not significantly reduce malaria in regions where ITNs/LLINs were supplied in the study by Bashar et al. (Bashar et al., 2012). In contrast, several African researchers claimed that when ITNs/LLINs were extensively distributed, rates of malaria transmission and accompanying morbidity were reduced to 50% (D'Alessandro et al., 1995; Njama et al., 2003). It is possible that the pesticides employed in the treated nets have become less effective against the malaria vectors in Bangladesh. Unpublished reports from Bangladesh's Directorate General of Health Services indicate that just 20% of malaria vectors were eliminated in recent bioassays. There is a need to do a more detailed analysis of how susceptible Bangladeshi mosquito vectors are to the ITN/LLIN active components. Alternately, there may be other factors affecting the effectiveness of the nets, such as the nets' quick loss of insecticidal quality owing to dust buildup, heat impacts from cooking in the same room where the nets are stored, or improper net washing. In the region of Bangladesh where malaria is endemic, these particular challenges require additional attention.

2.10 Control and Prevention Scenarios

The main reason for the decline in malaria cases was the national malaria control program funded by the Global Fund. This program included measures like insecticide-treated bed nets, long-lasting insecticide-treated nets (LLINs), rapid diagnosis tests (RDTs), and new treatment approaches like artemisinin-based combination therapy (Clark et al., 2008). Over the five years before 2008, risk variables at the household and individual levels, as well as ownership and use of insecticide treated nets (ITNs) and LLINs, have altered (Clark et al., 2008; Syed et al., 2009; Haque, Hashizume, et al., 2010) and helped to reverse the trend in malaria transmission (Syed M. Ahmed et al., 2011). In Bangladesh, coverage of LLINs and insecticide-treated nets has already surpassed predetermined goals (Syed et al., 2009; Syed M. Ahmed et al., 2011). Opportunities for focused and more affordable malaria control are created by identifying the risk factors and hotspots for transmission of the disease (Carter et al., 2000).

The clustering of high incidence unions (Smallest administrative unit) along local and national borders has a number of policy and practical implications, and both internal and international migration could increase the potential risk of malaria transmission. Migration into and out of the CHTs and their unions is frequent (Galagan et al., 2014). According to reports, internal migrant populations, such as traditional slash-and-burn, or jhum, cultivators, face a higher risk of contracting malaria (S. Ahmed et al., 2013; Shannon et al., 2016). Therefore, it is possible that these populations that are moving within their own country contribute

to the spread of malaria across district lines. A lot of the hotspots also border India and Myanmar. Short- and medium-distance population mobility has been linked to the spread of malaria internationally (Kar et al., 2014; Martens & Hall, 2000), and cross-border migration is frequent along the borders of Bangladesh, Myanmar, and India. For instance, since August 25, 2017, more than 500,000 Rohingya refugees have sought asylum from Myanmar to Bangladesh's southeastern area (Inter Sector Coordination Group, 2017). One study provides evidence that artemisinin-resistant malaria parasites have expanded west and north from the Thai Myanmar border (Ménard et al., 2016). There are worries that refugees and migrants from these regions may bring in parasites that are resistant to antimalarial drugs (McMichael, 2015; Wangdi et al., 2016).

2.11 Malaria Elimination

Bangladesh's National Malaria Elimination Programme (NMEP) has achieved 100% coverage of long-lasting insecticidal nets (LLIN) in the southeastern region since the distribution of the 2007 Global Fund, and artemisinin-based combination treatment is now free nationwide (Mogeni et al., 2017; Alam et al., 2016). Despite these efforts, there are still malaria-prone unions in Khagrachhari, Bandarban, and Rangamati. Invariably, high incidence unions are found around national and/or local boundaries, in the direction of northern Bandarban and southern Rangamati. The results of malaria elimination efforts reported here are also able to identify areas of comparably high malaria incidence within the districts (Global Malaria Programme, 2017, Mogeni et al., 2017).

With 2.62 malaria cases per 1000 people at risk reported annually between 2013 and 2016 in Bangladesh's endemic unions by the BRAC-led NGO Consortium (BLNC), it is possible to classify the nation as having "extremely low transmission" (Global Malaria Programme, 2017). However, this classification does not accurately describe the spatiotemporal heterogeneity inside the nation. To effectively reduce, and finally eliminate, the malaria burden, it is necessary to identify and focus on locations with different transmission rates in the affected areas. To assure accuracy and the efficacy of interventions, increased temporal and spatial resolution data generation is essential (Mogeni et al., 2017). At the local level, where practices and interventions can be examined more closely, the KAP study presented here will deliver useful information to guide policy makers to make appropriate interventions.

2.12 Conclusion

It is evident that interventions in Bangladesh lack cooperative strategies with local residents in order to increase awareness and put effective preventive measures in place against diseases spread by mosquitoes. Knowledge, Attitudes, and Practices (KAP) studies have shown that health professionals in malaria-

endemic regions often lack the necessary training to offer effective counseling aimed at changing certain deeply rooted traditional behaviors. These behaviors include spending time outdoors in the evening, improper use of bed nets, and inconsistent use of insecticides while sleeping. Addressing these gaps in local knowledge about malaria requires targeted efforts to enhance training among health professionals and promote behavior change within communities.

There have not been studies that evaluate the environmental factors and socio-cultural aspects of malaria transmission in the endemic zone. The resources provided in these areas are not equally accessible for everyone, including healthcare services, due to harsh environmental features within the region. Studies examining the environmental and socioeconomic components together of malaria transmission in Bangladesh are lacking, and this study will address that gap.

The CHTs are in a relatively isolated location making transportation, communication and resource allocation difficult due to the topography of the area. Researchers investigating malaria in various countries have examined a variety of characteristics, such as elevation, topographic convergence, slope, wetness index (a rough estimate of expected water accumulation), aspect, stream order, and stream network, to forecast malaria risk at finer spatial scales. Very few studies in Bangladesh looked at the potential implications of topographic and hydrologic conditions, which influence the locations and availability of vector breeding sites. These sites coupled the attitudes and practices of the respondents play a key factor in the spread of malaria. Since the existing literature focuses more on the environmental aspects of transmission, little can be said about how the people's interaction with the environment impacts the process.

Furthermore, there is a severe lack in record keeping of healthcare data and accessibility to resources related to disease transmission in the hill tracts. Since there are significant disparities in service delivery and public perception, it is important to assess the relative importance of the two factors in order to develop the best possible policy and control strategies to eradicate malaria from Bangladesh. It is vital to locate and target areas with varied transmission levels in the afflicted areas in order to efficiently diminish and eventually eradicate the burden of malaria. Increased temporal and geographical resolution data gathering are necessary to guarantee accuracy and the efficacy of interventions (Mogeni et al., 2017). The data gathered should not only focus on environmental/physical aspects of transmission but also emphasize and reflect how people perceive the disease and act to combat it.

Chapter 3: Community perceptions and Socio-cultural factors associated with malaria endemicity in Chittagong Hill Tracts, Bangladesh

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ABSTRACT

Although malaria is nearly eradicated in Bangladesh, the disease is still prevalent in 13 of the country's 64 districts, with Bandarban, Khagrachhari, and Rangamati in the Chittagong Hill Tract (CHT) districts reporting the majority of cases. While studies have examined malaria in Bangladesh, no research has identified the behavioral factors that may contribute to malaria's persistence in the CHT districts. Therefore, the purpose of the study is to look at the behaviors that may contribute to the persistence of malaria in Bangladesh's endemic region. Within the Lama and Alikodom subdistricts of the Bandarban district, information was gathered utilizing surveys and key informant interviews (KII). A key result is the identification of tribal villages (different ethnic origin) in the district as having the highest concentration of cases. The findings imply that inhabitants of tribal villages lack fundamental information about malaria and malaria prevention, and residents would benefit from targeted education campaigns. In particular, residents of tribal villages were unclear of the root causes of malaria and its effects on them. Their understanding of the most efficient preventive methods differs from the guidelines established by public health professionals. KIIs revealed that socio-economic dynamics between tribal and local Bengali communities were a key cause as to why these people were not accepting towards the knowledge that was provided by the NGO because of the tension. Furthermore, their occupation and malarial sickness were found to be closely related. These findings can help guide policy as Bangladesh works to eradicate malaria within its borders and protect the tribal minority from its effects.

3.1 Background

In their pursuit of a world free from disease, the World Health Organization (WHO) has aims to eventually eradicate malaria, with current efforts going toward elimination of the disease within individual countries (WHO, 2024). Global efforts have yielded promising results, with a number of countries successfully eliminating the disease within their borders. Over the past two decades, eleven nations have earned WHO's certification as malaria-free, signifying the interruption of indigenous malaria transmission for a minimum of three consecutive years, resulting in a total of 43 nations and one territory that have eliminated malaria (WHO, 2024). However, within the Southeast Asian Regional Office of WHO, nine countries, including Bangladesh, remain malaria-endemic. Since 2000, the number of countries in the region reporting fewer than 100 malaria cases, rose from six to 27 in 2021; however, during that time period, Bangladesh experienced a surge in indigenous cases (WHO, 2022). Even though, from 2000 to 2020, Bangladesh achieved a remarkable 93% reduction (Figure 1) in malaria cases through a systematic, phased elimination strategy at the district level (Haldar et al., 2023).

Thirty-four mosquito vectors out of 41 dominant vectors for malaria, all of the genus *Anopheles*, have been found in Bangladesh (Islam et al., 2013). *Anopheles* mosquitoes do not bite during the day; they are only active during late evening and at night (Aubourg et al., 2022). The most prevalent *Anopheles* mosquito species found in Bangladesh are those that thrive in forested and rural areas (Islam et al., 2013). For example, one of the most prominent species, *An. dirus*, thrives in forested mountainous areas and foothills (Sriwichai et al., 2016). *An. minus* is common in vegetation with running water (Dev & Manguin, 2016), while *An. vagus* is found in rice fields, muddy ponds, and forested areas (Alam et al., 2020). The specific malarial parasite responsible for most malaria cases in Bangladesh is *Plasmodium falciparum*, followed in importance by *P. vivax*.

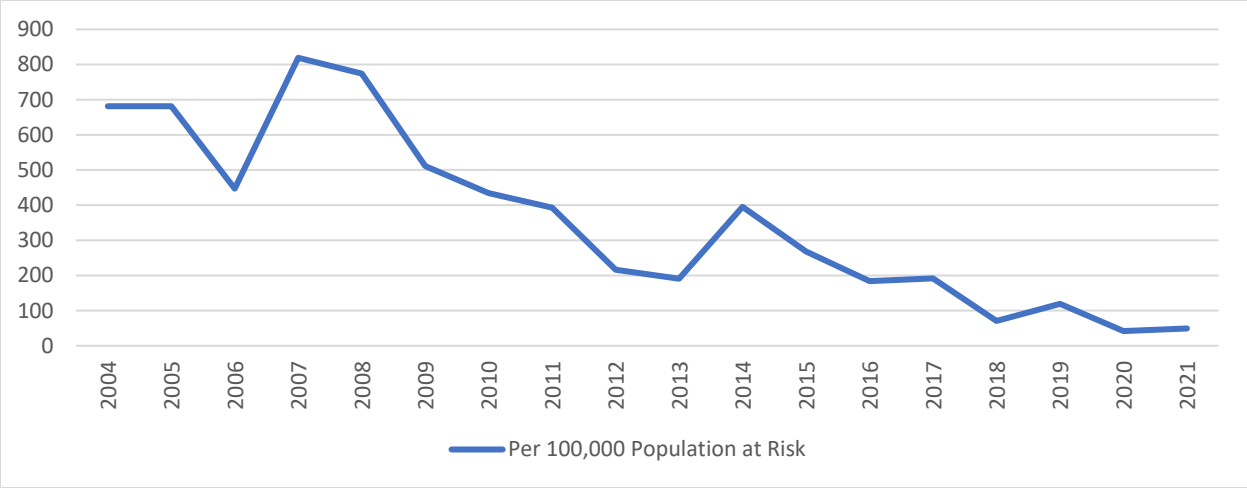


Figure 1 Incidence of malaria in Bangladesh (per 100,000 population at risk) (Data Source: https://data.worldbank.org/indicator/SH.MLR.INCD.P3?locations=BD)

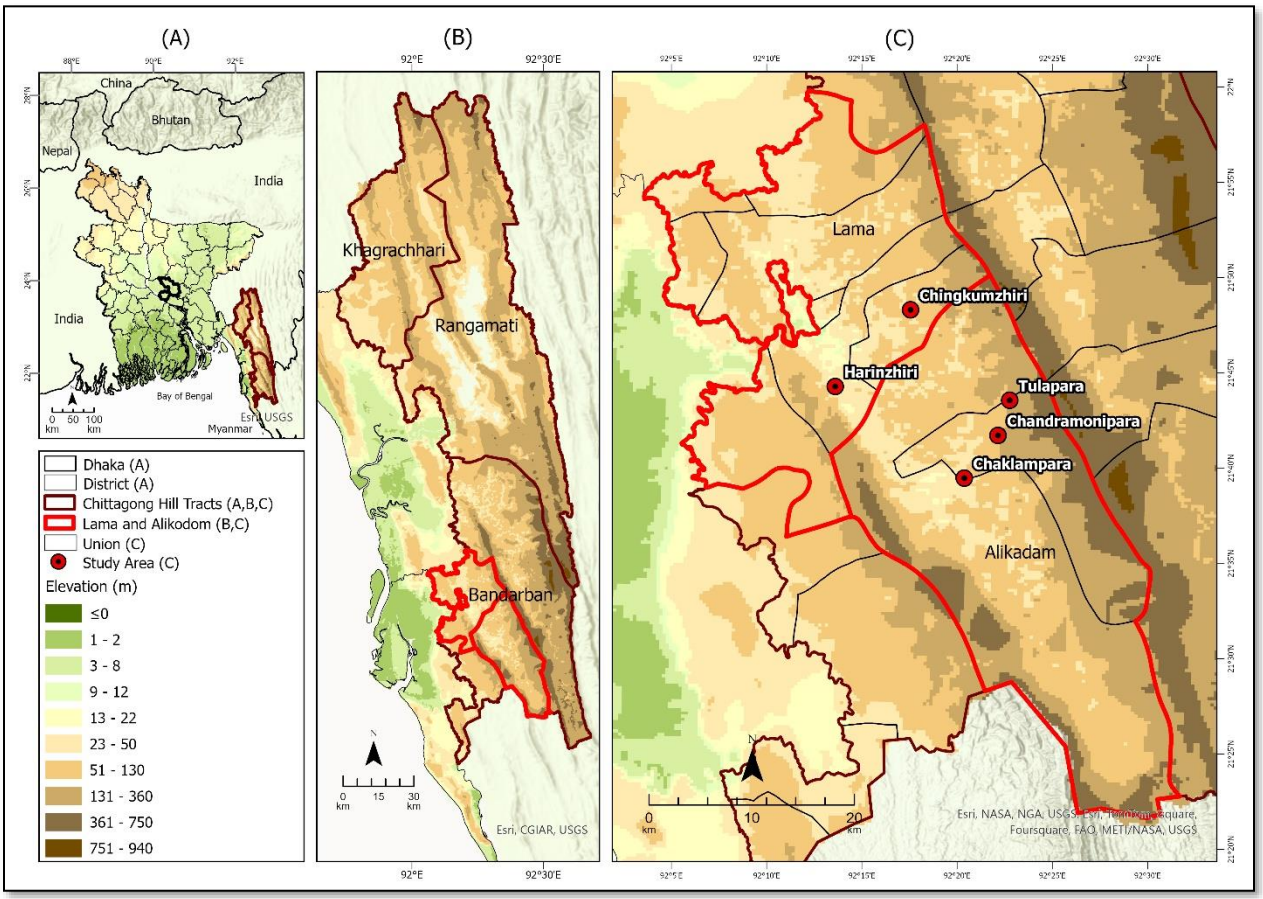


Figure 2 Study Area Map

Malaria has a very long history in southeastern Asia (Poolsuwan 1995), and the disease was firmly entrenched in Bangladesh prior to the country's independence in 1971. Early control attempts within the

