



Cross Border Malaria Control Programs

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ABSTRACT

Cross-border malaria control programs have become indispensable components of regional and global health strategies aimed at achieving malaria elimination. These initiatives emphasize cooperation among countries sharing porous borders where human mobility, environmental factors, and socioeconomic disparities facilitate sustained transmission. The Global Fund to Fight AIDS, Tuberculosis and Malaria, established in 2002, remains the principal funding mechanism supporting these efforts, having disbursed over US\$21.7 billion to more than 150 countries. Recent innovations, particularly Geographic Information Systems (GIS), mobile health (m-health) applications, and decision-support systems are revolutionizing the detection, monitoring, and control of malaria in endemic regions. GIS technology facilitates spatial mapping, vector surveillance, and environmental modeling, allowing for evidence-based decision-making in malaria control programs across Africa, Asia, and Latin America. Likewise, m-health applications enable timely reporting, real-time case management, and improved coordination among health workers, particularly in remote and border communities. Community engagement and education remain central to malaria elimination success, fostering local ownership and compliance with preventive interventions such as indoor residual spraying (IRS), insecticide-treated nets (ITNs), and early diagnosis initiatives. Furthermore, monitoring and evaluation frameworks have evolved to capture dynamic indicators beyond morbidity and mortality, focusing instead on transmission foci, parasitological confirmation, and imported case tracking. However, challenges persist in sustaining funding, harmonizing policies, and ensuring cross-border coordination. The future of malaria control depends on integrating sustainable practices, strengthening research and development, and mobilizing domestic political will to complement international support. Effective cross-border malaria control will require adaptive policy mechanisms, regional data-sharing platforms, and sustained commitment to innovation, ultimately driving the global malaria eradication agenda toward 2030.

KEYWORDS: Cross-Border Malaria Control, Geographic Information Systems (GIS), Global Fund, Mobile Health (m-Health) Innovations, and Regional Health Collaboration.

INTRODUCTION

Cross-border malaria control programs are joint efforts implemented across two or more countries aiming to reduce or eliminate malaria transmission in border areas. Considered a region where the 14-day incidence of confirmed malaria cases is more than 10 per 1,000 inhabitants either from one country or both a cross-border malaria control program combines a defined geographical area where neighbouring countries or states coordinate malaria interventions, aiming to accelerate progress towards malaria elimination and providing mutual benefits to neighbouring countries [6]. Malaria remains a major public health concern, with over 240 million cases and 600,000 deaths worldwide [1]. Since the 1950s, global efforts including vector control, treatment programs, and initiatives such as the Global Malaria Eradication Programme (GMEP), Roll Back Malaria (RBM), and the Global Fund have significantly reduced the malaria burden. Nevertheless, challenges such as insecticide and drug resistance, border malaria, and human population movement continue to impede elimination goals [5]. Cross-border malaria, detected along or near international boundaries, accounts for 13% and 9% of the populations at risk in the WHO African Region and the WHO Region of the Americas, respectively [5]. It is a long-standing,

complex challenge; border areas typically face higher vulnerability to malaria infection, poor access to health services, and the presence of mobile populations that perpetuate transmission. In response, regional malaria control initiatives and cross-border collaborative frameworks increasingly support national malaria control programs and facilitate regional cooperation [3]. The Global Technical Strategy for Malaria 2016–2030 advocates that by 2030 at least 35 countries should eliminate malaria and calls for increased country-to-country and regional collaboration. Consequently, bi-national and multinational efforts have targeted border malaria, but uncoordinated interventions, implementation of control strategies, and policy differences have hampered progress. An innovative approach addresses cross-border malaria through establishment of a malaria buffer zone extending a defined distance from both sides of the border, enabling a joint elimination program and collaborative work with local borderland residents and other stakeholders to develop effective solutions [2].

Global Malaria Burden

Malaria remains a globally significant public health challenge [1]. The latest estimates from the World Malaria Report indicate that, among the more than 240 million cases of malaria reported worldwide in 2020, more than 90% were from 29 countries, the majority in Africa [1]. Over 600,000 deaths from malaria were reported, with the largest proportion occurring in Africa. Malaria also remains a public health burden in parts of Asia and America. Nigeria, the Democratic Republic of the Congo, Uganda, Mozambique, Niger, Burkina Faso, Mali, Cameroon, and India continue to be the countries most affected based on the proportion of cases and deaths or from where the disease has spread to other countries [2]. Global efforts in vector control, diagnosis, and treatment combined with improved housing constructions have contributed to a significant reduction in the malaria burden and mortality over the last two decades [1].

