



# Malaria in Humanitarian Crisis Settings

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## ABSTRACT

Malaria remains one of the most serious public health threats worldwide, particularly in humanitarian crises marked by displacement, conflict, and the collapse of healthcare systems. This paper explores the multifaceted response to malaria in emergencies, emphasizing the role of international organizations, innovative technologies, and research advancements in control and eradication efforts. The World Health Organization (WHO) has established coordination mechanisms to strengthen malaria responses through resource mobilization, capacity building, and improved communication. Similarly, Médecins Sans Frontières (MSF) continues to provide emergency medical assistance to vulnerable populations in over 70 countries, ensuring access to life-saving treatment during crises. The study also examines innovative approaches such as digital technologies, artificial intelligence, geospatial mapping, and mobile health systems, which are enhancing disease surveillance and timely intervention. Research and development remain critical, particularly in vaccine innovation, genetic studies, and the creation of new vector control tools. Policy recommendations underscore the need for strong health systems, improved coordination among humanitarian agencies, and sustained funding to close research and operational gaps. The discussion on vaccine and genetic research highlights promising developments like RTS,S/AS01 (Mosquirix) and genetic mapping of malaria parasites, offering new hope in controlling transmission. Ultimately, a holistic approach that integrates technology, policy, health system strengthening, and collaborative action is essential to reduce malaria's global burden, especially in crisis-affected settings.

**Keywords:** Malaria, Humanitarian Crises, World Health Organization, Médecins Sans Frontières, and Vaccine Development.

## INTRODUCTION

Malaria is a mosquito-borne infection caused by several species of single-celled Plasmodium parasites. Transmitted only through the bite of female Anopheles mosquitoes, malaria symptoms are characterized by cycles of fever, headache, chills and vomiting [1, 2]. Malaria episodes commonly occur several times per year, and each episode, depending on the Plasmodium species involved and the management of the individual case, can last anywhere between several days to weeks. Malaria remains a significant global health problem, with an estimated 2.5 billion people nearly 40% of the world population living in areas where malaria is endemic [1]. Severe morbidity typically affects children and pregnant women, while severe and complicated malaria can be fatal for individuals of any age if left untreated. Malaria causes approximately 429,000 deaths annually worldwide, including a large number of childhood deaths in sub-Saharan Africa [2].

### Understanding Humanitarian Crises

Humanitarian crises are defined by exceptional suffering and threat; they require external assistance and frequently result in mass population displacement [2]. Although civil war precipitates many emergencies, natural disasters, complex emergencies, and widespread food shortages can also generate similar impacts [1]. Humanitarian crises pose significant hazards for local populations, including heightened risk of malaria. Crises intensify exposure to malaria vectors by forcing populations into overcrowded settlements with inadequate shelter, sanitation, and water [2]. Access to preventive measures and treatment declines, while local health

infrastructure becomes fragmented or collapses [1, 2]. Population displacement and increased population mixing cause shifts in malaria epidemiology. Additionally, changes to the local environment due to large-scale population movement may exacerbate transmission [1].

### **The Intersection of Malaria and Humanitarian Crises**

Malaria is a major cause of human morbidity and mortality [1]. A malaria-like illness is documented in the medical literature as early as 2700 BC and probably existed much longer as the dominant relationship between humans and *Plasmodium* is thought to date back 100 million years [3]. Malaria affects human health and economic development through the direct impact on health, the productivity losses within the agriculture and economic sector as a whole, poor crop yield and the cost of treatment and prevention [4]. In 2009, there were over 243 million cases and approximately 863,000 deaths of which most occurred in young children living in Africa. The economic cost to Africa is estimated at millions of US dollars annually which place a considerable strain on a region with limited financial resources. Humanitarian crises, such as fragile states, conflict, displacement, natural disasters and food insecurity, increase the risks from malaria [1, 3, 4]. The combined effects of population displacement/mobility, resettlement, collapse or disruption of health services, food insecurity and malnutrition, increased breeding sites, poor shelter, infrastructure destruction and increased vector-human contact all have the potential to amplify malaria transmission in both high- and low-endemicity populations [3]. Malaria transmission persists and disproportionately affects displaced communities relative to host communities; children within IDP sites have a significantly higher risk of contracting malaria than children in more stable communities and displaced persons experience limited access to services and low levels of use of vector prevention methods [4, 3, 1].

### **Epidemiology of Malaria in Crisis Settings**

Humanitarian crises present exceptional challenges to the delivery of public health services, and malaria is frequently a major threat to human health in these settings [3]. The epidemiology of malaria is well understood and has been documented comprehensively by numerous groups; selected examples of relevant data are presented here together with an emphasis on the additional challenges to malaria control in humanitarian humanitarian crisis settings [1]. Malaria transmission throughout the tropics is highly variable both spatially and over time and is often characterized by large epidemics, resulting in substantial disease burden for affected communities and fatalities among displaced populations [1]. Exposure to malaria in those living in crisis-affected communities or in displacement camps is almost inevitable. The risk of infection with *Plasmodium* is a function of transmission intensity, immunity and access to effective prevention and treatment [3]. Two general categories of people are particularly at risk during humanitarian crises children under five years and nonimmune individuals of any age who enter a highly malarious area [3]. Displacement also results in increased mobility, which may link together communities with different levels of immunity and transmission intensity, potentially seeding outbreaks or altering the dynamics of ongoing local transmission. Malaria transmission is also affected by broadscale changes to human geography and land use, as well as a reduction in malaria control activities [3].