country using dichlorodiphenyltrichloroethane (DDT) were thwarted by natural disasters, political upheavals, and the eventual ban on DDT (Rahman, 2013). Until the early 2000s, Bangladesh lacked focused measures to counter the disease, but a turning point came in 2006 when the Global Fund to Fight AIDS, Tuberculosis, and Malaria (the Global Fund hereafter) have distributed 39.6 million USD to support Bangladesh's National Malaria Control Program (NMEP) (Haque et al., 2011; Haque et al., 2014). The funds catalyzed initiatives at the community level, including insecticide-treated net (ITN) distribution, the introduction of coartem combination therapy and rapid diagnostic tests (Haque et al., 2011; Haque et al., 2014). In 2007, non-governmental organizations (NGOs) conducted Bangladesh's first malaria prevalence survey, marking the initiation of renewed efforts against the disease (Haque et al. 2009. Despite this progress, challenges persist in remote, densely forested areas, hindering malaria prevention, detection, and treatment. The disease is still endemic in 13 out of 64 districts, with over 90% of cases reported in Cox's Bazar and the Chittagong Hill Tract districts (CHTs) (Figure: 2) (National Malaria Control Programme, 2015). Strikingly, these districts defy conventional malaria topography, being at a higher elevation and having hilly terrain as opposed to the low-lying flat topography typically associated with malaria. This peculiar situation underscores the need for deeper research into the persistence of malaria in eastern Bangladesh, where topographic conditions are less favorable and cultural norms differ from the rest of the country.

After the consolidation of Bangladeshi nationalism following independence, the CHTs have developed under a unique history that affects current socio-cultural and political conditions, which in turn, contribute to malaria's persistence in the region. While independence marked a significant moment in the nation's history, the subsequent phase of state formation and nation-building revealed challenges for the majority ethnic group, the Bengali, particularly in recognizing the cultural identities of minority ethnic groups (Also referred to as tribal communities/ hill tribe hereafter) residing in the CHT region. One core issue in the region is the perceived lack of recognition by the Bangladeshi state towards the unique cultural identities of the original Indigenous inhabitants of the CHT and more recent migrants from neighboring countries. These communities are a part of the ethnic minority of the country. Despite the distinctiveness of the groups, the central government has been criticized for not affording sufficient acknowledgment, political autonomy, or promotion of the region's culture and languages. This neglect has contributed to a growing sense of grievance among the hill tribes that has affected aspects of malaria control (Panday & Jamil, 2009).

Addressing these concerns would support a more inclusive and harmonious relationship between the ethnic minority of the CHT and the broader Bangladeshi state (Panday & Jamil, 2009), including addressing the current high rate of malaria as the government works to eliminate the disease. While significant strides have been made, minimal research has focused on the unique characteristics of eastern Bangladesh, and

addressing this gap in the literature is key if Bangladesh hopes to eventually eliminate malaria. Previous studies have provided some explanation for eastern Bangladesh's challenges with respect to malaria control, for example indicating inadequate usage of prevention methods in endemic zones, highlighting the need for improved education (Ahmed et al., 2011). Bed net distribution did not significantly reduce malaria in regions in the CHT, where ITNs were supplied in the study by Bashar et al. (2012), but in contrast, several African researchers found that when ITNs were extensively distributed, rates of malaria transmission and accompanying morbidity were reduced to 50% of previous levels (D'Alessandro et al., 1995; Njama et al., 2003); this discrepancy in the CHTs with respect to effectiveness of ITNs, which have been documented to reduce malaria cases and deaths in other parts of the world, needs to be examined and understood. Another study in Bangladesh found that low bed net coverage per household, penetrable walls made up of mud, grass, straw, etc., and a high density of housing were the biggest risk factors for malaria infection, and the risk of malaria was not significantly correlated with hydrologic or topographic factors (Haque et al., 2013). This previous work along with the CHTs socio-cultural and political setting suggest that malaria's persistence in the region is the result of a complex interplay among different factors.

To effectively combat malaria in the CHTs, public health officials must comprehend this interplay between public perceptions, knowledge, and cultural practices, as the country works toward elimination of the disease. Therefore, this research aims to answer the following critical questions, with a focus on Bandarban within the CHTs:

- What is the level of knowledge, attitudes, and practices regarding malaria in Bandarban, within the endemic area of Bangladesh?
- Which socio-cultural factors should be targeted to combat malaria transmission in Bandarban?

Answers to these questions, using qualitative methods including interviews and a knowledge, attitudes, and practices (KAP) survey, will not only advance scientific understanding but also guide policy implementation and health interventions crucial for sustained progress in malaria control and eventual elimination.

3.2 Methodology

3.2.1 Study Area

We selected specific study sites based on the number of malaria cases within the CHTs. Within Bandarban, the district with the highest number of reported malaria cases in Bangladesh, the subdistricts with the highest cases were identified for inclusion in our study: Lama, Alikodom and Thanchi. Due to travel restrictions associated with political conflict at the time of fieldwork, Thanchi was excluded from the study.

Within Lama and Alikodom (Figure 2) and following consultation with a local NGO official, six neighborhoods in five villages were chosen for interviews based on the number of malaria cases, accessibility, and researcher safety.

Our research team consisted of 3 members- the lead author accompanied by two data collectors who also were from Bangladesh. We were escorted to these villages with a guide (who served as a health worker for the NGOs) from the tribal communities we were visiting to help with translation and accessibility. In order to include households that have and have not experienced malaria cases in the past, we designed an intentional sampling scheme to include participants from both groups. To identify households with malaria cases in the past, a purposive sampling method was used at the study sites in which we asked the community health worker to indicate households which had prior cases of malaria. After the households with cases had been identified, the remaining households of the sample size (which did not have cases) were chosen by switching to simple random sampling.

Only one neighborhood within the study region was Bengali, with other villages comprised of tribal communities who were an ethnic minority. Table 1 indicates the locational information and other characteristics about the samples in the study area.

Table 1 Characteristics of Study Sites

Subdistrict	Village (Neighborhood Name)	Ethnicity	Households (#)	Sample Size (#)	Approximate Distance to Nearest Clinic
Lama	Harinzhiri (Bangalipara)	Bengali	120	7	5 km
Lama	Harinzhiri (Marmapara)	Marma	90	6	
Lama	Chingkumzhiri	Mro	40	11	2 km
Alikodom	Chaklampara	Mro	22	8	3 km
Alikodom	Chandromonipara	Tripura	26	7	10 km
Alikodom	Tula Para	Mro	19	11	15 km

Bandarban district, the specific focus of this study, is characterized by mountainous topography (Figure 2) and sub-tropical climate conditions. The average monthly maximum temperature ranges between 25 and 34 °C, and between 2032 and 3910 mm of rainfall is received annually on average, with the majority falling between May and September (ADB, 2001, Gafur, 2001). Main sources of income are agriculture (61.95%), commerce (9.92%), non-agricultural labour (7%), and industry and transportation (1.59%) (BBS, 2011). There are very few, if any, non-farm income options in the rural areas outside of Bandarban town, and food is grown through subsistence methods. Traditionally, upland rice, maize, sweet potatoes, yams, vegetables, and spices like ginger, turmeric, and chiles have been grown under shifting agriculture. Known as jhum

locally, shifting agriculture is a common practice used by the eleven tribal communities in Bangladesh's Chittagong Hill Tracts (CHT) (Rasul et al., 2004). It is based on the slash-and-burn method of field preparation.

Within Bandarban, eleven distinct tribal communities make up nearly half of the district's population (Rasul et al., 2004), equating to 197,975 people out of a total of 481,109 in the district (BBS, 2022;). The Marma, Mro, and Tripura are three of the most prominent ethnic minority groups in the country, and in Bandarban. They account for 13.59%, 3.18% and 9.49% of the population respectively in the country (BBS, 2022). These three groups have different socioeconomic characteristics. The Marma typically resides next to rivers and streams, and their socioeconomic situation is comparatively better than that of the Mro, who are the most economically deprived among the tribal groups of the region and who typically reside at higher elevations. Finally, the Tripura live at higher elevations in more isolated settings. Compared to the Bengali, the largest population group in Bangladesh, these ethnic groups share more ethno-cultural links with other Sino-Tibetan people living in Myanmar and the neighboring Indian states of Tripura and Mizoram (Panday & Jamil, 2009). The remaining individuals in the district are Bengali migrants who moved to the area from nearby lowland areas within the CHTs.

3.2.2 Data Collection and Analysis

The study was designed using primary data collection, which occurred in June 2023. Data were collected using observation, a knowledge, attitude and practice (KAP) survey, and key informant interviews (KII). The privacy and confidentiality of the research participants were maintained, and all respondents were over the age of 18. The study protocol was approved by the Institutional Review Board (IRB) of Virginia Polytechnic Institute and State University prior to fieldwork, and permission was obtained from local government officials from the National Malaria Elimination Program. Individual informed consent was received from each participant.

- **Observations**

Observation is a method of data collection that involves observing events, behavior, or physical features without any manipulation of the situation (Ciesielska et al., 2018). While visiting villages to conduct interviews, observations, categorized as descriptive, inferential, and evaluative, were made in both indoor and outdoor spaces. Cleanliness and the presence of water and vegetation around the household, i.e., overgrown vegetation, waste, and potential mosquito breeding sites, were noted. Household conditions were ranked from 1 to 5, with one representing a very clean setting and 5 representing the least clean as shown in Table 2. Inferential observations included indoor and outdoor behaviors, emotional responses to

questions, and other actions. While interpreting the KAP survey and KII responses to these descriptions, inferences and evaluations made using observation were used to summarize the findings.

Table 2 Household Observation Scale and Features

Observation
1= Very clean, no breeding sites, no bushes around the house
2= Clean
3= The household is moderately clean, some bushes found.
4= Not very clean, presence of waste found, breeding site found
5= Very unclean, animal waste found, breeding sites found, bushes found.

- **KAP Survey**

A Knowledge, Attitudes, and Practices (KAP) survey investigates people's comprehension, convictions, and actions concerning a particular topic (Hairi et al., 2003; Lee et al., 2021). In this comprehensive KAP survey, 53 questions (See appendix) were crafted to gather a thorough understanding of participants' perspectives. The survey was conducted with paper questionnaires and audio recorded with consent, and responses were then transcribed in QuestionPro. The interviews were primarily conducted in Bengali and given that many respondents from ethnic minority communities did not speak Bengali, our guide in these cases worked as a translator. After exporting the responses in a spreadsheet, all survey interviews were later translated to English in MS Excel for analysis.

This semi-structured questionnaire for the KAP survey (See appendix to view the survey questions) asked questions regarding participants' perceptions about malaria's spread in their community, methods for combatting transmission, their current knowledge about the disease, and their tendencies to follow measures and form habits that will help prevent transmission as listed in Table 3.

Table 3 Themes in KAP survey.

Knowledge	**Attitude**	**Practice**
Transmission	Thoughts about management	ITN usage
Treatment		Cleanliness
Prevention	Fatality of the disease	Water storage
		Evening outdoor habits

Following data collection and entry, major themes, common ideas, and similar wordings from each section were categorized using a content analysis (Content analysis, 2016). To assess the level of knowledge, the percentage of correct responses to knowledge-based questions was examined. Attitude questions explored the variety of perceptions about malaria, with responses categorized into 'Not Sure', 'Agree', 'Somewhat Agree' and 'Disagree'. This categorization helped determine if participants were making positive or

negative inferences about the situation presented. In order to comprehend reported behaviors and identify situations in which effective interventions might not be followed, practices related to malaria prevention were evaluated. The behavior of respondents was noted against effective practices, with responses categorized as 'Always', 'Occasionally', Most of the time' and 'Never'. Descriptive statistics were then calculated.

While performing the content analysis, responses were counted and categorized after which a more in-depth examination of the meaning, context, and underlying themes present in the data was conducted, allowing for a thorough interpretation. The interpretations also accounted for the inferences made by the respondents.

- **Key Informant Interviews**

Key informant interviews, in-depth discussions with those knowledgeable about a particular issue, were used in a semi-structured manner to elicit information from experts (Gilchrist, 1992). To get a broad idea of disease mechanisms in the study area, it was necessary to talk to personnel who have been working with malaria control efforts within Bangladesh. The interviews (See appendix), recorded with the consent of the interviewees and then transcribed, followed a general structure based on the KAP survey questions. The questions centered around the management of cases, the intensity of cases and their causes and elimination efforts. Key informants were chosen from three levels and scales of operation: the first interviewee was an epidemiologist at the National Malaria Elimination Program (NMEP), the second interviewee was the program manager of an NGO working towards controlling malaria in the CHTs, and the third participant was a land surveyor who had field experience collecting malaria data in the CHTs and nearby Cox's Bazar. The input from key informants was crucial for drawing conclusions from KAP surveys related to how respondents perceive and combat malaria.

In the course of the three KIIs, recurring themes emerged, shedding light on participants' perspectives related to malaria. Common themes were identified and cross-validated by comparing scripts of different participants to find any related or contradictory statements. Specific points pertaining to the socio-economic status, behavioral characteristics, and the attitudes and practices of the interviewees towards malaria were summarized. Furthermore, discussions with the informants centered on exploring viable strategies to mitigate these barriers and enhance the overall effectiveness of malaria elimination efforts. Since the respondents were from different levels of management, they were able to provide community-level insights as well as an overview of the broad scenario related to malaria control and elimination.

- **Validation**

This is study for validation we used the method member checking. Member checking stands as an element, embodying a fundamental tenet of qualitative research: recognizing participants as experts (Knapik, 2006).

Given that the findings hold greater significance for readers than mere transcripts, participants contribute to refining them (Wertz, 2014). After crafting a draft of the findings, participants were invited to offer their insights. This collaborative approach ensures that participants' expertise enriches the final output, enhancing its value and relevance.

In our study, member checking was done during the field interviews. During an interview, the details were repeated before questioning the participant to ensure understanding. Once an interview ended, member checks were conducted by presenting all findings to involved participants, enabling them to scrutinize and provide feedback on the results. Participants then either confirmed or denied that the summaries align with their perspectives and experiences or indicate discrepancies. Their responses were noted and rectified.