Importance of Cross-border Collaboration

Cross-border collaboration plays a critical role in effectively addressing malaria, a disease that continues to afflict over 240 million people and cause approximately 600,000 deaths annually [1]. The most successful programs employ a multifaceted approach incorporating surveillance, vector control, case management, advocacy, and cross-sectoral engagement [1]. Coordination across neighboring countries is essential to surmounting the pivotal challenges to malaria elimination and to sustaining elimination where achieved [2]. The historical and ongoing global burden of malaria underscores the necessity for cross-border initiatives. The disease accounted for an estimated 228 million cases in 2018 alone, with the majority occurring in Sub-Saharan Africa and among vulnerable populations. Seventeen countries accounted for 80% of the estimated burden; eleven countries represented 70% of the global deaths [1]. Although efforts such as the Malaria Eradication Programme, Roll Back Malaria, and the Global Fund have reduced this burden by nearly half over the past 20 years, many national malaria programs are now pursuing malaria-elimination objectives [1, 8]. The World Health Organization (WHO) has set a goal for at least 35 countries to be free of malaria by 2030, but several key challenges remain, including insecticide and parasite resistance and, especially, border malaria. Border malaria, defined as malaria transmission occurring in areas along or near international land borders, is typified by complex epidemiological situations, including neighboring countries at different stages of elimination, high receptivity in border regions, and various social, cultural, ethnic, and language issues that hinder control and prevention efforts [5]. Compared with the national malaria program model, successful cross-border malaria control programs incorporate broader and more context-specific strategies designed to address these peculiarities and complexities [13]. The Southern African Development Community (SADC) Cross-Border Malaria Initiative, launched in 2006, aims to coordinate activities and mobilize partner support to accelerate elimination in the SADC region [1]. The Greater Mekong Subregion (GMS) and the Amazon Malaria Initiative (AMI) unite participation from eleven countries with the objective of achieving malaria elimination through funding and implementation of cross-border and national programs, with strategies addressing malaria control and elimination, health systems strengthening, vector-borne disease control, surveillance, and community engagement [6]. Success depends, however, on overcoming a range of political, operational, and financial challenges and ensuring continued technical focus on the drivers that threaten progress; these challenges and prospects are examined in each case [8]. International organizations have supplied leadership, resources, and technical assistance, making them central to cross-border malaria management [1]. The World Health Organization (WHO) has been a key player since the launch of the Global Malaria Control Strategy in 1993, and economic development agencies such as the U.S. Agency for International Development and the Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund) have directed funds and technical support to cross-border activities in multiple regions [1]. The Roll Back Malaria Partnership to End Malaria, initiated by WHO, UNDP, UNICEF and the World Bank, has coordinated partner activities in several border regions. WHO Regional Offices have maintained a key role in coordinating cross-border programming, emphasizing consensus building, advocacy, resource mobilization, strategic planning, guidelines development, and

technical support. Nongovernmental organizations have also assisted [1, 4]. For national malaria programs and their partners, the essential tool is a cross-sectoral, multi-country package of control activities designed to achieve elimination for the region as a whole. Four components are essential for effectiveness: enhanced surveillance, prompt case management, effective vector control, and strong community engagement. Multiple delivery mechanisms exist for each component, ranging from formal health services using volunteers and primary schools to combined approaches. Selection is informed by ecological, economic, and cultural considerations [18]. The Greater Mekong Subregion Elimination Programme has developed a model surveillance system that allows real-time monitoring of each of these components by parameter using dashboards that not only display progress against national targets but also facilitate rapid identification of underperforming districts and sites [11]. Innovative approaches are emerging to strengthen cross-border malaria control and have considerable potential for adoption. Geographic information systems (GIS) tools can integrate mapping, epidemiological and human migration data to identify high-risk areas targeted for surveillance and intervention [1]. Mobile phone-based applications provide a platform for timely capture and analysis of key information and for rapidly disseminating data, protocols, and program alerts to program personnel in remote locations [16]. The Elimination Scenario Planning Tool (ESPT), a relatively simple software package for designing and prioritizing surveillance strategies, has been developed, allowing countries to generate tailored, program-relevant, user-friendly outputs to guide strategies and interventions with a focus on efforts to detect, respond to, and prevent malaria transmission [1, 15].

Historical Context of Malaria Control

The history of malaria control spans several decades, originating in the 1940s with the Global Malaria Eradication Program and evolving into modern initiatives such as Roll Back Malaria and the President's Malaria Initiative [1]. National approaches continue to shape current efforts, which remain strongly influenced by cross-border concerns [3].