### **Transmission Dynamics**

Malaria transmission patterns are highly sensitive to changes in human population distribution and population immunity [5]. The epidemiology of malaria in any particular area will be determined by: local malaria vector species and their behaviors (e.g., indoor or outdoor biting, preferential biting times, and preference for human rather than animal blood meals); the intensity of malaria transmission; and the degree of pre-existing immunity in the human population [5]. Malaria transmission can be unstable in situations where the population has a poorly developed or waning immunity to malaria [5]. Factors affecting vulnerability and the potential for epidemic outbreaks include the types of parasites present, the local vector and its efficiency, climate patterns, effective treatment coverage, population density, levels of malnutrition, and other concurrent diseases such as HIV [1]. Populations at high risk of malaria morbidity and mortality in humanitarian emergencies include newcomers from non-malaria-endemic areas, immunologically naïve children and pregnant women, and individuals with reduced access to preventive or curative health services [5]. Displacement and population movement have been associated with increased malaria transmission and outbreaks, through multiple mechanisms including transmission of parasites into more susceptible populations, increased exposure to more efficient vectors, movement to higher transmission areas, disruption of malaria control programmes, and disruption of health services [1]. Ecosystem changes such as food shortages, deforestation and other environmental changes may also affect transmission patterns [1]. Decreasing immunity among displaced populations who have been settled in low transmission areas for a prolonged period may lead to more severe malaria following the resumption of exposure [1].

### **At-Risk Populations**

Four main groups are at increased risk of malaria infection and severe disease during humanitarian crises [1]. These groups are: Internally displaced persons (IDPs) and refugees; host communities; pregnant women; and

children less than five years of age [3]. In addition, migrants and mobile populations those are poor or have limited access to health services face a very high risk of infection and of developing clinical disease [1, 4]. Malaria transmission during humanitarian crises also varies according to the location of the crisis in relation to malaria transmission and the immunity profiles of the affected population. In areas of high endemicity, displaced populations who are settled or display limited mobility are most at increased risk [1]. Migration of non-immune individuals from non- to high-transmission areas can lead to the emergence and development of large-scale epidemics. Emergency conditions, such as destruction of shelter and housing, lack of bed net and repellents, and displacement of non-immune populations to highly endemic areas, can all increase the risk of infection and disease [4]. Finally, populations displaced from endemic to non- or low-transmission areas are likely to face increased risk of epidemic outbreaks during the absence of control measures [4].

### **Impact of Humanitarian Crises on Malaria Transmission**

Pastoralist and internally displaced groups are most vulnerable to epidemics of malaria. Population displacement exposes non-immune groups to unstable malaria and presents a large pool of parasites to vector populations increasing transmission intensity [3, 5]. Increased movement also assists dissemination of drug resistant parasites drawn from areas of high drug pressure [4, 6]. The displacement of large populations changes the geographical range of the parasite and offers access to groups with no semi-immunity. As vector populations adapt and re-establish, changes in species distribution, abundance, seasonality and contact with humans alter transmission dynamics. The collapse of health infrastructure and surveillance systems, combined with the insecurity associated with protracted conflict, restrict the implementation of vector control. Refugee and stranded migrants often occupy sites with elevated risk of mosquito breeding [6]. This may result from poorly planned housing or access to sites with limited political or economic influence where clearance of breeding sites, insecticide spraying or screening is absent [3]. Worldwide data on malaria transmission and conflict demonstrates an increasing correlation between the two; the risk amplitude is spatially heterogeneous and dependent on the duration of the conflict and the endemicity of malaria prior to deployment [6].

### **Displacement and Mobility**

Population movements are undoubtedly a key factor contributing to the spread of many infectious diseases. Displaced populations moving from areas of low to higher malaria transmission have an increased risk of infection and mortality, and the presence of unprotected non-immune internally displaced persons influences local transmission rates, as observed in the east of Sudan [7, 9]. Malaria also impacts the ability of a population to re-establish itself following mass displacement. These consequences are exacerbated when displaced people move from one malarious area to another, especially if the origin and destination regions experience different intensities of transmission [5]. For example, movement from a low-endemicity area to a high-transmission area increases the risk of severe infection considerably, both because refugees and internally displaced persons have reduced anti-malarial drug resistance and because populations arriving from low-transmission areas are less able to tolerate infections without developing symptoms [4]. Displacement represents an exacerbating factor, but it is frequently linked to additional variables that render the epidemiological picture more complex. Movements are rarely random; often, populations are transferred under conditions of poor or no shelter or other protection, which makes them more subject to vector bites than usual [7]. A further complication stems from the fact that a section of the population may move to more highly malarious areas of the country usually lowland areas while others remain in the place of origin (often a highland area). The impact of mobility differs depending on whether it is scheduled or unscheduled; unscheduled movements tend to produce bleaker scenarios [5]. On the other hand, limited population displacement also carries epidemic potential, involving in particular younger older adults who have left their place of origin without their families, possibly exposing themselves to novel transmission dynamics or facing less care-seeking behavior [5].

### **Environmental Changes**

Events leading to displacement frequently involve the destruction of shelters, the disruption of water and sanitation systems, and the interruption of healthcare infrastructure [5, 8]. A key consideration is the extent of population movement, which varies widely and includes periods before, during, and after displacement. Environmental changes such as deforestation, altered agricultural practices, stagnant water, and the creation of ponds or pits for sanitation can create additional breeding sites for *Anopheles* mosquitoes. Individuals forced to leave their usual residences may settle in environments with different levels of vector abundance or risk compared to their area of origin, exposing populations with reduced immunity to increased malaria transmission [1]. The precise epidemiological consequences depend on numerous factors, including the ecological characteristics of the original and new locations, the presence and seasonal rhythms of vector species, the dominant *Plasmodium* species, and acquired immunity in the population [1]. Population displacement disrupts routine malaria control, with

availability of diagnosis and treatment further reduced at a time when the impact of malaria and other diseases is most severe [1, 6]. The re-establishment of these services is one of the most difficult tasks following a complex emergency.

### **Challenges in Malaria Control during Crises**

A wide range of factors combine to make the control of malaria during humanitarian emergencies particularly challenging. In most emergency situations, the health-care infrastructure has been seriously damaged or otherwise degraded [2, 3]. Access to health services is often severely compromised, and the implementation of even the most basic interventions is difficult because of the breakdown of normal systems and structures, the lack of skilled human resources, ongoing insecurity and widespread population displacement [1, 5]. Access to and uses of personal protective measures are often limited among displaced populations, while widespread population movements disrupt delivery of preventive interventions and timely diagnosis and treatment of cases. Surveillance, case reporting and health information systems are frequently impaired, making it challenging to determine whether there have been outbreaks or to identify areas or groups at highest risk [1, 7].