3.3 Findings

3.3.1 Observations

Observations of household conditions are summarized in Table 4. Only one household in the sample maintained all elements according to public health standards (CDC, 2023; HUD, 2016; Environmental Health & Safety--EPH-EHS--, n.d.). Most households (33) had maintained adequate standards. Seven out of forty-nine households had substandard conditions, at the poorest ranking.

Table 4 Household Observation Rankings

Rank	Observation	Household
1	The household is very clean, respondent tries to keep the household clean in part due to malaria; stagnant water is not present, resting place for domestic animals is cleaner comparatively to other houses.	2%
2	The household is clean. No observation of significant places such as bushes or stagnant water where mosquitoes can breed. Residents regularly clean their surroundings. No presence of domestic animal excretions.	28%
3	Household condition moderately clean, resting place for domestic animals unclean, and garbage can be found near house.	38%
4	The household is not very clean, soot from cooking and garbage present, unclean resting places for domestic animals identified.	2%
5	Very unclean, area surrounding home has lot of bushes and excretion of animals, which is not considered dirty by respondents. There are many places around the houses where mosquitoes can breed.	14%

Each household's residence had an outdoor portion that was open, similar to a deck or patio (Figure 3c), and so, even if respondents reported not leaving the household, they could be exposed to mosquitoes by sitting in the exposed portion of the home, as indicated by several respondents. Vegetation present throughout communities accommodates mosquito breeding. Furthermore, the traditional build of houses includes several open portions throughout the structure in addition to windows for ventilation (Figure 3b). These home features render interventions like remaining inside after dusk or installing window screens useless when homes are not fully closed.

Results indicated that the health workers and the respondents from the tribal communities interact very little. The health workers primarily belonged to the Bengali community, and there appeared to be considerable mistrust between the ethnic majority and minority groups. When a tribal community member became sick, a representative from the community would collect the medicine from the health workers. This would make the community representative the bridge between the community and health workers from the NGO. This also meant that community members did not engage or facilitate any form of communication with the health workers themselves. These tribal community representatives did not themselves have clear knowledge about the disease as indicated by many inferences and later during the KAP survey. During prior campaigns to collect data from the tribal communities they were unwilling to participate. Due to tension between the two ethnic groups the Bengalis were afraid to associate closely with the tribal community members. While the NGOs hired community representatives and volunteers, they were skeptical about appointing any of them in a decision-making role.

(a)

(b)

(c) (d)

Figure 3 (a) Staying out after dusk is a cultural practice, (b) Traditional households with openings all around, (c) An extended open section part of every household, and (d) Unclean and muddy soil under households.

3.3.2 Interview and Survey Results

While talking to key informants and KAP survey respondents, the overall malaria management scenario came to light. Treatment and preventative measures for malaria in this region of Bangladesh are primarily provided by two NGOs: Building Resources Across Communities (BRAC) and Ekota. They each have designated zones in which they operate, and with both receiving funding from the Global Fund, their code of conduct is similar. These local NGOs provide ITNs, medicine, and diagnostic tests for free if community members inform them about suspected patients. There is one health worker assigned to each neighborhood who is contacted if a resident is suspected of contracting malaria.

The three interviewees shared similar views about socio-cultural conditions of the study area, the presence of political unrest, the lifestyle of the region's residents, malaria transmission and prevention scenarios, malaria control measures, obstacles to malaria elimination, and isolation of the ethnic minority residents of the study area. Given that the three key informants work at different levels (national level, upazila (subdistrict) level, and local field level), their perceptions about these issues varied.

KNOWLEDGE

Survey and interview questions related to knowledge addressed route of transmission, symptoms, preventative measures, treatment options, and overall general understanding about the disease. Regarding general knowledge, a difference between responses from the ethnic majority Bengali and ethnic minorities was identified. Respondents from the ethnic majority demonstrated a thorough understanding of most aspects of the disease, but some respondents from the ethnic minority were unfamiliar with the term

“malaria” itself; several (14%) had the wrong idea about the term or could only guess about the meaning of the disease’s name. In response to a question about knowledge of cases in their neighborhood over the past year, despite a high number of cases in the study tribal villages, the majority of respondents from those villages recalled learning about a malaria case only one or two times. Only nine out of 43 respondents (20%) from these communities associated malaria with mosquitoes, with several of these respondents expressing a misunderstanding of mosquito breeding dynamics.

A project manager of an NGO explained during his interview that malaria is prominent among the tribal communities due to their livelihood, local ecological conditions, and communication challenges. The ecological conditions on which their livelihood is based expose them to mosquitoes that carry the malarial parasite. When people residing in villages go into the forest, which occurs during jhum cultivation, and are bitten by mosquitoes unique to the forest, they could be infected by the disease. It is a common practice to stay overnight for several days in a shed-like structure near the fields in order to tend crops. Infected people would then return to the villages, and mosquitoes in the neighborhood could spread the disease further. However, there is no evidence that this transmission chain is the only scenario, and this chain likely represents just one possible way that malaria is introduced into villages. This route was also confirmed by our other interviewees who had local-level experience working for the NGOs.

KIIs performed with health workers revealed that residents were sometimes unable to identify that they were having a malaria outbreak in their communities and were also sometimes unable to identify the name and cause of the disease or the means to prevent it. While interviewing the respondents, this issue was also evident, and the symptoms of the disease had to be explained for them to grasp that malaria was being discussed.

When asked about the transmission, it was revealed that two-thirds (n=30) of respondents that resided in tribal villages had no knowledge about malaria’s transmission by mosquito. One respondent explained that he does not know how malaria spreads. He then shared, when asked if malaria is spread by mosquitoes during a follow-up question, that when he stays for two or three days in an uphill location for jhum cultivation, he does not take the bed net, which is why malaria spreads. Another respondent made a similar statement while connecting mosquitoes and malaria saying, “my son went to hilly regions in search of work. He got infected as he had to stay there for 7-10 days. He got bitten by insects and mosquitoes; that’s how he got malaria.” Additional respondents connected malaria with land cover and occupation, with one stating that, “It is a contagious disease. It occurs randomly as they pursue work in the forest”. One respondent reported that only one Bengali person in the study neighborhood of Harinzhiri, which had over 120 households, was affected by malaria. While investigating the reason behind it, the respondent revealed that the affected person had gone into the forest to collect wood.

All respondents were assessed for their understanding of malaria's symptoms. Over one-third (34%) of respondents correctly answered that fever and shaking chills are typical symptoms, with some respondents describing additional symptoms such as vomiting, dizziness, bloodshot eyes, and other side effects of malaria. Almost 26% of the respondents were not able to name any symptoms. The remaining 39% of the respondents answered the question incorrectly. Several respondents said that malaria could only be identified through testing. Many listed "headaches" as a defining symptom without mentioning other key symptoms, indicating that they associate fever with headaches as the main indicator of the disease. One person said, "it's a viral fever which can only be diagnosed when tested."

While assessing the study population's awareness of the role of local NGOs, almost all respondents said that treatment for malaria was available from the local NGO, specifically responding with the name of the healthcare worker responsible for their area rather than the name of the NGO. Few of them responded that treatment is available at the nearby hospital or community clinic. One respondent specified that primary care for malaria was available only to the NGO workers, not residents of the region.

Generally, residents of the tribal neighborhoods do not prefer to go to the hospital for malaria, and so the hospitals did not usually tend to malaria cases. If a malaria patient came to the hospital, patients would be directed to the local health worker from the NGO unless it was a life-threatening situation. Furthermore, the respondents and NGO workers indicated that the health clinics and pharmacies do not provide or carry the drugs to treat malaria.

When asked about the quality of case management, respondents instead described how malaria was managed according to their knowledge, without commenting on the quality of care received. Those who did comment on the quality of malaria management said that they were satisfied with a notable exception. One respondent explicitly said, "The responsible authority is lazy and because of that, the neighborhood can't avail itself of treatment. Government help is much needed. When people try to test for malaria with the testing kits provided by the NGO, one person has to be tested multiple times to get the results." He went on to say, "Although improvement is needed in many aspects, if BRAC wasn't here to support us, half of us would be dead."

While some respondents did not know the location of the nearest healthcare center, most were aware of the distance, responding correctly by either absolute or relative distance. However, the most malaria-prone villages were isolated in the hills, in remote locations with no proper transportation route. Even the most accessible neighborhoods require a trek of at least 20 minutes through the hills to reach a transportation route accessible by a vehicle.

Perceptions about Prevention

Prevention discussions centered around the use of insecticide-treated bed nets (ITNs), with 24% of respondents answering that malaria could be prevented with this method. Some also mentioned mosquito coils (a spiral made from the dried paste of pyrethrum powder, which, when lit, burns slowly to produce a mosquito-repellent smoke) as a device that could prevent transmission. Since respondents were poor, they stated that they were unable to afford means of prevention other than the NGO-provided ITNs. While all homes had ITNs, many were unaware of why they were using them to prevent mosquito bites. Over one-third of the respondents explained that the only way to prevent the disease was by going to the hospital or taking medicine, which was only provided by the NGO. Another one-third of respondents did not express any understanding about methods to prevent malaria transmission.

Only 80% of the respondents offered their ideas about the main obstacle to malaria prevention and most (49%) shared that unawareness about the disease, including prevention and transmission, was the key issue. Many respondents also blamed uncleanliness and their financial situation. One person from the Mro community in Chaklampara said that they themselves were responsible for the disease due to them being unclean and dumping water under the houses by stating, “If I must honestly answer, the area is surrounded by a jungle, the Mros are unclean, they wash their dishes in a container and dump the container below their houses (Figure 3d). There are bushes around the house. They are unaware that these things can accelerate mosquito breeding.” Another person from Chinkumjhiri echoed this idea of a lack of cleanliness, sharing “It is because of the pig waste here and there. I often see mosquitoes hovering over them.” Finally, a few of the respondents thought that the government and the responsible NGO were lacking efforts to prevent the disease.

While respondents talked of the region’s poor financial conditions, they specifically pointed out their occupation as a key factor supporting transmission, since whenever they went to nearby hilly areas for jhum cultivation, they shared that they got infected from the forest, with some respondents mentioning the role of mosquitoes.

ATTITUDE

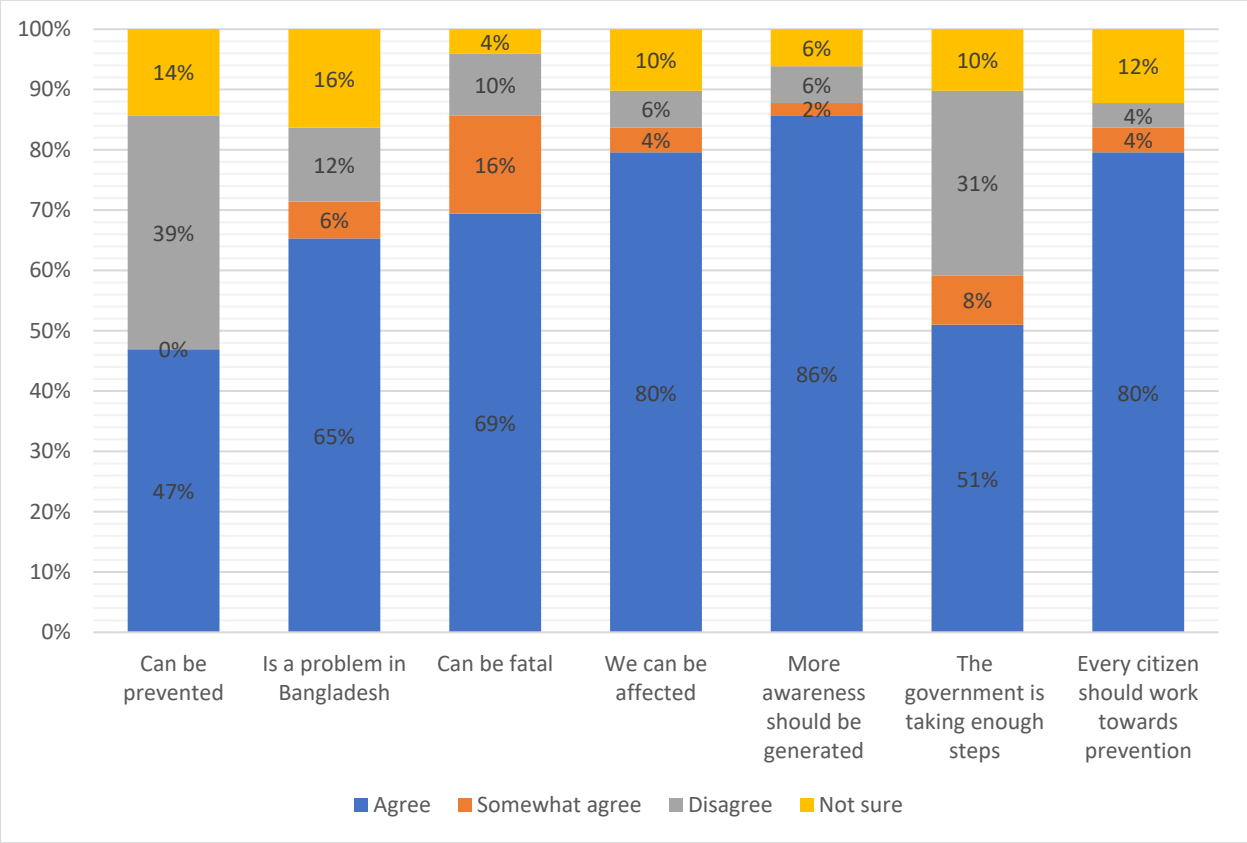


Figure 4 Attitudes Related to Malaria

While assessing attitudes toward the disease, respondents were asked to describe their level of agreement with specific statements. Notably, a significant portion of respondents acknowledge the severity of mosquito-borne diseases, with high percentages agreeing that these diseases can be fatal (69%) and that more awareness should be generated for their prevention (86%). Furthermore, a substantial majority of participants (80%) believe that both the government and citizens should work together to prevent these diseases. However, there is a notable level of uncertainty and disagreement about the government's efforts in this regard, with 31% disagreeing that the government is taking sufficient steps.

However, there was a difference in the responses of the ethnic majority and the ethnic minority groups. When asked to respond to the statements, ‘Malaria is a problem in Bangladesh’ and ‘Malaria can be fatal’, all seven respondents from the Bengali community disagreed while most tribal community members (over 34 respondents) agreed. Figure 6 provides insights into public perceptions and emphasizes the importance of awareness and collaborative efforts in combating malaria in the study population. These findings are presented in Figure 4.

While interviewing the key informants, it became evident that these interviewees developed their perspectives about the possibility of elimination of malaria in the region based on their own experience with the affected community. Interviewees with local-level contact within the region were not optimistic about malaria elimination given socio-cultural conditions; however, the NMEP official was optimistic given the countermeasures employed.

PRACTICES

Practice-related questions focused on the day-to-day behaviors and habits related to mosquito exposure and control that could increase or reduce malaria infections. While discussing practices within the affected communities, it became apparent that members of ethnic minority communities are retaining their traditional values and lifestyles, while rejecting forms of communication commonly used in malaria awareness campaigns. Most members of the ethnic minority have no formal education and are isolated from other parts of the country and modern day effective preventive measures aside from ITNs like mosquito repellent creams or aerosols. Residents rarely leave their neighborhoods, except to practice jhum cultivation, further isolating them.