Key Strategies in Cross-border Programs

Posing a significant global burden, malaria remains a serious public health threat to the human population [1]. Since malaria mortality and morbidity data are reported according to political boundaries of countries, the real measure of the health burden of the disease in many pockets of sub-Saharan Africa (SSA) is non-existent [3]. This is largely because it never takes a political boundary for an *Anopheles* mosquito to determine its flight range for a blood meal [7]. Hence, the aspect of cross-border malaria is inevitable, and many of the current single-country initiatives aimed at fighting malaria in SSA are unlikely to succeed without seriously incorporating a component of cross-border malaria control and elimination [9]. Cross-border malaria originates from complex interactions of political, sociocultural, and economic factors, which weaken health systems in SSA. This further worsens the continent's existing challenges including poverty, illnesses, and poor governance [1]. Outlined below are the three key areas that cross-border malaria control programmes were designed to address: designing appropriate cross-border surveillance systems, vector control for cross-border malaria movements, and case management and health care services [16]. Surveillance programmes act as the main pillar of notification, confirmation, treatment, and response in real-time by gathering vital data directly from the community and health facilities using mobile applications. These programmes ensure the timely flow of information between neighbouring countries and minimise the risk of uncontrolled transmissions or resurgence [13]. Vector control programmes are designed to reach every household in cross-border areas with preventive vector control interventions, which frequently use indoor residual spraying (IRS) and long-lasting insecticidal nets (LLINs) [15]. Treatment activities promote early diagnosis through screening and proper case management, molecular testing to determine parasite resistance and treatment of all species of the malaria parasite in selected health facilities in cross-border regions [12]. Engagement and consultation with various stakeholders at international, national, and local levels are critical for building trust, fostering political commitment, and educating communities along border areas on how to achieve successful control and elimination using joint platform strategies [16].

Surveillance and Monitoring

Malaria surveillance systems are a pivotal source of information on malaria cases [3]. These systems enable health officials to monitor the situation and provide essential data that informs the delivery and impact of interventions [1]. Surveillance encompasses data gathering accompanied by rigorous analysis and interpretation, alongside prompt dissemination to policy makers and program implementers [3]. Earlier usage of the term frequently referred to strategic collection and analysis of data concerning malaria determinants like weather and mosquito abundance, so a broader emphasis on data utilization (and rigorous interpretation) is particularly important now [4]. Surveillance is a vital underpinning of any programme, offering a mechanism to monitor progress towards elimination targets [4].

Vector Control Measures

Border regions between states often share climatological, vectoral and community social characteristics, which are critical determinants of malaria transmission vulnerability [1]. The Standard Operating Procedures on cross-border vector control highlight the criticality of vector control in a malaria elimination agenda and the necessity to coordinate vector-control strategies between countries [2]. Vector control is implemented through a combination of indoor residual spraying (IRS) and insecticide-treated nets (ITNs/LLINs) or in special circumstances, through a larval source management (LSM) strategy [4]. The Lubombo Spatial Development Initiative (LSDI) and the MOSASWA program have operated joint IRS campaigns using DDT, Bendiocarb and selected pyrethroids since 1999. (A.) The strategy is complemented by the distribution of LLINs and harmonization of case management guidelines between two or more countries or provinces [7]. The LSDI evaluated the effects of the joint vector-control programme through vector-monitoring in the Lubombo region using routine mosquito collections. The Kwando-Kunene Malaria Initiative (KKMI) between Namibia and Angola has assessed the effectiveness of LLINs in preventing malaria among children [5].

Treatment Protocols

Treatment protocols modify standard case management measures to coordinate care across borders [1]. Vector control measures and preventive therapies remain common components of malaria control programmes [7]. Managing uncomplicated malaria presents challenges in countries that offer free diagnostic testing and treatment through public facilities, as patients tend to seek first-line treatment elsewhere [2]. Established protocols for managing complicated malaria refer patients to the nearest designated treatment facility if no appropriate personnel are available on-site [7]. A new Malaria Treatment Protocol was developed to identify drug-resistant cases more effectively and to align treatment options with those used in neighbouring countries [5].