### **Healthcare Infrastructure**

The provision and quality of healthcare infrastructure are critical components of malaria control [4]. A review of healthcare facilities in three humanitarian crises demonstrates that many had limited capacity to manage cases on site and often faced intermittent interruption of services. The illegal status of undocumented migrants in large cities represents a further barrier to access [1]. For internally displaced people living in camps, inadequate shelter reduces the effectiveness of personal vector control measures such as insecticide-treated bed nets [1]. People residing in camps are at higher risk of mosquito bites due to overcrowding and improper shelter. AID agencies in some settings have distributed antimalarial drugs for presumptive treatment of fever but often without sufficient diagnostic and clinical support [1, 4].

### **Access to Preventive Measures**

In humanitarian crises, access to key malaria-preventive measures is often compromised, and treatment available only for particular groups [1, 4]. Insecticide-treated nets (ITNs) remain the most important prevention tool, but ownership and use among displaced populations are often lower than in surrounding communities. Displaced populations have limited access to treatment; a recent review found that coverage remains low [1,7]. Prompt access to a curative anti-malarial depends on the presence or otherwise of functioning health services. The continued availability of standard first-line therapy for uncomplicated malaria is necessary in all health facilities, including mobile clinics [1]. Suspected cases of severe or complicated malaria should be referred immediately to a health facility that can provide appropriate diagnostics and therapeutic interventions. Village volunteers or Malaria Village Workers (MVWs) can provide a means of increasing access to care in the absence of formal health facilities, provided they receive adequate training, supervision and supply of appropriate commodities [7]. Requiring MVWs to diagnose and treat malaria only after a positive diagnostic test on an RDT or through microscopy is an efficient and cost-effective use of resources, and reduces overconsumption of artemisinin-based combination therapy (ACT)[1].

### **Surveillance and Reporting**

The collection of accurate, timely malaria data that can be used by decision-makers to guide control efforts is of particular importance in humanitarian crises where an upsurge in cases is anticipated, ongoing control activities may be interrupted, and resources need to be best targeted to an evolving and uncertain situation [8, 9]. However, routine reporting systems, even when established and functioning prior to the crisis usually deteriorate [9]. Surveillance data are difficult to record and transmit when health services have been disrupted, stocks of commodities such as reporting forms and laboratory materials exhausted, and transmission shifts between affected populations and host communities [8, 9]. As a consequence, routine systems in many humanitarian crisis settings rely only on case detection and fail to record key interventions that might explain any observed changes, such as head counts, population movements, death rates or LNs distributed [8]. In most crisis settings, investigators are therefore forced to draw on whatever information is available from pre-existing sources and ongoing systems in the pools of both refugees and displaced persons [9, 10].

### **Malaria Prevention Strategies**

Anopheles-transmitted human malaria parasites *Plasmodium falciparum*, *P. vivax*, *P. malariae*, *P. ovale*, and *P. knowlesi* cause an estimated 229 million clinical cases annually and 0.4 million deaths [10]. Humanitarian crises create conditions conducive to the increased transmission of malaria, precipitating outbreaks and increased mortality [6, 10]. Prevention strategies such as insecticide-treated nets, indoor residual spraying, chemoprophylaxis, and community engagement minimise the risks of contracting malaria, so reducing the



morbidity and mortality associated with the disease [4, 6]. Malaria transmission increases in humanitarian crises because displaced populations frequently originate from areas of low or no malaria transmission where they possess little or no immunity [12]. They have increased exposure to vectors in environments where ongoing transmission levels are high, where new settlements have an abundance of vector breeding sites or where their vulnerability is increased through malnutrition and increased exposure to mosquito bites [4, 7]. The risk is often compounded when displaced people return to their homes, since the means to protect themselves and treat episodes of malaria may no longer be available [4, 5]. Displaced populations usually present a mixture of immunity to malaria ranging from full immunity among residents originating from high-transmission areas to low or absent immunity among newcomers from non-endemic areas. Continued population movements of displaced persons and their hosts make it challenging to target malaria control programmes and ensure a population's adequate protections, particularly when a high proportion of the population is on the move [6, 10].

### **Insecticide-Treated Nets**

Pyrethroid-treated nets have been the cornerstone of malaria prevention for over two decades, as deploying either insecticide-treated nets (ITNs) or long-lasting insecticidal nets (LLINs) has repeatedly eradicated malaria from refugee settlements [2]. By providing a physical barrier and chemically reducing mosquito numbers, these nets reduce an individual's risk of malarial infection by approximately 50% [11]. Recent advances in both the application of PSTs and the development of LLINs ensure that the chemical treatment can be effective for 20+ washes, while new insecticide-delivery designs, like wall-hanging tools, also permit an 'ITN-like' effect even where the fabric of a net is not available [2, 11]. The effectiveness of PSTs and LLINs, however, is somewhat conditional on a number of factors, including the type of vector, the ecology of the local environment, the prevalence of alternative biting opportunities (such as cattle), and, not insignificantly, household use by the at-risk population. Currently, 30% of non-ITN interventions in refugee settings involve supplying nets to the locally displaced population, but the delivery may reach far fewer than the majority of individuals sleeping in these tents. In practice, this leads to a population protected from infection alongside a sub-population who bear the brunt of infection without any physical barrier, and spreads the infection throughout the wider community [2, 12]. Following a large-scale ITN distribution during the Sri Lankan civil war, nets were going unused due to discomfort, inappropriate lighting, lack of information, and insecurity about the personal value of nets on display; meanwhile persistent transmission by zoophilic vectors and considerable outdoor activity hampered the efficacy of the chemicals themselves [10]. Additional care including enhanced community engagement and supplementary vector control tools may often be required to maximise the impact of any network of PSTs or LLINs [14, 11].