Mosquito Exposure

For those in one of ethnic minority groups (Mro) included in our study, it is a common cultural practice to gather together at dusk after returning from a hard day of farming in the uphill forests, potentially exposing themselves to mosquito bites (Figure: 3a). Thirty-eight households explicitly said that they had family members who stayed outside regularly either for work or to gather in the neighborhood. Some respondents interpreted the question to refer to spending time outside of their neighborhood. Therefore, negative responses (7) may indicate outside the household or outside the neighborhood, but either option could potentially result in exposure.

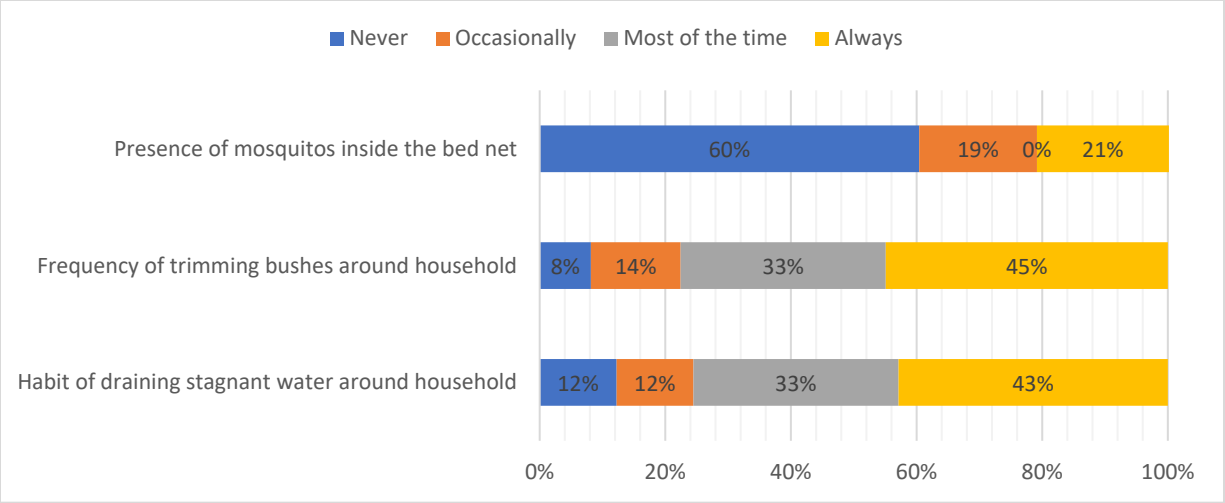


Figure 5 Practices: Mosquito Exposure

The data in Figure 5 indicates that a concerning proportion of respondents (60%) reported often noticing mosquitoes inside their bed nets, highlighting potential issues with the effectiveness of this preventive measure. Respondents do recognize the importance of removing excess vegetation and stagnant water. Combined, over three-quarters of participants described their regular habit of trimming bushes around their homes as "most of the time" (33%) or "always" (45%). A significant portion of respondents reported draining stagnant water or moist areas around their homes "most of the time" (33%) and "always" (43%).

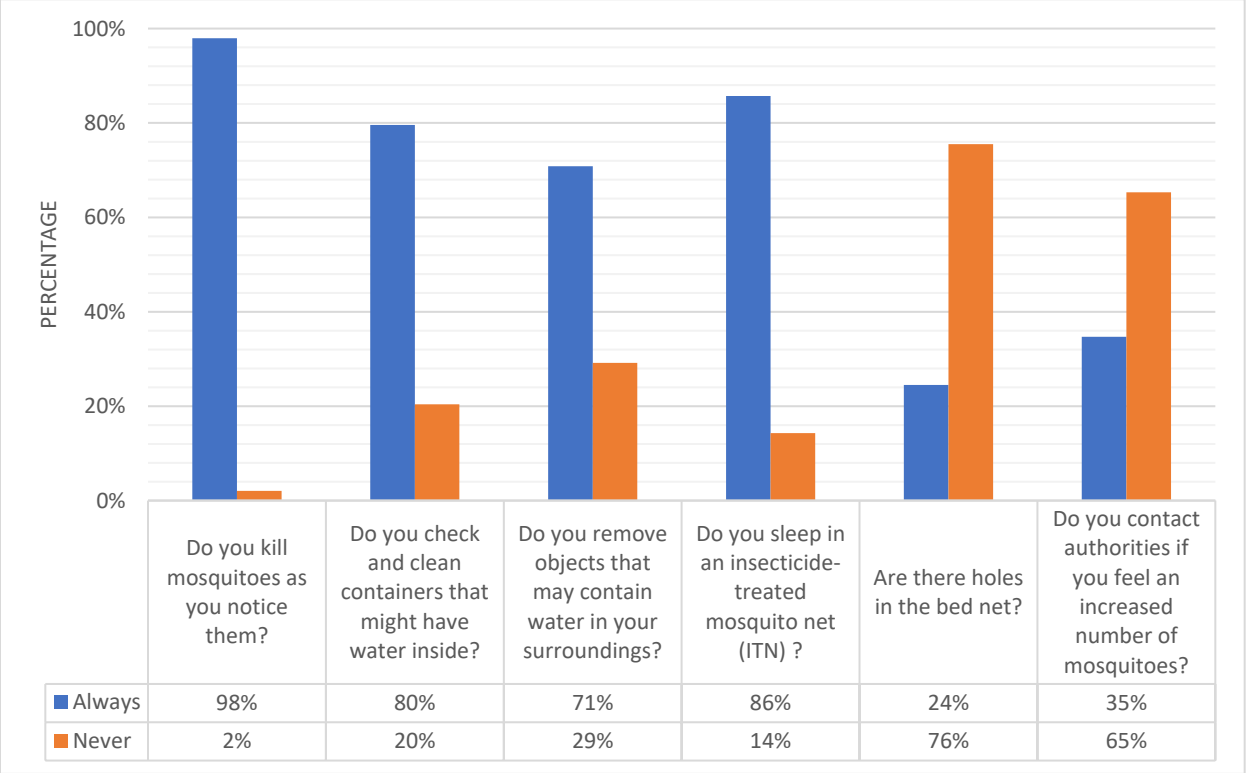
Mosquito Control Practices

When asked about mosquito breeding sites, eight respondents did not know how mosquitoes breed, with an additional eight respondents stating that there were no mosquito breeding zones in their surroundings. The remaining respondents (19) stated that there were areas in the neighborhood that had mosquito breeding zones, specifically related to bushes or domestic waste; they did not indicate stagnant water as a breeding zone. The remaining responses could not be grouped as they were either interpreted incorrectly by the respondents or not answered at all. All respondents stored water in containers in the household, using separate containers for drinking water and water for household use. When describing water storage practices, respondents only discussed the usage of drinking water and stated they never keep the water for more than one or two days.

ITNs are provided by the NGO responsible for the zone in which the neighborhood is located. The maximum capacity of one mosquito net is three people, but 12 households reported that they had over three people sleeping within one ITN. Seventeen respondents reported that they wash their bed nets, which decreases effectiveness and can damage the material, according to the community health workers. One ITN is active for up to two years, and 13 households shared that they have been using the provided ITN for at

least two years and possibly longer. The remaining respondents used the same provided ITN until a new one was distributed to their household by the NGO, but they did not mention the timeline of ITN distribution. Most respondents reported regularly checking for holes or tears, but eight respondents never examined their ITNs for damage. Almost 86% of them responded that they sleep under insecticide-treated mosquito nets and all of their family members used them too. Concerning the condition of their bed nets, a noteworthy 76% reported having no holes in them.

A large majority of respondents (98%) indicated that they actively kill mosquitoes as they notice them, and check and clean water storage in their homes to prevent mosquito breeding (80%) as indicated in Figure 6. Additionally, a considerable portion of participants stated that they remove potential mosquito breeding sites from their surroundings (71%), with a relatively smaller percentage of individuals (35%) stating that they contact their local government office when there is an increase in mosquitoes.



	Do you kill mosquitoes as you notice them?	Do you check and clean containers that might have water inside?	Do you remove objects that may contain water in your surroundings?	Do you sleep in an insecticide-treated mosquito net (ITN) ?	Are there holes in the bed net?	Do you contact authorities if you feel an increased number of mosquitoes?
Always	98%	80%	71%	86%	24%	35%
Never	2%	20%	29%	14%	76%	65%

Figure 6 Practices: Preventative Measures

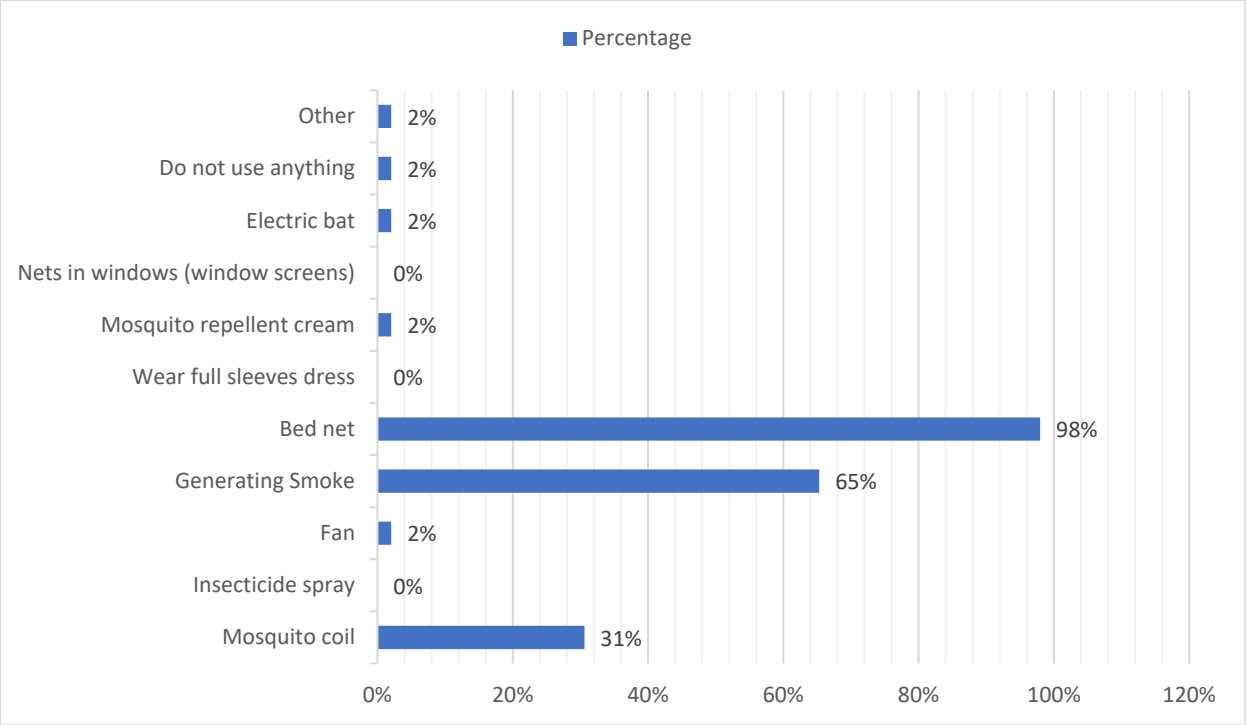


Figure 7 Prevention Methods

Figure 7 provides information on the percentage of respondents who reported using various mosquito prevention measures. The data reveal that a large majority of respondents use bed nets (98%) as a preventive measure, which is a common and effective way to protect against mosquito bites, particularly in areas with a high prevalence of mosquito-borne diseases. Additionally, "generating smoke," referring to the use of smoke-producing devices or coils to repel mosquitoes (65%), is also commonly used. However, it is worth noting that no respondents reported using insecticide spray, nets in windows or window screens, or wearing full dress as prevention methods. Other measures such as using a fan, mosquito repellent cream, or an electric bat (a mosquito swatter that electrocutes mosquitoes) were reported by a small percentage of respondents (2% each), while a similar percentage mentioned using no preventive measures at all or opting for other methods not specified in the table.

One respondent shared that, even though his family used bed nets, he never used one. “I stay up on the hill for agricultural work for several days, so I don’t sleep inside the house most of the time and because of that I’m not aware of the holes in the bed nets or how long the family has been using the bed nets. When I work on the hill, I smoke tobacco,” believing that the smoke created from tobacco repels mosquitoes.

3.4 Discussion

This study is the first to conduct an in-depth local scale analysis of the socio-cultural factors contributing to malaria's persistence in the Chittagong Hill Tracts of Bangladesh. The assessment of knowledge, attitudes, and practices surrounding malaria in villages of Lama and Alikodom within the CHTs has revealed both challenges and opportunities for effective control measures while furthering our understanding of malaria's persistence within campaigns striving toward the disease's elimination. The community's awareness of malaria, prevention measures, and treatment appears to be a critical factor influencing the success of interventions.

Knowledge about malaria was lacking among some residents of the region as cultural practices, beliefs, and social norms play a significant role in shaping community behaviors related to health. While a number of participants demonstrated knowledge about transmission and many participants recognize that malaria is a fatal disease, some participants, including those who had previously been infected, did not know that a disease called malaria existed. In a study in Saudi Arabia and Nepal, similar outcomes were noted, with inaccurate perceptions of the disease leading respondents to believe that malaria was a contagious and deadly illness indicating that medication or preventative measures are not available or effective (Khairy et al., 2017; Joshi & Banjara, 2008). This finding is relevant to education efforts as Owusu et al., (2018) found a correlation between higher chances of malaria parasitemia and inaccurate understanding of the disease's origin and preventative measures. Respondents commonly identified fever as the most prevalent symptom of the disease, followed by pain, vomiting, sensations of cold, and weakness. This observation aligns with similar findings in other studies in which people correctly identified symptoms like fever, chills, body ache and other associated impacts of malarial infections (Hlongwana et al., 2009; Dunyo et al., 2000).

This study also indicates a need to consider community attitudes toward malaria prevention and treatment. The socio-cultural factors influencing malaria transmission in the Chittagong Hill Tracts are multifaceted. While only seven participants were from the ethnic majority, there was a clear difference in attitudes toward the disease between the ethnic majority and the ethnic minority. In particular, fear about disease and contentment about management were exactly opposite in the two communities. Ethnic minority communities feared the disease to be fatal while the majority perceived it to be yet another treatable fever. Studies done in Ghana, Senegal, and Ethiopia, where malaria is also a prominent disease, showcase respondents having similar attitudes about the fatality of the disease within ethnic minority groups (Tairou et al., 2022; Lopez & Brown, 2023). However, studies done in many countries (Comoro et al., 2003) (Eko et al., 2013) such as Ghana (Attu & Adjei, 2018; Malik et al., 2006), Kenya (Nyamongo, 2002), and Uganda (Ndyomugyenyi et al., 2007) indicate that patients tend to resort to self-medication; this phenomenon was

also observed among respondents in this study (Matin et al., 2020). If these treatments were found to be ineffective, it was the norm to reach out to the community representative who would later collect medication and test kits from the community health worker.