Case Studies of Successful Programs

The Southern African Development Community (SADC) cross-border malaria control programme has played a pivotal role, establishing a functional framework for collaborative cross-border activities within the economically integrated Southern African region [5]. This model offers a blueprint for designing cooperation frameworks that encompass other sectors linked to health outcomes in border districts and for neighboring countries of differing economic statuses [8]. In the Mekong Subregion, the four countries with the highest malaria burdens Cambodia, Lao People's Democratic Republic, Myanmar, and Thailand account for over 90% of all reported cases [7]. These countries have prioritized cross-border activities as essential elements of funding proposals to the Global Fund to Fight AIDS, Tuberculosis and Malaria [5]. The Amazon Basin Malaria Elimination Initiative (AMBI) provides a case study of coordinated regional efforts for eliminating *Plasmodium falciparum*. Backed by the Bill and Melinda Gates Foundation, AMBI represents a partnership involving national malaria control programmes (NMCPs), ministries of health, and technical partners working collectively to implement and scale up elimination strategies aligned with each country's goals and recent strategies [8]. Initiatives such as the MEI and AMI have demonstrated the effectiveness of coordinated regional collaboration in addressing shared health concerns; however, gaps in operational capacity remain, partially due to insufficient national resources and government support [6]. Complementary and novel strategies, including strengthened cross-border and regional collaborations, remain essential components for the future acceleration of malaria elimination [1].

Africa: The Southern African Development Community

The Southern African Development Community (SADC) comprises 15 member states: Angola, Botswana, the Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe. Four of these Angola, Mozambique, Tanzania, and Zambia exhibit high malaria transmission, while the remainder has low and unstable transmission or is malaria-free [6]. The SADC has pledged to eliminate malaria throughout the region. Since cross-border collaboration is pivotal for sustainable elimination, several initiatives have been implemented to accelerate progress [8]. In 1999, the Swiss Tropical Institute launched a tri-border project involving Mozambique, South Africa, and Swaziland to address the malaria epidemic and associated risks from economic projects and tourist influx in the Maputo River area [8]. This project was subsequently integrated into the Lubombo Spatial Development Initiative (LSDI), a partnership founded in 1999 by Mozambique, South Africa, and Swaziland, in collaboration with the World Bank [6]. Its primary goal was to stimulate socio-economic development by developing the natural resources of the Lubombo mountains while controlling malaria in the targeted area [5]. Initiatives included enhancing malaria-control programs, improving access to prevention and treatment services, strengthening community participation, and rebuilding national malaria control programs [7]. The implementation included vector control through indoor residual spraying (household coverage exceeding 85%), prompt diagnosis and treatment with artemisinin-based combination therapy (ACT), regular entomological surveillance, communication efforts, and environmental

management [8]. The program effectively diminished the risk for *Plasmodium falciparum* malaria across significant portions of the three countries. Recently, international funding has been secured to broaden the program to cover a 75,000 km² area, protecting over 6 million people across Mozambique, South Africa, and Swaziland [6].

Southeast Asia: The Greater Mekong Subregion

The Greater Mekong Subregion (GMS), consisting of Cambodia, China (Yunnan Province), Lao People's Democratic Republic, Myanmar, Thailand and Viet Nam, is located in one of the most tropical and biologically diverse regions of the world [9]. The region represents a substantial proportion of malaria mortality in the World Health Organization (WHO) Southeast Asia region with widespread artemisinin-resistant malaria and the risk of re-importation of malaria from neighbouring countries [8]. Recent achievements in the containment of malaria, along with increasing funding and political commitment, signify that malaria can be averted [9]. An advanced framework for cross-border collaboration could sustain current containment and elimination efforts. Nevertheless, remote border areas remain vulnerable to disease spread, requiring tailored and targeted strategies to address these threats [10].

Americas: The Amazon Basin Initiative

In the context of cross-border malaria control, the Amazon Basin Initiative stands as a pertinent case study [5]. Malaria remains endemic in seventeen countries of the Americas, with 723,000 cases reported in 2019, mostly in the Amazon Rainforest, which accounts for about 90 % of the regional burden [11]. Brazil and Peru together represent 31 % of cases [10]. The territories of the region include the Amazon River basin, the Guiana Shield, the Andes mountainous range, and important forested zones such as the Atlantic Forest and Chocó as well as different ecosystems subject to deforestation and human settlement [13]. A malaria-control strategy tailored to both transmission environments and local health systems is therefore imperative [17]. Several global malaria-control programs have targeted the region with varying degrees of priority; that of Amazonian malaria has remained comparatively limited. The Amazonia ICEMR programme offers such a tailored safety-net [15].

Challenges in Implementation

Cross-border malaria control programmes advance the prevention, diagnosis and treatment of malaria through collaborative initiatives across political boundaries, thereby mitigating the risk of reintroduction in countries that have achieved elimination [8]. These programmes include surveillance and response systems, vector control, case management and health promotion programmes [3]. Health posts located near borders are a vital platform for implementing cross-border malaria control activities, enabling coordination and exchange of information between participating countries [4]. However, their capacity to provide malaria services on a 24-hour, seven-day basis is limited, necessitating supplementary outreach services [1]. The Multi-National Malaria Initiative established to achieve regional elimination promotes coordination, facilitates information exchange and mobilizes resources at borders [6]. The programme encourages regional leaders to engage with partners such as the Global Fund, and to engage health ministries and local stakeholders [9]. Malaria cases occurring at borders could jeopardize the progress made within countries; many infections are detected in migrants originating from bordering areas where complete elimination has yet to be achieved [2].