### **Indoor Residual Spraying**

Indoor residual spraying (IRS) of the inside walls of houses with insecticides is one of the primary vector control interventions available in humanitarian settings [12]. It is particularly relevant during complex emergencies and protracted crises when the entomological and epidemiological profile of the local disease-specific vector is well documented and can support tailored responses [12]. Properly timed, effectively executed, and actively monitored, IRS can disrupt the transmission cycle of multiple vector-borne diseases, including malaria [13]. Due to reliance on indoor and indoor-outdoor feeding and resting behaviours, IRS interventions are ineffective against exophilic vector species such as *Anopheles albimanus*; therefore, knowledge of the local vector species composition is crucial to guide control activities [13]. Where such vector preferences prevail, Azondo window traps combined with systematic case detection and treatment can be used as an alternative vector control strategy. Mechanistically, IRS implementation is straightforward and cost-effective but requires active engagement of and acceptability by communities particularly those with established health-seeking behaviour and trust in governing authorities [14]. When those conditions are met, IRS can provide protection to everyone in a target area, including vulnerable populations such as infants and pregnant women, provided that coverage is sufficiently high [12]. Coverage targets vary according to contextual determinants but usually hover around 90 %, closing to the 100 % available from other malaria prevention approaches such as insecticide-treated netting (ITNs). Lower delivery thresholds (80–85 %) have demonstrated efficacy in some countries [14]. Once in place, IRS infrastructure can be adapted for other indoor vector-borne diseases, providing additional health benefits [12, 13, 14].

### **Community Engagement**

Community engagement is widely acknowledged as a crucial element in the successful implementation of health interventions [15]. It extends beyond the dissemination of information to encompass active participation in the design and execution of strategies. Early involvement and direction by local leadership are therefore essential, as community leaders serve as pivotal entry points to acceptance and collaboration. Experiences during the 2014-2016 Ebola outbreaks demonstrated the importance of establishing strategic partnerships with influential community and religious figures at the outset of the response. Community health workers (CHWs), often

nominated through local leadership or democratic processes, constitute the primary interface with affected populations [15, 16]. Their enduring presence fosters trust, and when their remit includes the delivery of a broad range of basic health services, the uptake of malaria interventions notably improves particularly in areas progressing towards elimination. A pre-existing network of CHWs can therefore underpin an effective and scalable response to outbreaks [16].

### **Treatment of Malaria in Humanitarian Settings**

Malaria is prevalent in many humanitarian emergencies, imposing a substantial additional risk on displaced populations [7]. Access to antimalarial drugs is often limited, although continuing supply is essential to reduce mortality and morbidity. Resistance to antimalarial drugs is common, including the emergence of multidrug-resistant parasites in some settings. Management of severe malaria remains a priority, despite the frequent lack of intensive care facilities and transfusion services [1, 17]. In the absence of intravenous antimalarials, a full therapeutic dose of an effective antimalarial is essential. Doxycycline and tetracycline are not recommended in young children and pregnant women [6, 17]. Normally, referral is indicated where intravenous therapy or blood transfusion is necessary, but this is rarely feasible. Immediate administration of rectal artesunate and transfer to a nearby health facility remain the best possible approach to the management of severe malaria in these settings [7].

### **Access to Antimalarial Drugs**

Prompt treatment with effective antimalarial drugs is a cornerstone of malaria control, yet several obstacles to universal access remain. Because of drug resistance and other barriers preventing them from receiving the correct treatment, many infected individuals continue to use ineffective medicines in both the public and the private sectors [18]. In sub-Saharan Africa, more than half of patients still seek treatment in the private sector, where artemisinin-based combination therapies (ACTs) are usually not available or are too expensive for the majority of people [18]. Governments play a key role in delivering malaria interventions to vulnerable populations but do not guarantee sufficient access to timely and effective treatment [1, 15]. Overall, although the volume of antimalarial supplies delivered through government channels has increased significantly in recent years, only 15% of children who reported fever in the 2 weeks preceding a household survey in 2009–10 received ACTs. Tanzania's malaria treatment guidelines include first-line drugs recommended for the treatment of uncomplicated malaria and second- and third-line drugs for the treatment of drug-resistant malaria or severe malaria [2, 14]. Following the emergence of *Plasmodium falciparum* parasite resistance to chloroquine and sulfadoxine-pyrimethamine, the country officially changed its first-line treatment policy from chloroquine to sulfadoxine-pyrimethamine in 2001 and subsequently to a fixed combination of lumefantrine and artemether in 2006 [5, 8]. ACTs can cost between 10 and 40 times more than traditional monotherapies or sulfadoxine-pyrimethamine, and treatment with the artemisinin monotherapies commonly used in the private sector is three times more expensive than ACTs. The widespread adoption of ACTs in sub-Saharan Africa has been supported largely by a significant increase in international funding through the Global Fund to Fight AIDS, Tuberculosis and Malaria [9, 12].

### **Management of Severe Malaria**

In the absence of access to specific diagnostic tests, the WHO recommends treating any severely ill patient with a fever or history of fever for severe malaria [19]. Treatment must begin immediately, with patients not already at a treatment facility given a single pre-referral dose of rectal artesunate before being transferred to a facility capable of providing comprehensive care. Personnel conducting pre-referral treatment should provide referral instructions to the patient or caregiver, and ongoing supportive care should be maintained throughout the referral process. Management generally follows WHO diagnostic criteria, integrating available clinical signs [20]. Appropriate facility care involves initiating artesunate-based antimalarial treatment as promptly as possible. In paediatric cases from high-transmission settings, combining parenteral artesunate with broad-spectrum antibiotics is advised to cover potential concomitant bacterial infections [18]. Referral to specialized centres for continued care remains essential throughout the illness period [19]. While advances such as artificial ventilation have enhanced intensive care capabilities, access to such technology remains constrained in many high-burden regions [19, 20]. Besides replacing quinine with artesunate, management protocols have changed little over recent decades. Empirical data indicated that aggressive fluid resuscitation increased the risk of pulmonary oedema, prompting a shift toward cautious fluid administration [18, 20]. Current guidelines do not favour the use of red cell concentrates over whole blood for anaemia management. The prevention and treatment of convulsions remains areas of clinical uncertainty. Routine use of phenobarbitone as prophylaxis has been associated with increased fatality, likely from precipitating respiratory depression [1, 19]. Levetiracetam emerges as a potential alternative, although definitive evidence supporting its efficacy and safety is still lacking. Prompt initiation of renal replacement therapy is recommended upon the onset of renal failure, complemented by frequent monitoring of blood glucose levels and

immediate treatment of hypoglycaemia. Ongoing research investigates adjunctive therapies such as paracetamol aimed at mitigating renal injury during severe malaria episodes [18, 19].