With respect to practices, findings indicate that residents of the study area primarily rely on ITNs for prevention, and each ITN is used for at least one to two years. This scenario has been observed in numerous studies conducted in rural areas in other parts of the world (Khairy et al., 2017; Joshi & Banjara, 2008; Dunn et al., 2011; Mboera et al., 2010). Of note for Bangladesh's efforts toward eliminating malaria, a study conducted in northern Tanzania points to signs of mosquitoes adapting their behavior by altering their biting patterns in response to the presence of ITNs (Braimah et al., 2005). This finding implies that in regions where insecticide-treated bed nets (ITNs) have been in use for a considerable period, mosquitoes might be shifting their peak biting times from the middle of the night to periods just after dusk and before dawn to avoid contact with bed nets. There are also concerns about the potential for weakened immunity due to decreased malaria transmission resulting from prolonged bed net usage (Askjaer et al., 2001; Maxwell et al., 2002; Dunn et al., 2011). Interestingly, this body of literature suggests that the continuous use of ITNs could introduce additional challenges to efforts in reducing malaria-related illnesses and deaths, and eventually elimination of the disease within Bangladesh's borders.

Agricultural practices also pose a challenge. Whenever respondents traveled into the hills for agricultural needs, they were exposed to mosquitoes. Staying overnight for jhum cultivation in the forest further increased the probability of getting bitten. Even if individuals do not understand the precise mechanism by which they were exposed, other studies have confirmed exposure to mosquitoes and infection by the malarial parasite while moving through forested areas (Bidlingmayer, 1971; Hendy et al., 2023). The specific behaviors of mosquitoes increase exposure potential for those tending their fields. Given the propensity of the specific mosquitoes found in the CHTs to thrive in forests and highly vegetated areas (as indicated in the background section) while biting in evening and at night, those who travel overnight to forests to tend their fields are especially vulnerable. Finally, guidelines for remaining inside their household are rendered useless as communications do not account for household structures that have openings all around them for ventilation and have an extended open portion as a part of the main household. Furthermore, after coming back from the forest at dusk, which was the prime time to be bitten by mosquitoes, it was a tradition to have a community gathering in the neighborhood or at the market. Measures and communication need to account for unique socio-cultural aspects. The only effective practices identified were vegetation removal and the clearing of water containers every one or two days, effective because *Anopheles* mosquito eggs take five days to mature.

The main risk factors identified in this study were the lack of formal education among residents, location of households in a rural setting, remoteness of neighborhoods, practice of jhum cultivation in the forest, and lack of awareness about the disease. To the respondents, malaria is yet another problem they must deal with every day. They are unaware their villages are among the few still struggling with the disease within Bangladesh. The relationship between the tribal community members and community health workers was limited to testing and the distribution of medicine and ITNs; there was very little communication as to how residents of the region were being infected or even if such information was communicated, little was comprehended and accepted. During our interviews, it became apparent that community health workers are not trained to serve and communicate measures to vulnerable communities according to their unique setting and needs. Prevention and control measures are communicated in a very generic manner and are of little use to residents because they have no means to utilize them when many of the measures are not applicable in the unique setting of the CHTs.

Jhum cultivation plays a significant role due to its association with increased exposure to mosquitoes. When farmers venture into forested areas for jhum cultivation, they are exposed to mosquito bites, particularly those of Anopheles mosquitoes, which are the primary vectors of malaria parasites. Spending extended periods in forested environments, especially overnight stays, further heightens the risk of malaria transmission as these areas are often breeding grounds for mosquitoes. The specific behaviors associated with jhum cultivation, such as working in the fields during dusk and dawn, coincide with peak mosquito activity times, increasing the likelihood of exposure to malaria-infected mosquitoes. Additionally, the practice of jhum cultivation often involves communal activities, such as collective farming or gatherings in the evening after returning from the fields, which may further facilitate mosquito bites and subsequent malaria transmission.

Secondary findings indicate that due to inadequate knowledge about the transmission and prevention of the disease (revealed during KAP survey), the marginalization of ethnic minority groups from the ethnic majority (Bengali) (identified during observation), the tendency of the ethnic minority to isolate themselves for historical reasons (highlighted during KIIs), and the concurrent poverty of the tribal communities, malaria is rampant, even though community-level and individual-level measures are in place. A mixed-methods study at CHTs yielded similar findings (Matin et al., 2020). This study found that feverish patients frequently self-treat using over-the-counter medications and home remedies before visiting a medical facility, and that ethnic minority communities in the CHT live in unstable socioeconomic circumstances that raise their risk of contracting infectious diseases. Access to public healthcare is also impacted when people from ethnic minorities feel that Bengali healthcare workers are uncommunicative, and that the quality of care is perceived as being substandard.

Many studies have revealed that even after having thorough knowledge about the disease among residents in an endemic area, malaria remained persistent (Owusu et al., 2018, Bamou et al., 2022). This persistence also exists with possession and utilization of control measures such as use of ITNs, improved housing, and other efforts to prevent malaria.

This study shows that despite having rigorous community-level interventions in place, the disease remains endemic due to socio-cultural practices, lifestyle choices, and marginalization. Identifying factors that shape attitudes is crucial for tailoring health communication strategies that resonate with the local population. Since the socio-cultural setup of disease transmission is unique in the CHTs, prevention and communication methods have to be tailored to the unique lifestyle of the respondents without harming their values, traditions, and livelihoods; without respect for and understanding of socio-cultural practices, recommended interventions will not be effective.

Public health measures and guidelines for malaria prevention are not communicated effectively according to the unique livelihood and household setup of the ethnic minority who are primarily affected by the disease. Collaboration with local communities and stakeholders is essential for successful policy implementation. By involving the community in the decision-making process, interventions are more likely to align with local needs and values, fostering a sense of community ownership. Additionally, ongoing monitoring and evaluation are crucial to assess the impact of interventions and adapt strategies based on real-time feedback (Wandersman & Florin, 2003; Rocha & Soares, 2010; Lassi et al., 2014).

Numerous studies recommend good practices in conjunction with knowledge and control measures at the community level (Owusu et al., 2018, Bamou et al., 2022). Thorough understanding of the malaria vector and preventive measures may stop the spread of the disease, particularly if the populace used this knowledge to utilize efficient control devices like ITNs. Such information has been shown to help lower the prevalence of malaria in Mwa, Kenya (Oketch et al., 2008).

While ITNs play a crucial role in malaria control, their potentially limited long-term effectiveness against indoor-biting mosquitoes underscores the necessity for supplementary control measures. Many studies have indicated that it is also essential to address outdoor-biting mosquitoes to enhance overall protection against malaria transmission (Bamou et al., 2022; Dunn et al., 2011). Therefore, there needs to be a combination of preventive measures in place for indoor and outdoor spaces, especially when residents of zones endemic to malaria may stay overnight in the forest near fields, which increases exposure risk. Indoor supplementary methods could include mosquito repellent creams, mosquito coils, screens in windows and as well as in ventilation openings; outdoor methods should include portable camping bug nets and bug repellents that would be effective interventions that could be promoted by the NGOs working in the region.

3.5 Limitations and Future Research Needs

Limitations of this study include challenges with participant recruitment and lack of access to remote areas. Despite data collection being conducted by a native Bangladeshi, participant recruitment was difficult because of cultural differences, a language barrier necessitating the need for a translator, and the need for residents of the region to tend fields. We attempted to address these limitations by including more women as the household representative who were roughly half our respondents and using the community representatives as our guide and translator, as they were trusted personnel in the community. Furthermore, the most remote areas of the region, in which malaria is also entrenched, were excluded due to political restrictions at the time of data collection; their inclusion in a future study would likely present a more nuanced understanding of the scenario in the CHTs. Future research opportunities could include investigating risk factors related to malaria across a broader scale, as this study was conducted in a limited area in order to acquire more detailed information. Furthermore, environmental factors should be investigated, as it was seen that environmental conditions, the rural setting, and the remoteness of communities played key roles in the transmission of malaria.

3.6 Conclusion

There is a scarcity of research on the knowledge, attitudes, and practices concerning malaria prevention and treatment in Bangladesh, potentially influenced by the lower prevalence of malaria compared to more prevalent communicable and non-communicable diseases like diabetes, cardiovascular issues, diarrhea, and typhoid among others. However, malaria is firmly entrenched in the CHTs, presenting a significant health burden to residents, and given Bangladesh's goal to eliminate malaria, it is important that this gap in the literature be filled; this research contributes key information toward that goal. This study systematically gathered and consolidated key information on knowledge, attitudes, and practices related to malaria awareness, prevention, and impact in this region. This research contributes to the global body of knowledge on malaria control and elimination by providing context-specific insights into the dynamics of transmission in the Chittagong Hill Tracts.

In conclusion, the comprehensive examination of knowledge, attitudes, practices, and socio-cultural factors in the Chittagong Hill Tracts provides a nuanced understanding of the challenges and opportunities in malaria control. By bridging the gap between scientific understanding and on-the-ground realities, this research lays the groundwork for informed policy decisions and targeted interventions, ultimately contributing to sustained progress in malaria control and elimination in Bangladesh and beyond.

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Chapter 4: Climatic Drivers of Malaria Incidence: A study in Naikhongchhari Sub-district, Bandarban, Bangladesh

This manuscript was prepared for submission to the *Weather, Climate, and Society (WCAS) Journal.*

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Abstract:

In the fight to eliminate malaria from its borders, Bangladesh still has this disease entrenched in 13 of its 64 districts. To identify the climatic factors associated with malaria in these areas, this study investigates the relationship between climatic variables and malaria incidence in the Naikhongchhari sub-district of Bandarban, Bangladesh, over a ten-year period from 2013 to 2022. Malaria case data were obtained from NGO registry books, while meteorological data on rainfall and temperature were sourced from the Bangladesh Meteorological Department. Cross-correlation analysis and multiple linear regression models were employed to explore temporal associations between climatic variables and malaria cases. The results reveal significant correlations between rainfall, temperature, and malaria incidence, with spikes in temperature and rainfall preceding increases in malaria cases. However, the study is subject to limitations, including potential inaccuracies in retrospective data collection and the omission of other relevant determinants of malaria transmission. Despite these limitations, the findings underscore the importance of considering climatic factors in malaria surveillance and control efforts. Further research is warranted to address these limitations and enhance our understanding of malaria dynamics in the study area and beyond.

4.1 Introduction

In their pursuit of a world free from disease, the World Health Organization (WHO) has aims to eventually eradicate malaria, with current efforts going toward elimination of the disease within individual countries (WHO, 2024). Global efforts have yielded promising results, with a number of countries successfully eliminating the disease within their borders. Over the past two decades, eleven nations have earned WHO's certification as malaria-free, signifying the interruption of indigenous malaria transmission for a minimum of three consecutive years, resulting in a total of 43 nations and one territory that have eliminated malaria (WHO, 2024). However, within the Southeast Asian Regional Office of WHO, nine countries, including Bangladesh, remain malaria-endemic. Since 2000, the number of countries in the region reporting fewer than 100 malaria cases, rose from six to 27 in 2021; however, during that time period, Bangladesh experienced a surge in indigenous cases in the endemic area (WHO, 2022). However, from 2000 to 2020, Bangladesh achieved a remarkable 93% reduction in malaria cases through a systematic, phased elimination strategy at the district level (Haldar et al., 2023).

Vector-borne diseases such as malaria are indeed heavily influenced by climatic factors, which not only enhance their transmission rate but also extend their geographic presence (Paaijmans et al., 2009). While temperature plays a crucial role in the survival of mosquitoes and the multiplication of the malaria parasite within the vector (Minakawa et al., 2006), additional environmental factors such as rainfall, humidity, wind patterns, and daylight duration also exert significant influence (Zhai et al., 2018). In regions with colder climates, mosquitoes and the malaria parasite have evolved strategies to survive during winter months, while in areas with extreme dry seasons, they adapt to persist through periods of reduced moisture (Martens et al., 1999). The circadian rhythm further affects mosquito behaviors such as feeding, resting, and oviposition, which are regulated by optimum times rather than ambient temperature alone (Martens et al., 1999). These complex interactions highlight the importance of considering the broader ecological context in malaria transmission dynamics (Dakorah et al., 2022; Koïta et al., 2012).

The disease is still endemic in 13 out of 64 districts, with over 90% of cases in Bangladesh reported in Cox’s Bazar and the Chittagong Hill Tract districts (CHTs) (National Malaria Control Programme, 2015). Strikingly, these districts defy conventional malaria topography, being at a higher elevation and having hilly terrain as opposed to the low-lying flat topography typically associated with malaria. This peculiar situation underscores the need for deeper research into the persistence of malaria in eastern Bangladesh, where topographic conditions are less favorable and cultural norms differ from the rest of the country. The average monthly maximum temperature of the CHTs falls between 25 and 34°C, indicating a sub-tropical

environment. Between 2032 and 3910 mm of rainfall is received annually on average, with the majority falling between May and September (ADB, 2001, Gafur, 2001).

In certain Sri Lankan districts, there are notable correlations between malaria cases and rainfall, both in short and long timeframes. While a causal link is plausible within a two-to-four-month lag, it becomes less likely with longer lags. For example, Amerasinghe et al. (1999) identified a 1.5-month lag between the peak abundance of *An. culicifacies* immature forms and malaria cases in a village in the Anuradhapura District. Similarly, Briët et al. (2008) found a positive correlation between malaria and rainfall with a two-month lag in most districts. A study found that rainfall occurring four weeks prior affects the correlation between malaria incidence and rainfall in subsequent weeks, suggesting an interaction effect between delayed rainfall and malaria (Wu et al., 2017).

There has been minimal research to explain this discrepancy in the distribution of endemic malaria in Bangladesh. When there is an outbreak, it usually takes the form of a cluster (Noé et al., 2018); these outbreaks are highly seasonal as well given the seasonality of precipitation. Prior research focuses on analyzing spatial patterns correlating environmental factors and malaria cases (S. Ahmed et al., 2013; Annister-Tyrrell et al., 2017; Shannon et al., 2016). Furthermore, public health officials require an understanding of the interacting role of public perceptions and environmental factors in order to continue pursuing malaria control and elimination. This study can guide proper policy implementation and help determine appropriate health interventions that are geared toward the factors promoting malaria transmission. In Eritrea, rainfall was identified as a direct driver of malaria with various lags (Lag 1, 2, 3, and 4) (Kifle et al., 2019). However, West Africa reported a negative association (Arab et al., 2014), and Ghana found an insignificant association (Darkoh et al., 2017). In China, while some studies have shown a close correlation between rainfall and malaria incidence, others have refuted such correlations (Zhou et al., 2010; Huang et al., 2011; Huang, Zhou, Zhang, Wang, et al., 2011; Zhang et al., 2010). Investigating how climatic variables interact with malaria incidence can enhance our understanding of this relationship (Erhart et al., 2005).

To effectively combat malaria in the CHTs, public health officials must comprehend this interplay between climatic variability, as the country works toward elimination of the disease. Therefore, this research aims to answer the following critical questions, with a focus on Bandarban within the CHTs:

- Are malaria cases temporally associated with climatic factors in the Chittagong Hill Tracts of Bangladesh?
- What climatic factors should be considered to combat malaria transmission in the Chittagong Hill Tracts of Bangladesh?

4.2 Methods

Malaria case data were sourced from the registry books of the NGOs working in the CHT districts to treat malaria cases. The record keeping of case data is still manual and for many sub-districts, records are incomplete. Only Naikhongchhari sub-district had a complete data record for a span of ten years between 2013 to 2022. Hence, the study period covered was from January 2013 to December 2022 ensuring comprehensive coverage of seasonal variations in climate and disease incidence. This study adhered to ethical guidelines and obtained necessary permissions from relevant authorities for data collection and analysis. Patient confidentiality and privacy were strictly maintained throughout the study process, and data were aggregated to the sub-district level for analysis.

The study was conducted in the sub-district of Naikhongchhari within the district of Bandarban in the CHTs. Meteorological data, including monthly rainfall and temperature measurements, were obtained from the Bangladesh Meteorological Department (BMD). There were two BMD weather stations in proximity of Naikhongchhari: Chittagong and Rangamati. The Chittagong station was closer to the Bay of Bengal and the surrounding areas had much less vegetation than Naikhongchhari, and therefore it did not share the same environmental dynamics of our study area. In contrast, the Rangamati station in Rangamati district is adjacent to the Bandarban district and both districts share similar environmental dynamics. Thus, the rainfall and temperature data were collected from Rangamati Station, over a span of 10 years from 2013 to 2022.

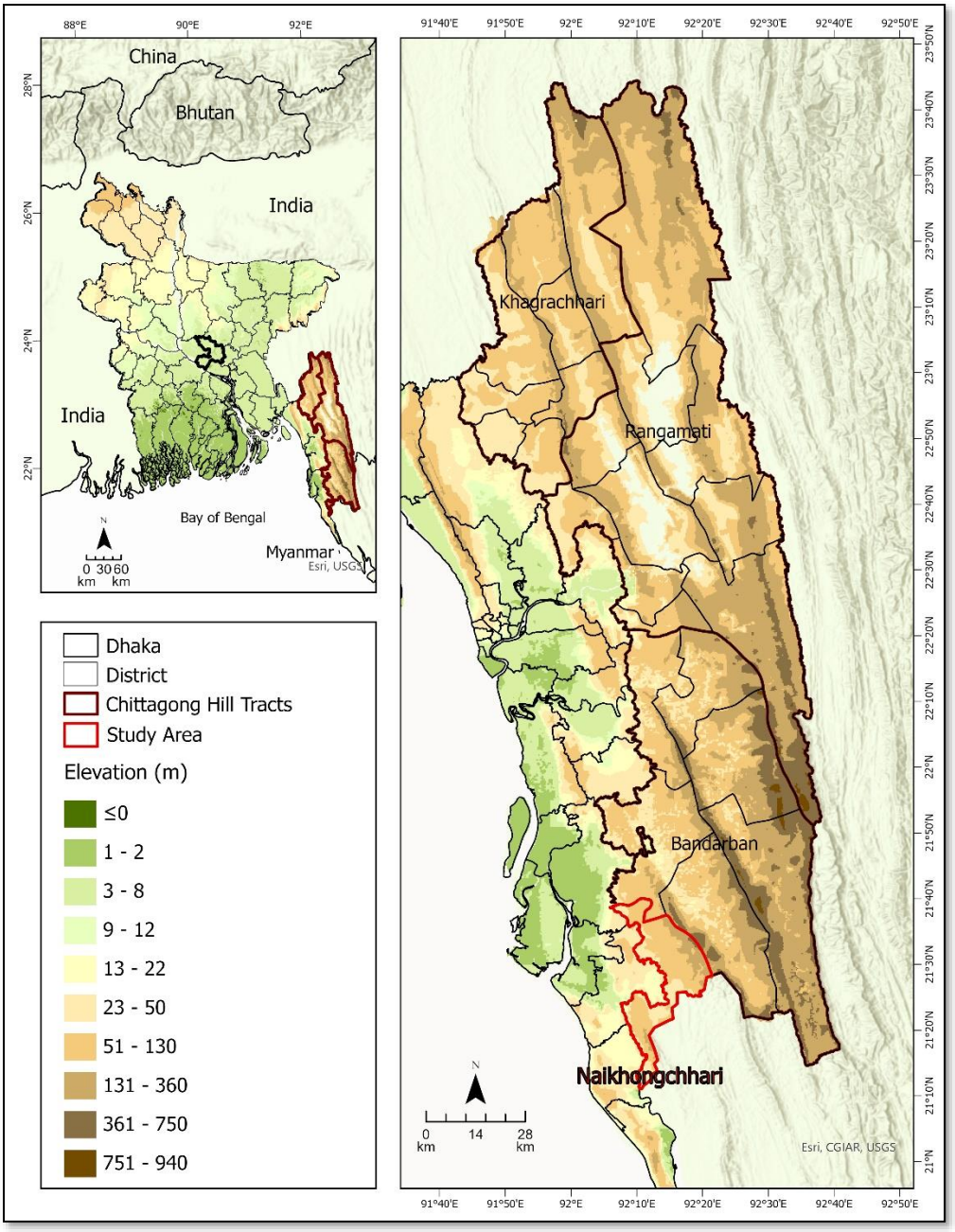


Figure 1 Study Area Map

The time series graph for malaria cases, rainfall and temperature strongly suggests a relationship between malaria cases and the climatic variables. Spikes in temperature and rainfall precede the spikes of malaria cases for every year over ten years (Figure 1). Therefore, to quantify these relationships across the time series, we employed a cross correlation analysis. To further validate the relationships acquired from cross correlation analysis, a multiple linear regression model with lagged climate variables was performed.

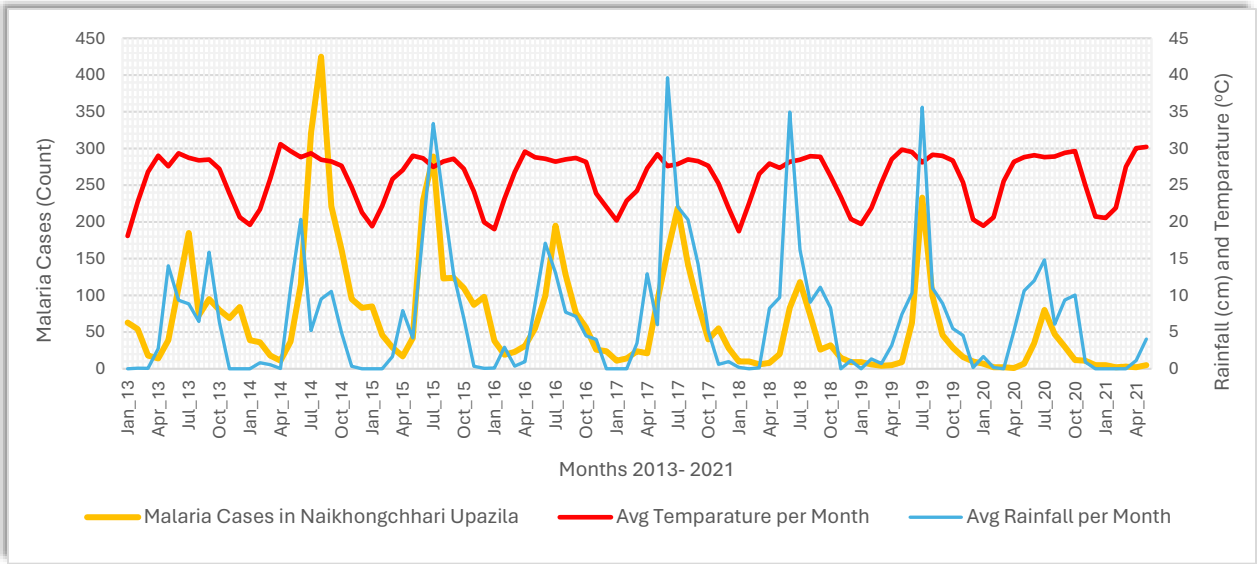


Figure 2 Trends in Rainfall, Temperature and Malaria Cases

Cross correlation analysis was employed to explore the temporal relationship between rainfall, temperature, and malaria cases. It is used to quantify the potential lagged associations between two time series or signals by measuring their correlation at different time lags (Horvatic et al., 2011; Vio & Wamsteker, 2001). In this study, we calculated the cross-correlation coefficients between monthly rainfall and temperature each with malaria cases, considering various lag intervals from one to 4 months. This lag time frame allows us to capture conditions prior to and during both the rainy and dry seasons, to determine if those time periods have an impact on malaria. Furthermore, this analysis allowed us to determine the time lag at which the climatic variables correlate most strongly with malaria incidence.

The Cross Correlation Function (CCF) values indicate relationship between the independent variable (rainfall or temperature) and dependent variable (malaria cases) at different time lags. It provides CCF values for the dependent variable in lags of leads (-1= lag, +1=lead). A positive CCF value suggests a positive correlation, while a negative value indicates a negative correlation.

To validate the analysis, a linear regression model was conducted to quantify the relationship between rainfall, temperature, and malaria cases while controlling for potential intervening variables (Intermediate lags). This linear regression model was constructed with monthly malaria cases as the dependent variable and rainfall and temperature individually as independent variables.

To explore temporal dependencies within the data, autocorrelation function (ACF) and partial autocorrelation function (PACF) were used. In our analysis, we utilized these functions to investigate whether there are significant spikes in the ACF or PACF plots at non-zero lags to identify if there are still

some systematic pattern or structure in the residuals that the model has not captured. The residual is often used in these analyses to evaluate the goodness-of-fit of a model to the data. If the residuals show significant autocorrelation (values outside the confidence bounds), it suggests that the model might be missing some temporal dependencies or seasonal effects.

All statistical analyses were performed using the R programming language in R Studio. Since malaria cases were non-linear, they were converted to the logarithm of the cases numbers. Descriptive statistics, including means, standard deviations, and correlations, were calculated to summarize the data.

4.3 Results

4.3.1 Descriptive statistics

The descriptive statistics of the variables are presented in Table 1. Across the time period, the data spans from a minimum of 18.09°C to a maximum of 30.59°C, with a median of 27.58°C and a mean of 26.02°C. Rainfall ranges from 0.0000 mm to 39.6333 mm, with a median of 4.5517 mm and a mean of 6.8485 mm. Malaria cases vary from a minimum of 1.0 case to a maximum of 425.0 cases, with a median of 38.0 cases and a mean of 65.2 cases. These statistics illustrate the distribution and central tendency of each variable, providing insight into the environmental conditions and disease prevalence within the studied region.

Table 1: Descriptive Statistics of Temperature, Rainfall, and Malaria Cases

	Average Temperature (ºC)	**Average Daily Rainfall (mm)**	**Malaria Cases**
Minimum	18.09	0.0000	1.0
1st Quartile	23.15	0.1724	12.0
Median	27.58	4.5517	38.0
Mean	26.02	6.8485	65.2
3rd Quartile	28.72	10.0323	87.0
Max	30.59	39.6333	425.0

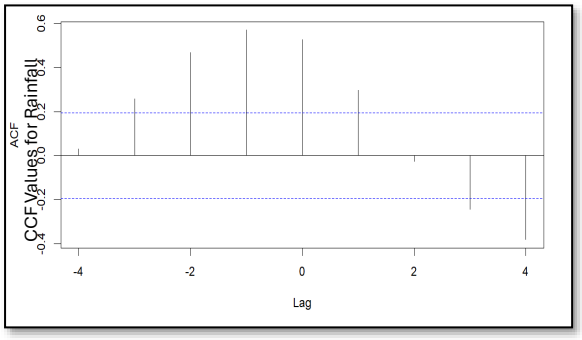
4.3.2 Time series analysis: Cross Correlation Analysis

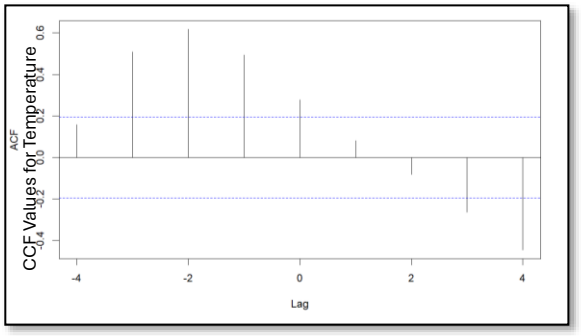
The cross-correlation analysis revealed statistically significant correlations between independent variable rainfall and dependent variable malaria cases at various lags. The CCF value for rainfall, computed at different lags, is presented in Table 2.

Table 2: Cross correlation Function (CCF) for Rainfall at Different Lags. The line at CCF 0.2 is the significant level. If a peak at any lag crosses over this value, it can indicate a possible association.

Lags	-4	-3	-2	-1	0

(A) Rainfall CCF	0.029	0.256	0.467	0.570	0.527
(B) Temperature CCF	0.157	0.508	0.617	0.495	0.277





In our analysis, we observed a positive correlation between rainfall and malaria cases at lags 3 to 1, with the strongest correlation occurring at a lag of 1 month (CCF = 0.570). Beyond lag 2 the CCF values decrease gradually. This relationship is also visible in the scatterplots (Figure: 3) where the highest peak is at lag 1 (t-1) and there are no significant peaks in scatter plot for rainfall at lag 4 (t-4).

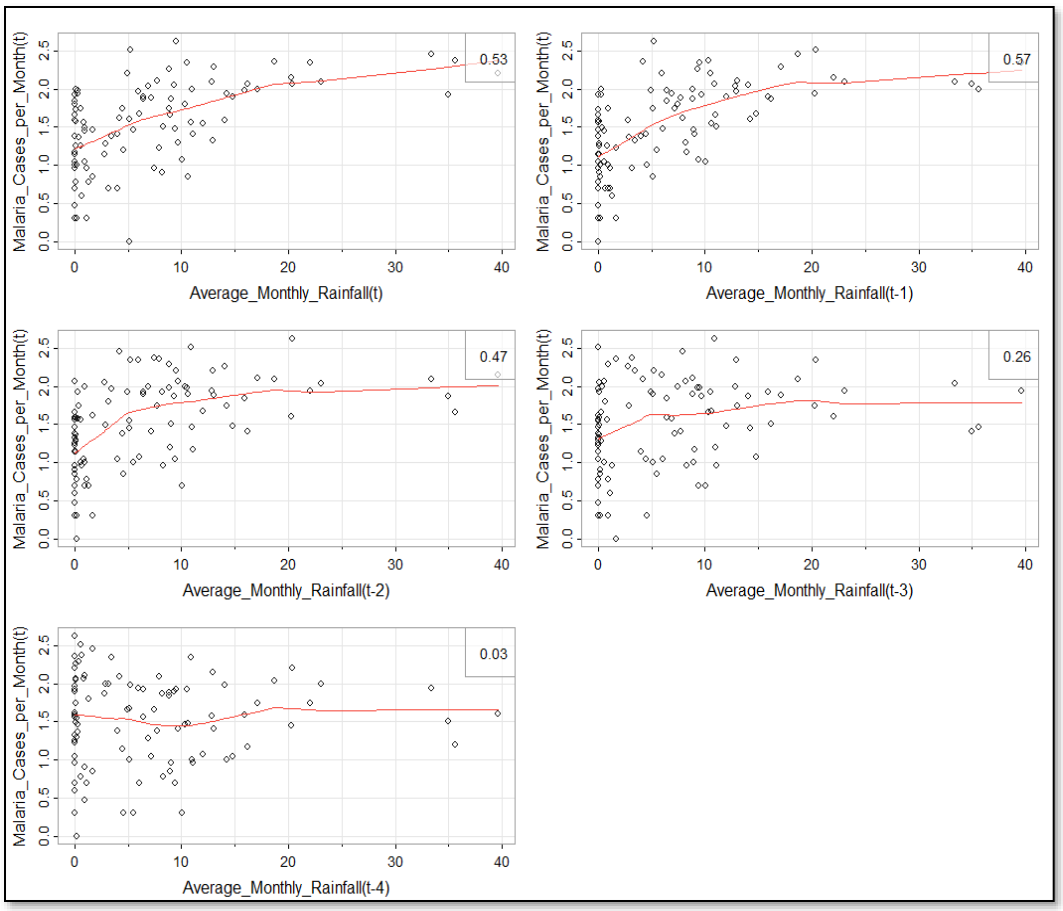


Figure 3 Scatterplots for Rainfall vs Malaria Cases. Here, t= 0 lag, t-1= 1 month lag, t-2= 2-month lag, t-3= 3-month lag, t-4= 4-month lag.