### **Case Studies of Malaria in Humanitarian Crises**

Humanitarian crises both rapid-onset disasters and chronic emergencies exacerbate malaria risk where transmission is ongoing by generating large populations of displaced non-immune individuals and disrupting control programmes and health care [1]. During a continuing complex emergency in South Sudan, Médecins Sans Frontières (MSF) treated approximately 146,000 parasite-positive patients, many of whom were children aged under 5 years, across six camps [21]. Intensified military conflict and fighting in Yemen following the Arab Spring of 2011 have been responsible for the resurgence of a highly epidemic form of malaria [2, 21]. Emergency situations also lead to cycles of population movement throughout malarious areas and into zones where transmission has been reduced or eliminated, thereby creating a vulnerable pool of non-immune hosts. In Syria, violent clashes from 2011 resulted in displacement of 3.8 million people, providing conditions conducive for malaria re-emergence [1, 21]. South Sudan's long-standing conflict has impeded control programmes and left large numbers exposed to infection. Similarly, Yemen's intensified military conflict following the Arab Spring has been linked to the reappearance of a robust epidemic malaria form. These case studies illustrate how crises can lead to elevated malaria risk if control measures and health-care access remain limited [1, 21].

#### **Syria**

The ongoing crisis in Syria, beginning in 2011, has caused extensive displacement. The subsequent outbreak of *Plasmodium vivax* since 2012 was the first for over 70 years [12, 30]. Interventions including the distribution of insecticide-treated nets (ITNs) and indoor residual spraying (IRS), such as from 2014 to 2018 in northwest Syria, have been consistent. Insecurity limited access until a humanitarian cease-fire was agreed in 2017. Voluntary and uncompensated treatment for *P. vivax* was offered until 2014, with a 14-day primaquine course implemented thereafter [11, 30]. Despite these efforts, attacks on healthcare facilities and medical personnel pose ongoing threats. Authorities have recognized the need to rehabilitate and expand malaria control programmes. Malaria services in southern Syria are limited, and interventions cannot be delivered within ISIS-held areas [13, 20].

#### **South Sudan**

South Sudan, already the most violent and unstable country in Africa, faces an even more acute health emergency with the risk of malaria transmission [21, 22]. The country, which gained independence from Sudan in 2011, suffers from a critical shortage of both specialists and even basic medical staff. Stubby corridors of the severely damaged hospitals convene with streets full of debris and demanding protestors [22]. Two drugs were introduced as first-line treatments after Sudan implemented a policy to switch from chloroquine to an artemisinin-based combination therapy (ACT) [20, 26]. While the failure rate for artesunate-sulphadoxine/pyrimethamine exceeded the 10% WHO threshold warranting a change in drugs, no single study has assessed the efficacy of artesunate-amodiaquine, the other first-line policy treatment [22]. This has led to sporadic changes in treatment guidelines. Despite considerable efforts to control the parasite, the health system continues to be weak, especially in terms of case surveillance and reporting. Malaria is one of the leading causes of death in both Sudan and South Sudan. By 2005, shortly after the end of the country's long civil war, Sudan had an estimated excess mortality rate from malaria of 27,942 deaths per month [11, 29]. A major concern for the control programme is the emergence of the parasites bearing gene deletions of *pfrp2/3* that could lead to false-negative rapid diagnostic tests (RDTs). The presence of these deletions could lead to inappropriate treatment, potentially increasing morbidity and mortality, along with transmission. Consequently, this would severely threaten the malaria control and elimination programme in the country [22]. To date, no survey has been conducted to determine the prevalence and geographical distribution of *pfrp2/3* deletions across the country [22]. Higher levels of transmission may be partly related to the presence of deforestation. Extensive destruction of infrastructure, including roads and water management systems, threatens to increase transmission risks; flood control systems and drainage channels could be blocked, resulting in extensive water logging and the proliferation of breeding sites [22]. Historical evidence from the late 1950s suggests that malaria was associated with a high mortality rate during previous Nu Season floods. In addition, 1.6 million people remain displaced or in several camps with limited access to protection and treatment, thus compounding the risk of outbreaks [20]. Evidence from health facilities is limited to only 57 locations, the majority of which are in more urban areas; thus, cases are likely under-reported and the highest-burden areas largely unknown [1, 13]. Gaps remain in the quality and accuracy of routine surveillance data in addition to the climate, geographical, and sociodemographic factors that would be needed to robustly estimate the spatiotemporal distribution of malaria. Both public and private facilities are included; however, a significant proportion of private health-care providers remain unmonitored and unregulated [4, 29].

Malaria is a parasitic disease that imposes an enormous burden globally, and conflict can destabilize malaria control in countries with endemic transmission [8, 18]. In Yemen, nearly two-thirds of the population lives in high transmission areas with increasing morbidity and mortality, but little is known about the current impact of on-going conflict and displacement on transmission or the delivery of malaria interventions [12, 24]. Yemen's health system has been severely disrupted, resulting in implemented programmes (including vector control, surveillance and epidemic prevention) being scaled back or interrupted, drug and diagnostic stock-outs at public facilities, and limited access to health services for displaced populations [23]. The majority of national malaria control funding comes from donors, with some support from the private sector, and the increasing dependence on humanitarian actors threatens to displace the government from playing a leadership and catalytic role [23].

#### **Role of International Organizations**

The World Health Organization plays a pivotal leadership role in the control of malaria during humanitarian crises and in the promotion of the health equity agenda [1, 16]. Following crises in the Sudan, the Geneva-based agency developed a specific policy and guidelines document intended to provide a reference point for those involved in providing emergency health care. Médecins Sans Frontières (MSF) contributes significantly to emergency responses treating between 3 and 4 million patients annually and is frequently the first humanitarian actor to arrive [1, 24]. Early deployment is critical to the effectiveness of any response and the control of malaria as a major public health issue. MSF experience also suggests that funding for malaria control is inadequate, both in absolute terms and relative to the disease burden during crises [1].

#### **World Health Organization**

The World Health Organization (WHO) is establishing a coordination mechanism to improve the response to malaria in humanitarian emergencies by pooling the expertise of agencies working in affected countries. In addition, resources will be mobilized to fill existing gaps; research and development will be supported; and effective communications strategies established to make information on malaria in emergencies available to officials and affected populations [1, 11, 20]. Malaria is a parasitic infection transmitted to humans through female Anopheles mosquito bites. Subsequent invasion of the liver and red blood cells results in common symptoms such as fever, headache, vomiting and chills. Severe malaria usually occurs within 7 days of infection, commonly resulting in coma or death [15]. Five types of Plasmodium can cause malaria in humans. Total cases in 2015 are estimated at 214 million, while total deaths number 438,000; a third of these deaths occur among displaced populations. The most vulnerable groups include children, pregnant women, disabled individuals and elderly people in displaced populations. Humanitarian crises are characterized by the breakdown of authority and normal life due to war or disaster [17]. The resulting displacement and disruption of essential services triggers public health emergencies such as food shortages and malnutrition, diarrhoeal and respiratory diseases, blood-borne infections, or vector-borne diseases including malaria [18]. Health systems are often incapable of coping with increased needs during crises, which contribute to high mortality and morbidity rates [23]. Given the area's population, the epidemic potential of malaria and the conditions typically associated with displacement, the humanitarian impact of this crisis is likely to be considerable [21]. Populations currently vulnerable to malaria include: (a) immunologically naïve returnee or refugee populations; (b) displaced populations who move into malaria endemic areas; (c) host populations suddenly exposed to high levels of transmission; (d) populations that have lost access to preventive measures; and (e) populations with reduced access to health care [1, 20, 21].

#### **Médecins Sans Frontières**

Malaria poses a major public health problem in humanitarian crises especially for children and pregnant women due to, among other factors, population displacement, and destruction of healthcare infrastructure, increased breeding sites, and disruption of control programs. Humanitarian crises therefore tend to increase malaria transmission in endemic areas. [24]. Médecins Sans Frontières (MSF) is a private international medical humanitarian organization established in 1971. The organization provides assistance to people whose survival is threatened by violence, neglect, or catastrophe, primarily due to armed conflict or epidemics such as malaria. MSF works in more than 70 countries worldwide, relying on approximately 40,000 volunteers who constitute its largest resource [20, 24]. The organization operates according to five principles: independence, impartiality, neutrality, bearing witness, and medical ethics. The first three principles preserve the link with all parties engaging in conflicts [20, 2]. The latter two ensure MSF's commitment to disadvantaged populations is carefully maintained [1].

#### **Innovative Approaches to Malaria Control**

The global situation of the coronavirus disease 2019 (COVID-19) pandemic has challenged health systems and economies around the world [23, 1]. Along with advancing therapeutic research, several digital technologies and



innovative techniques have been applied in the surveillance and control of the pandemic. Examples include the application of digital technologies and artificial intelligence, the creation of new drugs and vaccines, and the adaptation and advancement of diagnostic methods [24, 3]. The use of digital technologies has assisted countries in their response to COVID-19 by rapidly collecting and processing information from the disease, allowing for scalability, efficiency, and safety, forming the basis for the development of tools to support health officials and improve the speed and accuracy of decision-making [25, 2]. Furthermore, geospatial technologies, including remote sensing (RS), geographic information systems (GIS), and global positioning systems (GPS), combine spatial information and health data in monitoring disease epidemiology and spatiotemporal dynamics [24, 7]. Modern geospatial technologies are being applied in various fields and have the potential to support researchers and decision-makers analysing the relationship between COVID-19 and environmental factors. Several studies have already depended on geospatial technologies to investigate the factors influencing the spread and transmission of diseases, such as cholera and dengue [25]. Monitoring public fitness and wellbeing with GPS-enabled sport watches, tracking individuals' movements to identify high-risk zones and potential sources of infection, and physical distancing informed solely by geospatial data are just some of the promising solutions made possible by modern space geodetic and Earth observation techniques [1]. Furthermore, geospatial visualisation of disease data can be a valuable tool for public health, aiding in robust decision-making and communicating accurate information to stakeholders and decision-makers [2].

#### **Use of Technology**

Since 2010, the availability of mobile phones has increased rapidly in Africa [26, 27]. Several projects have used this technology to support health workers with malaria, for example to report cases or receive training. Although very promising, most of these solutions have not been designed or evaluated carefully enough [26, 27]. A study has reviewed existing and on-going eHealth and mHealth projects in developing countries to identify common strengths, weaknesses and pitfalls, and then used this knowledge to design a method and a set of tools to help researchers and developers to better assist health workers in managing malaria and to increase the chance of success of new projects [26]. The use of a simple and inexpensive mobile phone system for real-time reporting of fever cases and monitoring of malaria treatment failure by village health workers (VHWs) was successfully demonstrated in the Muheza District of North-Eastern Tanzania [26, 27]. This approach has great potential as a disease surveillance tool for the timely detection and response to possible disease outbreaks especially in remote areas of low and unstable malaria transmission [27].