The same methods were employed to determine the relationship between temparature and malaria cases. At lag 0, the CCF value of 0.277 suggests a moderate positive correlation between temperature and its immediate past. Moving away from lag 0, the CCF values gradually decrease, indicating a weakening correlation between temperature and its past values as the lag increases. However, significant correlations persist at shorter lags, with the highest CCF value of 0.508 observed at lag -3. This indicates a strong positive correlation between temperature and its values three months prior (Figure: 4).

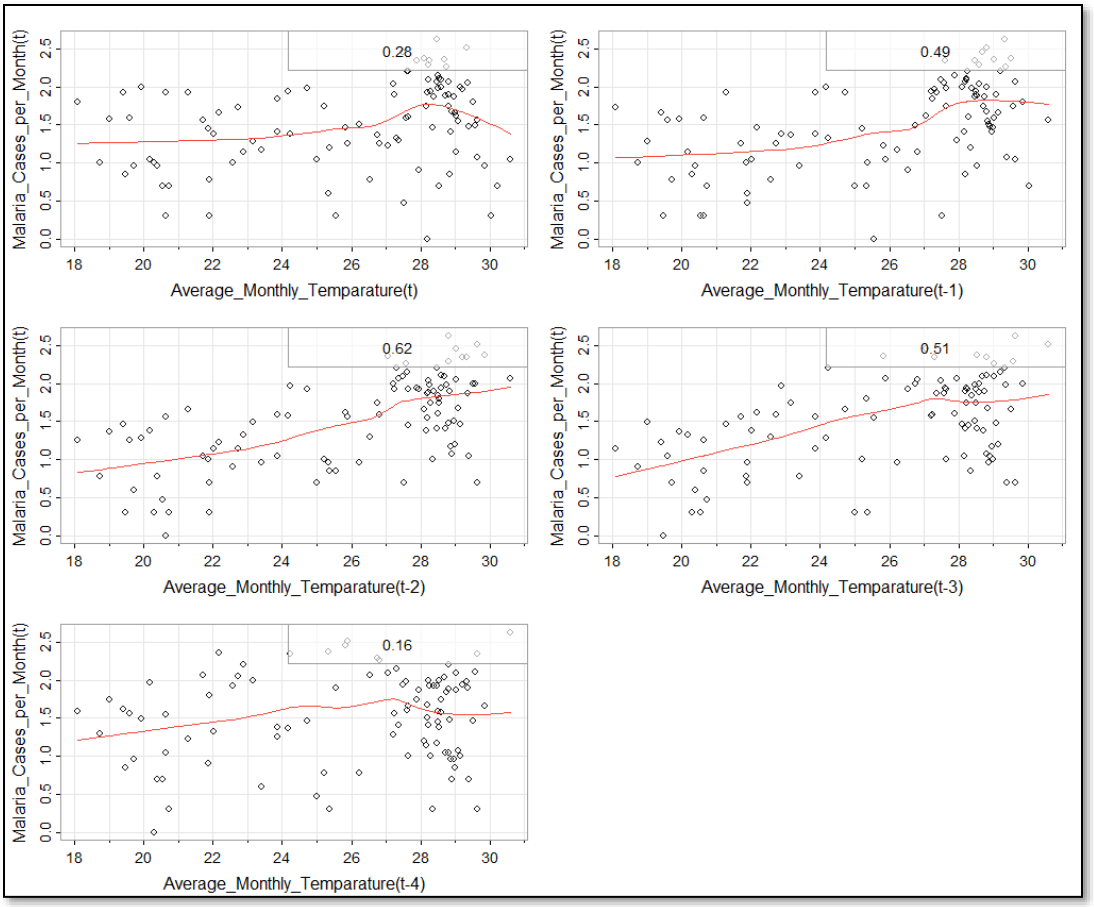


Figure 4 Scatterplots for Temperature vs Malaria Cases

4.3.3 Regression Coefficients and Residuals

The regression analysis was conducted to further investigate the relationship between the variables. For rainfall and malaria cases, considering the effect of rainfall at various lags. The model's coefficients and residuals are presented in Table 3.

Table 3: Regression Coefficients and Residuals for rainfall

Residuals:				
Min	**1Q**	**Median**	**3Q**	**Max**
-1.22125	-0.31527	-0.02738	0.31622	0.90535
Coefficients:				
Lag Variable	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
(Intercept)	1.088857	0.069793	15.601	$< 2 \times 10^{-16}$ ***
Rain	0.023515	0.006448	3.647	0.000438 ***
Rainlag1	0.018630	0.007215	2.582	0.011384 *
Rainlag2	0.012402	0.007216	1.719	0.089000`
Rainlag3	0.005693	0.006437	0.884	0.378765
Signif. codes: 0*, 0.001**, 0.01*, 0.05`**				

Residual standard error: 0.4416 on 93 degrees of freedom
Multiple R-squared: 0.4453
Adjusted R-squared: 0.4215
F-statistic: 18.67 on 4 and 93 degrees of freedom,
p-value: 2.716 X 10^{-11}

The regression coefficients represent the estimated change in malaria cases associated with a one-unit increase in the respective variables. The intercept term indicates the expected number of malaria cases when rainfall and its lags are zero. Since this is significant, it can be surmised that even when there are no rainfall malaria cases will still persist. The coefficient for rainfall (Rain) is statistically significant (p = 0.000438), suggesting that an increase in rainfall is associated with a positive change in malaria cases. Additionally, the coefficients for Rain lag 1 and Rain lag 2 are also statistically significant (p = 0.011384 and p = 0.089000, respectively), indicating a lagged effect of rainfall on malaria cases. The residuals, representing the differences between observed and predicted values, exhibit a range from -1.22125 to 0.90535. The residual standard error, an estimate of the variability of residuals around the regression line, is 0.4416.

The overall model fit is assessed by the multiple R-squared value (0.4453), indicating that approximately 44.53% of the variance in malaria cases can be explained by the independent variables included in the model. The adjusted R-squared value (0.4215) considers the number of predictors in the model, providing a more conservative estimate of the model's goodness of fit. The F-statistic (18.67) tests the overall significance of the regression model, with a corresponding p-value of 2.716e-11, indicating that the model as a whole is statistically significant.

Moving towards the effect of temperature, the coefficient for temperature (Temp) is 0.07040 with a p-value of 0.0193, indicating statistical significance. This suggests that for every unit increase in temperature, there is an associated increase in malaria cases. Thus, higher temperatures are positively correlated with higher malaria incidence. Temperature lagged by one month (Templag1) and two months (Templag2) do not show statistically significant effects on malaria cases (p = 0.5377 and p = 0.1764, respectively). This suggests that temperature from one- or two-months prior does not significantly influence current malaria incidence. However, temperature lagged by three months (Templag3) has a statistically significant positive effect on malaria cases (coefficient = 0.06114, p = 0.0366). This indicates that temperature from three months ago is associated with an increase in malaria cases in the current month.

The multiple R-squared value of 0.4637 indicates that approximately 46.37% of the variance in malaria cases can be explained by the variables included in the model. The adjusted R-squared value of 0.4407 provides a more conservative estimate of model fit, considering the number of predictors in the model. The F-statistic of 20.11 with a p-value of 5.882×10^{-12} indicates that the overall model is statistically significant,

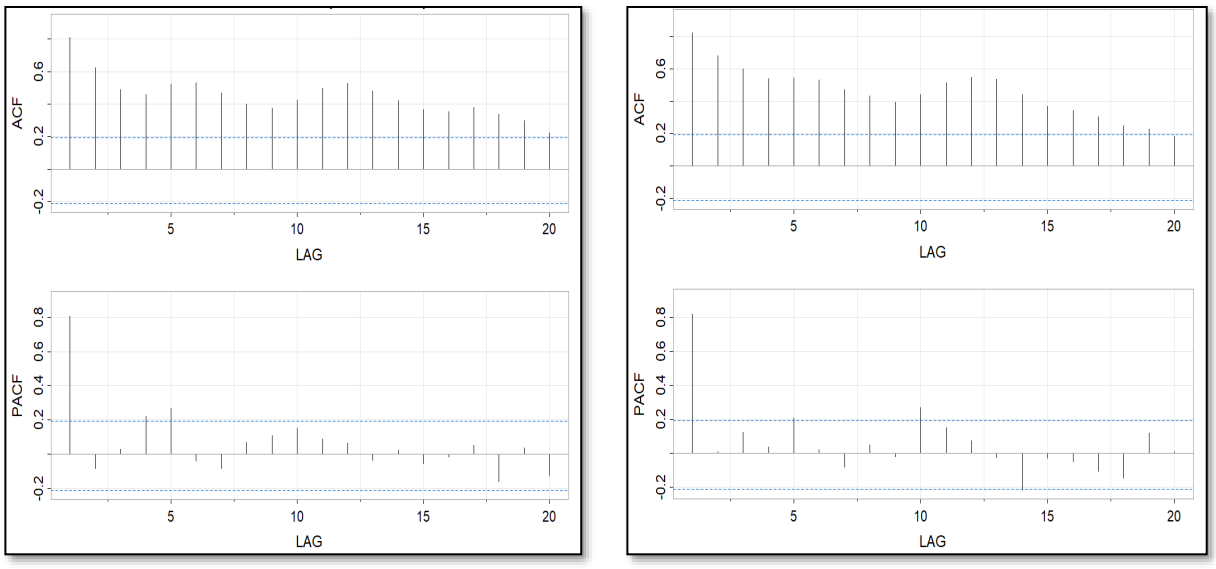
suggesting that at least one of the predictors in the model significantly contributes to explaining the variance in malaria cases.

The residuals represent the discrepancies between observed and predicted values of malaria cases. They range from -0.94778 to 0.72507, indicating the extent of prediction error. The residual standard error of 0.4342 provides a measure of the variability of residuals around the regression line.

Table 4: Regression Coefficients and Residuals for Temperature

Residuals:				
Min	**1Q**	**Median**	**3Q**	**Max**
-0.94778	-0.26874	0.04516	0.29841	0.72507
Coefficients:				
Lag Variable	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
(Intercept)	-2.83813	0.57545	-4.932	3.55×10^{-6} ***
Temp	0.07040	0.02958	2.380	0.0193 *
Templag1	-0.02993	0.04840	-0.619	0.5377
Templag2	0.06562	0.04817	1.362	0.1764
Templag3	0.06114	0.02882	2.121	0.0366 *
Signif. codes: 0*, 0.001**, 0.01*, 0.05`**				
Residual standard error: 0.4342 on 93 degrees of freedom				
Multiple R-squared: 0.4637				
Adjusted R-squared: 0.4407				
F-statistic: 20.11 on 4 and 93 degrees of freedom				
p-value: 5.882×10^{-12}				

Our findings revealed notable patterns in the ACF and PACF values for the rainfall test (Figure 5a). Specifically, the ACF values gradually declined as the lag increased, indicating a diminishing correlation between the variables as we moved further back in time. However, we observed significant correlations at shorter lags, with the highest ACF value recorded at lag 1, suggesting a strong positive correlation between the variables and their immediate past. Similarly, the PACF values exhibited distinct patterns, with high values at lag 1 indicating a direct relationship between the variables and their first lag. Beyond lag 1, the PACF values showed more variability, suggesting the presence of complex dependencies that may require further investigation.



(a) *(b)*

Figure *5 Residuals* for *rainfall (a) and* temperature *(b)* data (values over 0.2 are significant)

For the residuals in temperature (Figure 5b), the ACF values remain relatively high up to lag 12 and it is higher at shorter lags. There is a gradual decline in ACF values as the lag increases. Significant PACF values are observed at various lags, with the highest value recorded at lag 1.

4.4 Discussion

The findings of this study underscore relationship between climatic variables and malaria incidence in the Naikhongchhari sub-district of the Bandarban district in the Chittagong Hill Tracts. We observed significant correlations and lagged effects between rainfall, temperature, and malaria cases, providing insights into the dynamics of malaria transmission in this region. Therefore, we can determine that climatic factors such as rainfall and temperature in the endemic districts influence malaria transmission. Our cross-correlation analysis revealed evidence of a temporal relationship between rainfall and temperature individually with malaria cases. For both rainfall and temperature, the CCF values for lags 0 to 3 were significant, suggesting a predictive relationship. For validation the regression model used only 0 to 3 months lags, to identify which of the lags were significant.

At lag 0, the CCF value remains high (CCF = 0.527), indicating a concurrent relationship between rainfall and malaria cases, supporting the notion that rainfall may directly influence malaria transmission. The high peak for lag 1 (t-1) suggests that increases in rainfall precede increases in malaria cases by approximately one month, indicating a potential predictive relationship. Beyond lag 2 the CCF values decrease gradually, indicating a weakening correlation between rainfall and malaria cases as the lag increases. Meaning that

malaria cases are less likely to be affected by rainfall preceding over two months. During validation the regression model showed that direct correlation at 0 lags and a one-month lag correlation were significant. These findings coincide with many other studies such as by Wu et al.- when rainfall is low at the fourth week lag, malaria risk increases with subsequent rainfall, indicating that rising rainfall levels promote malaria transmission when preceding rainfall is low (Wu et al., 2017). Higher rainfall leads to a greater relative risk but a shorter lag time for malaria cases (Wu et al., 2017). In another study, rainfall showed a positive correlation with malaria occurrences at lag 0 and lag 2 months, indicating an increased risk of malaria transmission during rainy periods and following a decrease in rainfall at the end of the second month lag (Dabaro et al., 2021). However, in many countries different lag periods were noticed, for instance, a study in Kenya noted an increased malaria incidence with a two-month lag in rainfall (Kipruto et al., 2017), while research in southwest Ethiopia found a positive correlation between mean rainfall and malaria incidence at lag periods of two to four months (Sena et al., 2015).