#### **Research and Development**

Malaria research and development efforts encompass drug discovery, vaccine development, vector control and mitigation strategies, innovative tools, and delivery methods [28, 29]. However, it is estimated that only 2% of the global malaria R&D funding between 2007 and 2016 was allocated to the development of new vector control tools [28]. Policy-level engagement with humanitarian actors to better understand their research questions is essential to enhance coverage of malaria interventions. The research questions generated through this engagement can be used by funders to inform the distribution of funds and researchers to guide their focus [29].

#### **Policy Recommendations**

Malaria is a preventable and treatable vector-borne disease caused by Plasmodium parasites and is transmitted by infected female Anopheles mosquitoes, primarily Anopheles gambiae, Anopheles coluzzii, and Anopheles funestus [4, 30]. It causes a wide range of symptoms, including fever and chills, and continues to be a major public health concern globally [4]. Humanitarian crises occur in many forms, including armed conflicts, complex emergencies, political instability and collapse, social unrest and displacement, and natural disasters [30]. The conditions created by these crises limited access to health services, forced displacement, population movement, food insecurity, shelter deficits, and poor living conditions can significantly amplify the risk of malaria transmission beyond that of surrounding endemic areas [4, 3]. Therefore, a thorough understanding of the direct and indirect impacts of humanitarian crises on malaria transmission is essential for devising effective control policies and strategies and delivering comprehensive interventions in such settings [28, 30].

#### **Strengthening Health Systems**

A strong and resilient health system is a critical foundation for integrated service delivery that is sustainable, particularly during humanitarian emergencies where access to routine care can be disrupted and replacement or supplementary services are needed [17, 30]. These systems are the first line of defence against the emergence or re-emergence of diseases, enabling quick responses that minimise transmission, morbidity and mortality. Strengthening primary healthcare is essential both to progress against malaria and to respond to emergencies and pandemics [17, 31]. This includes sectors such as agriculture, environment, housing, roads, water, sanitation and education, which influence transmission and access to health services [31]. Countries that have eliminated malaria

have worked closely with various government departments and agencies; at subnational levels and within the private sector, building or strengthening effective alliances is important. Health system strengthening contributes directly to malaria control and elimination and to health and well-being more broadly [20, 31]. The malaria community should consider health system strengthening a core component of its mission. Coordination with agencies focused on other sectors can help provide a supportive environment, and grant opportunities are opening up to encourage collaboration with sectors beyond health [19, 31]. Programmes must consciously decide to integrate health system activities such as financing, supply chains, staff training and health information systems [20, 31]. A number of prevention interventions, including continuous distribution of insecticide-treated nets and intermittent preventive treatment of malaria in pregnancy, have been successfully integrated into maternal and child health services [31]. In many countries, malaria programmes deployed to rapidly scale up control activities in the early 2000s were simply added as a new vertical service within weak or deteriorating systems [25, 31]. High-burden countries remain largely dependent on donor funding [26, 31]. There is insufficient emphasis on actual health system strengthening within malaria efforts that mobilise financial resources and advocate for increased support. Partly, this result from the nature of grant and donor finance and the preference of many agencies for target-driven activities aimed at delivering rapid, tangible and measurable effects [25, 30]. Even where systems have been improved to some degree, the momentum behind strengthening activities tends to be weak [18, 30].

### **Enhancing Coordination among Agencies**

During large-scale emergencies, the capacity of individual humanitarian actors is insufficient to meet responding populations' needs and to appropriately coordinate with others [20, 32]. Coordinated actions have therefore become the norm for humanitarian assistance, including for health provision, especially after the 2004 World Health Assembly which further emphasized the necessity for coordination and advocating for the Cluster Approach [19, 32]. A cluster is a coordination mechanism designed to ensure that international responses to humanitarian emergencies are predictable, accountable and sufficiently capacitated to address complex crises and associated disease outbreaks such as malaria [26, 32]. It supports enhanced strategic coordination of field-level prioritization to ensure sufficient capacity and timely responses to chronic and complex emergencies. The system was official launched by the Inter Cluster Working Group in 2006, and it subsequently led to the creation of the Inter-Agency Standing Committee (IASC) clusters which provide a categorization of the main sectors of humanitarian work [25, 32]. The IASC clusters include global and country level ones, each cluster having specific functions and activities: Global clusters report to the UN Emergency Relief Coordinator and focus on the elaboration of standards and policies, capacity building of humanitarian responders and operational support [24, 32]. Country-level clusters are designed to support humanitarian response with regard to the delivery of assistance, communication and advocacy, contingency planning, monitoring and evaluation, and national capacity building [23, 32]. Global clusters operate on a continuous basis through the humanitarian programme cycle, whereas country-level clusters are only activated "[when a government currently is unable to (or does not intend to) respond effectively to the situation and local capacity to respond is overstretched." When the situation improves and gaps are addressed, clusters are subsequently deactivated [22, 32]. The cluster approach, which actively facilitates the involvement of host governments, national and international actors, therefore provides a platform from which to enhance predictability, accountability and partnership in humanitarian aid [22, 32]. It also ensures greater predictability and transparency, provides global guidance and strategy, and fosters surge capacity as well as leadership, technical support and operational coordination [22, 32].

### **Future Directions in Malaria Research**

Despite the Ebola epidemic, malaria continues to be a leading cause of morbidity and mortality [29, 33]. To meet the Millennium Development Goals, progress in malaria control both globally and in countries at the brink of elimination must be sustained and intensified to reduce the transmission of the disease [28, 34]. Foci from uncontrolled transmission due to drug resistance remain a continuous threat, and mass drug administration efforts must continue until prompt diagnosis and treatment, vector control, and other measures bring all nations to elimination [29, 34]. In this context, the international community must maintain vigilance to ensure that appropriate diagnostics, drugs, and technologies are made available to the populations most in need. Detection of low-density parasitemia is fundamental in addressing residual transmission, and new diagnostic tools are a pressing need [29, 34]. Comprehensive risk assessments and real-time disease mapping are more important than ever in evaluating the response to malaria and the challenges posed by epidemics such as that of Ebola [30, 34]. Analysis of years at risk alongside demographic and epidemiological assessments can provide guidance for addressing remaining research challenges. Investigations on spatial heterogeneity, improved preventive measures, and the effective delivery of control interventions will be necessary to meet the long-term goal of global

eradication and enable effective strategies in a complex and fast-changing epidemiological landscape [32]. As the epidemiology of malaria shifts, a strategic review of requirements to achieve malaria eradication is timely, both for improving control in high-burden countries and to ensure effective containment, elimination, and prevention of reintroduction in the face of decreasing transmission [34]. The major steps required to achieve elimination include closing the gap in available interventions, identifying infected individuals to treat, and interrupting transmission. Meeting these needs will require a range of tools tailored to epidemiological settings, transmission intensities, and the biological and behavioural responses of local populations [33]. The complicated, fast-changing situation in which prevention programmes operate demands greater engagement from governments, donors, and international agencies, including in regions where transmission is sporadic or normally close to elimination. Identifying and delineating areas with different levels of transmission facilitates the development of appropriate control strategies and ensures that resources meet the varied needs of a heterogeneous target population [33, 34].

### **Vaccine Development**

*Plasmodium falciparum* and *Plasmodium vivax* remain the dominant malaria species worldwide, with *P. falciparum* responsible for the majority of malaria fatalities [33]. The development of a safe, effective, and widely deployed malaria vaccine represents an important tool in the control and eradication of malaria. RTS,S/AS01 (RTS,S, Mosquirix) remains the only malaria vaccine in widespread use, although several alternative vaccine candidates continue to progress through clinical development; both approaches demonstrate proof of principle that a malaria vaccine is possible [35]. The primary health objective for a malaria vaccine depends largely on the epidemiological context and target population. Pregnant women, infants, and young children generally experience the highest malaria burden in endemic areas [33]. A pre-erythrocytic vaccine, focused on protecting infants and young children from the most severe and life-threatening infections, is being pioneered by RTS,S and next-generation candidates, including whole parasite-sporozoite vaccines, R21, and various subunit vaccines [36]. In vaccinating infants under 1 year of age, pre-erythrocytic vaccines reduce parasite burden before blood-stage infection occurs and prevent clinical episodes as the immune system matures [34]. Because infants often receive vaccines according to a schedule of other childhood vaccinations, the opportunity to bundle a malaria vaccine with established immunization programs is attractive [35]. Maternal immunity may also provide transient protection for the infant, but this effect is generally short lived. Malaria in pregnancy (MiP) remains a widespread and serious concern in moderate to high transmission endemic areas. A vaccine designed to protect primarily against infection in pregnant women is therefore highly desirable [36]. Two vaccine candidates targeting VAR2CSA, the immunodominant surface antigen of CSA-binding infected erythrocytes, have completed first-in-human trials. An initial report suggests these vaccines can induce functional activity against homologous parasites, but future studies will determine their ability to induce heterologous activity boosted during pregnancy malaria infections to confer protection over multiple pregnancies [37].

### **Genetic Research**

Malaria remains prevalent globally, particularly in humanitarian settings [2]. Control programs benefit from investigation of parasite and mosquito genetics through improved understanding of health risks, susceptibility, transmission dynamics, and persistence [37]. The MalariaGEN study in rural Ghana focuses on genetic factors affecting immune responses. Enrolment of pediatric cases showed consent challenges in low-literacy populations and emergencies [38]. Analysis of genome-wide association study data from 17,000 individuals across 11 countries examined more than 1.5 million SNPs [37]. The sample included severe malaria cases and population controls, with imputation based on a reference panel enriched for African genomes [1]. Five loci reached genome-wide significance, collectively accounting for roughly 10% of heritability. A novel locus on chromosome 6 strongly associated with cerebral malaria lacks a known function [39]. Functional evidence suggests possible mechanisms at established loci and simulations indicate systematic positive selection on protective alleles [37]. Co-evolutionary dynamics might also affect parasite genetic diversity [38]. Future work should incorporate parasite variation. Malaria genomics modeling reveals changes in transmission intensity and complements traditional methods limited by difficulties in quantifying mosquito-to-human transmission from routine data. Genotyping advances enhance tracking of parasite populations over space and time to detect local outbreaks and optimize interventions [39, 40].

### **CONCLUSION**

Malaria continues to impose an enormous burden on global health, particularly in fragile and crisis-affected contexts where displacement, conflict, and environmental disruption heighten vulnerability. The coordinated response of international actors such as the World Health Organization and Médecins Sans Frontières demonstrates the importance of global solidarity and structured mechanisms in addressing health emergencies. Strengthening coordination through frameworks like the Cluster Approach ensures predictability, accountability,

and rapid deployment of resources in large-scale emergencies. The integration of digital innovation, including geospatial analysis, artificial intelligence, and mobile technologies has significantly improved malaria surveillance, monitoring, and response in remote and unstable regions. However, the long-term success of malaria control depends on sustained investments in research and development, encompassing new antimalarial drugs, next-generation vaccines, and vector control strategies. The progress of RTS,S/AS01 and emerging candidates targeting both infants and pregnant women marks an encouraging step toward malaria elimination. Similarly, genetic studies are expanding understanding of parasite evolution, resistance mechanisms, and transmission dynamics, paving the way for precision-targeted interventions. To achieve lasting impact, malaria responses must go beyond medical treatment to address systemic vulnerabilities in health infrastructure, governance, and coordination. Strengthening health systems, ensuring equitable access to preventive tools, and enhancing collaboration across sectors are essential pillars for effective malaria control and eradication. Future efforts must align humanitarian priorities with sustainable development goals, ensuring that the most vulnerable, particularly children, pregnant women, and displaced populations are not left behind. Through sustained international cooperation, scientific innovation, and community-driven strategies, global malaria elimination can move from aspiration to achievable reality.

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