Similarly, temperature exhibited a significant correlation with malaria cases, albeit with distinct lag patterns. While immediate temperature measurements showed moderate positive correlations with malaria cases, stronger associations were observed at shorter lags, particularly at lag -2 months. This suggests that temperature fluctuations from two months prior have a more pronounced effect on current malaria incidence. However, during validation, the regression model showed that a direct correlation and lags at 1 and 3 months are statistically significant. Temperature is a critical parameter in mosquito development, biting, and survival, with warmer temperatures increasing infection rates as mosquitoes reproduce faster, thereby amplifying the likelihood of infection after a mosquito bite (Le et al., 2019). These findings align with the range found in the study by Le et al. which showed that although the specific effect of temperature on the incidence rate ratio (IRR) of malaria increased at a two-month lag, the cumulative IRR significantly increased at lag periods of one to four months. This increase in cumulative IRR may be attributed to the heightened multiplication rate due to global warming, which extends the mosquito breeding season (Le et al., 2019).

Despite the high temperature values compared to the optimal temperature for malaria transmission of 29°C, the lagged effects of temperature provide sufficient time to design interventions to interrupt malaria transmission (Shapiro et al., 2017). This finding aligns with previous studies demonstrating how temporal disease risk shifts in response to temperature changes, with an increase in maximum temperature significantly affecting malaria incidence rates in the current and subsequent months (Beck-Johnson et al., 2017; Chuang et al., 2017).

In the regression analysis the intercept value was significant for both independent variables indicating that even with the presence of the average rainfall and temperature of the area, malaria cases will still be present.

This suggests that there are other factors present in the CHTs that play a significant role in malaria transmission. However, regarding the lag values, interventions should be placed keeping in mind that malaria cases will spike 1 or 2 months after the first hit of monsoons. Responsible authorities should prepare to combat malaria with this timeline in mind.

Climatic factors play a crucial role in malaria transmission by influencing vector abundance, survival, and parasite maturation (Teklehaimanot et al., 2004). Therefore, according to our findings, prevention interventions should be implemented during the lag periods found in this study for the climatic variables. These lags are important because the mosquitoes cannot mature without temperature and moisture both being present. In some years the monsoons may arrive sooner or later than expected, temperature increase is more or less stable. In the endemic area cases spike between may through august depending on this arrival of monsoon (Figure 2). We can now forecast that one month after the arrival of the monsoons the outbreaks would be the highest and that's when to focus on preventative interventions and start preparing to combat the outbreaks through replenishing testing kits, medicine etc. Since temperature spikes precede rainfall spikes, preparation should intensify following the first rainfall increase. This is the optimal time for awareness campaigns and educational efforts, encouraging community members to identify and mitigate mosquito breeding zones. Intervention protocols should be designed so that authorities concentrate manpower and logistics after the initial temperature rise, focusing on treatment preparation and awareness campaigns following the onset of monsoon rains. Anticipating a high number of cases a month after the monsoon's arrival allows for better resource management, reducing waste and ensuring efforts are distributed effectively throughout the year.

4.5 Limitations

The primary limitation of this study is the reliance on retrospective data from NGO registry books, which may be subject to incomplete or inaccurate recording of malaria cases. Despite efforts to ensure comprehensive coverage by focusing on a sub-district with complete data records, the potential for missing or misclassified cases cannot be entirely ruled out. Furthermore, while the analysis incorporated meteorological data, other potential determinants of malaria transmission, such as vector density, human behavior, and socioeconomic status, were not included due to data constraints. This may have resulted in an incomplete understanding of the factors driving malaria incidence in the study area. Lastly, the study's observational nature precludes causal inference, and although statistical methods were employed to explore associations between variables, the possibility of unmeasured confounding cannot be fully addressed. Overall, while this study provides valuable insights into the relationship between climatic variables and malaria incidence, its findings should be interpreted cautiously within the context of these limitations.

4.6 Recommendations and future research opportunity

Moving forward, it is imperative to conduct more extensive research that incorporates a broader range of determinants, including interventions, environmental factors, and socio-demographic variables. Standardization of indicators and reporting practices would facilitate comparability between studies and enhance the robustness of malaria risk assessments. Additionally, future studies should explore diverse environmental and population settings to capture the contextual contributions to malaria risk comprehensively.

Over the past decades, there have been unprecedented changes in ecosystems and climate, with significant implications for human health, particularly regarding the potential increase in the distribution of vector-borne diseases such as malaria (McMichael, 2013). Malaria transmission necessitates interaction between the host, vector, and parasite. The parasite, which completes its life cycle inside the mosquito and human host, cannot develop outside a specific temperature range, varying depending on the Plasmodium species. Strategies have evolved, such as those employed by P. vivax to survive winters in colder climates (Rossati et al., 2016). Recommendations for future research on malaria include conducting more comprehensive studies that examine various determinants of malaria, including interventions, environmental factors, and socio-demographics. Researchers should explore diverse environmental and population settings to better understand contextual contributions to malaria risk. Standardization of indicators is essential to improve comparability between studies and ensure a cohesive approach to managing and reporting results.

Environmental variables that have consistently shown a relationship with malaria risk should be incorporated into future studies assessing the effects of climate and interventions such as land use and landcover usage etc.. This will facilitate data pooling and enable clear descriptions of variables, categorizations, timescales, units of measurement, and lagged effects. A comprehensive and systematic description of interventions is crucial for understanding the types of interventions studied and their effectiveness. Detailed descriptions of interventions, context, and actors involved are necessary to explain the success or failure of interventions (Ruggiero et al., 2017).

4.6 Conclusion

The climatic variables- rainfall and temperature are associated with the endemic nature of malaria in the CHTs. The timeframe in which temperature and rainfall spike each year is of key importance and can be used to predict malaria case peak periods in the endemic region. Three months after the spike in temperature and one after the spike in rainfall is when a peak in cases can be forecasted. Human resources, testing kits, treatment products and awareness campaigns should be geared towards this timeframe so that the vulnerable

community is prepared to combat the disease. Every year, the lags in rainfall and temperature have to be monitored for improved management of the disease in the area.

In conclusion, advancing our understanding of the complex interplay between climatic factors and malaria transmission is essential for developing targeted interventions and mitigating the disease's burden. By integrating multidisciplinary approaches and fostering collaboration across diverse stakeholders, we can enhance our ability to combat malaria and improve public health outcomes globally.

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Chapter 5: Conclusion

Malaria has been a significant public health issue in Bangladesh, but concerted efforts over the years have led to remarkable progress in controlling and reducing the disease. The country has seen a dramatic decrease in malaria incidence, especially from the late 2000s to the present. In 2019, the malaria incidence rate in Bangladesh was recorded at 1.2 cases per 1,000 population. This is a significant reduction, reflecting the success of various malaria control programs. By 2020, the number of malaria cases had fallen by 93% from the 84,690 cases reported in 2008 to just 6,130 cases (Haldar et al., 2023, Sinha et al., 2020) . Despite these national successes, malaria remains a substantial health issue in specific regions, particularly in the Chittagong Division. This division accounts for over 85% of the estimated 150,000-250,000 annual malaria cases in the country, with 80% of these cases occurring in the CHT (Maude et al., 2012).

The geographical and socio-economic characteristics of the CHTs, such as its hilly terrain, dense forests, and the presence of ethnic minority groups with limited access to healthcare, contribute to the persistence of malaria in this area. Social and climatic factors associated with malaria endemicity in the Chittagong Hill Tracts (CHTs) of Bangladesh encompass a range of elements. The study delves into the climatic factors associated with the disease focusing on forecasting outbreaks using lags of rainfall and temperature, and the socio-cultural fabric influencing malaria persistence, with particular focus on knowledge, attitudes, and practices regarding prevention and treatment.

The socio-cultural analysis revealed that jhum Cultivation increases exposure to mosquitoes. Strategies should be developed to reduce this exposure, such as providing protective clothing, encouraging alternative farming practices, or establishing mosquito control measures around Jhum cultivation areas. Communities are unaware of effective malaria treatments. Tailored education campaigns that respect and integrate local customs and languages are essential to improve awareness and acceptance of malaria prevention and treatment protocols. Since, Ethnic minorities suffer the most have limited involvement in the creation and implementation of health policies. Empowering these communities to participate actively in determining prevention protocols can ensure the measures are culturally appropriate and more widely accepted. Addressing these social tensions through community-building activities and inclusive dialogue can foster a more unified approach to malaria prevention and control. Improving literacy rates and providing education about malaria can help communities understand and adopt effective prevention measures. Educational programs should also focus on raising awareness about the importance of health-seeking behavior. While ITNs are crucial, relying solely on them is insufficient. A comprehensive strategy that includes indoor residual spraying, environmental management, and the use of larvicides, among other measures, should be implemented to provide varied and effective prevention.

Climatic factors, including rainfall and temperature, also play a crucial role in malaria transmission dynamics, with significant correlations observed between climatic variables and malaria incidence. Malaria transmission is heightened during the arrival of summer and monsoon seasons. Prevention interventions must be intensified during these periods, with timely distribution of ITNs, increased health surveillance, and rapid response teams to handle outbreaks. Especially with peaks in rainfall, it can be anticipated that there will be a spike in malaria incidence after the next four weeks. This is when the socio-cultural factors affecting malaria cases in the endemic region should be addressed and resolved with increased manpower and logistics. By addressing these socio-cultural and climatic factors with targeted, inclusive, and context-specific strategies, malaria transmission in the Chittagong Hill Tracts can be significantly reduced.

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Appendices

Appendix 1: KAP Survey Questionnaire

O1. Name of village _____

O2. Part of a tribe?

- Yes
- No

O3. Location (Latitude and Longitude) _____

S1. Roof of the house

- Straw
- Thatch
- Tin
- Concrete
- Cement
- Other _____

S2. Partition of the house

- Jute stick
- bamboo
- Tin
- Concrete
- Cement
- Mud
- Curtain
- Other _____

S3. Openings between roof and walls

- Present
- Absent

H1. Age of respondent _____

H2. Gender

- Male
- Female
- Other

H3. Occupation _____

H4. Educational level:

No formal education

- Primary
- Secondary
- Higher Secondary
- Tertiary

H5. Number of family members _____

H6. Monthly income of family _____

H7. Number of kids in the family: (write the age in parenthesis) _____

H8. Age of members who've been affected by malaria _____

S4. Domestic animals

- Present
- Absent

S5. Resting places for domestic animals (Shared space with animals)-

- Inside house
- Outside house

S6 Grass/bushes around house

- Present
- Absent

K1. How is malaria transmitted?

_____
_____
_____

K2. What are the symptoms of malaria?

_____
_____
_____

K3. How can you prevent malaria?

_____
_____
_____

K4. Where is treatment for the disease provided?

_____
_____
_____

K5. Which of the following do you think is an obstacle to the prevention of mosquito breeding or mosquito-borne diseases? (Unawareness / financial condition/lack of public attachment/ lack of governmental approaches)

_____
_____
_____

K6. How many times have you noticed malaria infections during the year?

_____
_____
_____

K7. How far is the closest healthcare center from your house?

_____
_____
_____

K8. How is the management of malaria cases?

_____
_____
_____

A1. We can prevent mosquito-borne diseases.

- Agree
- Disagree
- Somewhat agree
- Not sure

A3. Mosquito-borne diseases is a problem in Bangladesh.

- Agree
- Disagree
- Somewhat agree
- Not sure

A4. Mosquito-borne diseases can be fatal.

- Agree
- Disagree
- Somewhat agree.
- Not sure

A5. We can be affected by mosquito-borne diseases.

- Agree
- Disagree
- Somewhat agree
- Not sure

A6. More awareness should be generated to prevent mosquito-borne diseases.

- Agree
- Disagree
- Somewhat agree
- Not sure

A7. The government is taking enough steps to prevent mosquito-borne diseases.

- Agree
- Disagree
- Somewhat agree
- Not sure

A8. Alongside the government every citizen should work to prevent mosquito-borne diseases.

- Agree
- Disagree
- Somewhat agree
- Not sure

A9. Reasons for agreement/disagreement

_____
_____
_____

P1. How often do you and your family members spend time outside after 5 pm? How do you spend time?

_____
_____
_____

P2. Do you think your surroundings have mosquito breeding place?

_____
_____
_____

P3. Do you kill mosquitoes as you notice them?

- Yes
- No

P4. Do you use any of the following to prevent mosquito biting?

- Mosquito coil
- Insecticide spray
- Fan

- Generating Smokes
- Bed net
- Wear full sleeves dress
- Mosquito repellent cream
- Nets in windows (window screens)
- Electric bat
- Do not use anything
- Other _____

P5. Do you keep your surroundings clean?

- Yes
- No

P6. Do you contact your local government office/administration if you feel the increase in the number of mosquitoes?

- Yes
- No

P7. Do you store water in the house? How?

_____

P8. Do you check and clean water storage in your house such as pot, flowerpot, refrigerator tray, AC?

- Yes
- No

P9. How often do you drain stagnant water or moist areas around your home?

- Never
- Once in a while
- Most of the time
- Always

P10. Do you remove any pots, coconut shells, plastic packets, plastic cups, or anything else besides the road that may contain water?

- Yes
- No

P11. How do you describe your habit of trimming bushes around your home?

- Never
- Once in a while
- Most of the time
- Always

P12. Do you sleep in an insecticide-treated mosquito net (ITN) or a regular bed net?

- ITN
- Regular
- Do not use

P13. Do all family members use bed nets? _____

P14. How many people sleep under one mosquito net? _____

P15. How often do you notice mosquitos inside the bed net?

- Never
- Once in a while
- Most of the time
- Always

P16. How long have you been using the same mosquito net? _____

P17. Are there holes in the bed net?

- Yes
- No

P18. How do you describe your habit of checking for holes/repair mosquito nets?

_____

P19. Where did you buy/collect your bed net?

_____

P20. Reasons for not using mosquito nets regularly.

_____

Appendix 2: KII Questionnaire

1. Why is malaria so problematic in the CHTs rather than rest of the country?

_____
_____
_____
_____
_____
_____

2. Is the socio-economic background of the locals in the area important the spread of malaria?

_____
_____
_____
_____
_____
_____

3. Which factors play a role in mosquito transmission? For example, socioeconomic characteristics, environmental setup, the remoteness of the area, accessibility issues etc.

_____
_____
_____
_____

_____

_____

4. Where is treatment for the disease provided? Is it sufficient? Do you think there should be more healthcare centers catering towards this?

_____

_____

_____

_____

_____

_____

5. What do you think is an obstacle to the prevention of mosquito breeding or mosquito-borne diseases?

_____

_____

_____

_____

_____

_____

6. How many times have you noticed malaria infections during the year? How would you explain the pattern?

_____

_____

_____

_____

_____

_____

7. How is the management of malaria cases?

_____

_____

_____

_____

_____

_____

8. What are your thoughts about the awareness generated to prevent mosquito-borne diseases, especially malaria?

_____

_____

_____

_____

_____

_____

9. Do you think the government is taking enough steps to prevent mosquito-borne diseases. Why do you think so?

_____

_____

_____

_____

_____

_____

10. Should there be efforts from every citizen alongside the government to prevent mosquito-borne diseases?

_____

_____

_____

_____

_____

_____

11. Do think we can eliminate malaria?

_____

_____

_____

_____

_____

_____