Political and Administrative Barriers

Within cross-border malaria frameworks, political and administrative boundaries influence the implementation of preventive and control strategies [7]. These barriers affect resource deployment and drug procurement, and exacerbate difficulties related to human and financial resource allocation [6]. Moreover, divergent national health systems further complicate efforts to harmonize and synchronize interventions at the local level [5]. Additional constraints pertain to barriers in information flow, service delivery, equipment availability, infrastructure, technical resources, cross-border management, and communication a pattern that intensifies among malaria-endemic countries sharing such boundaries [1].

Resource Allocation

Resource allocation is a crucial consideration in malaria control programs, particularly initiatives that span across international borders [1]. Collaborative programs often involve distributing commodities, such as medicines and untreated nets, from neighboring countries with surplus supplies to those facing stock deficits [1]. Regional partnerships in Southern Africa and the Mekong Blood Partnership exemplify such cooperative arrangements, sharing essential commodities to stabilize resources across the border [3]. Comprehensive regional programs also benefit from coordinated budget mobilization; multiple countries collectively raise funds to finance interventions that principally target border areas [2]. This joint approach to financing alleviates the financial burden on individual nations, contributing to the viability of long-term cross-border malaria control efforts [6].

Cultural Differences

The Malakit project provides insight into the cultural dimensions of cross-border malaria control [7]. The initiative sets up a cross-border action-research project designed to control malaria among mobile and hard-to-reach populations in the forested areas of the Guiana Shield[3]. Benefiting from a strong participation of health and non-health actors, the Malakit project was implemented in approximately a year and a half despite constraints from a complex international context [7]. These include distance working, diversity in cultures and languages, regulation barriers, and a mobile target population. Key success factors include stakeholder complementarity, incorporation of feasibility information, a participatory approach for developing community-adapted materials, and effective external communication. Administrative facilitation, like the reduction of visa and customs formalities, further enables activities in border areas [18]. Border malaria constitutes a particular risk for reintroduction and is a risk for countries at different stages of cross-border collaboration. Malakit identified factors that influence malaria dynamics: remoteness, mobility, security challenges, policy divergences, and cultural differences [15]. In French Guiana, malaria can occur not only at borders but also in remote interior zones, which suggests a broader mandate for joint cross-border studies[11]. Cooperation examples include Laos and Vietnam's exchange of surveillance data and joint implementation of indoor residual spraying. Beyond describing the operation of an innovative cross-border control strategy, Malakit strengthens the existing network by augmenting stakeholder knowledge, improving communication, and enhancing coordination capabilities [12].

Role of International Organizations

Malaria posed a risk to an estimated 247 million people in 84 countries in 2021, an increase from 238 million cases in 2020 and 227 million in 2019 [1]. Cross-border collaborative efforts involve political, administrative, and operational agreements and actions aimed at controlling malaria across contiguous countries, states, and provinces to prevent reintroduction and achieve elimination [7]. The World Health Organization (WHO) advocates for the formation of cross-border malaria control initiatives, and the Global Fund to Fight AIDS, Tuberculosis and Malaria endorsed "catalytic investments" as initial funding for eligible countries in 2017[8].

World Health Organization

Cross-border malaria control programs undertake intensified malaria control activities in demarcated border zones to reduce significantly cross-border parasite transmission [5]. These programmes enhanced the control of malaria among vulnerable populations living in border districts, and many border areas have seen a steady decrease in the malaria burden that led to elimination [7]. Malaria remains a major health threat in developing countries. Countries in Africa, South-East Asia and Latin America have already established or are setting up cross-border control and elimination programmes[10]. A malaria control programme between Botswana, South Africa and Swaziland launched in 2000 (the Lubombo Spatial Development Initiative) was shuttered in 2011 because of funding issues [7]. The three countries have not implemented any major cross-border programmes since [1]. Malaria control programmes in the Asian and Latin American regions have proceeded despite entrenched and ongoing insurgencies in parts of the respective border regions. Since 2015, several Southern African countries have revitalised efforts at cross-border control and elimination via a new mechanism known as MOSASWA involving Mozambique, South Africa and Swaziland [13]. Disease vectors transmit pathogens to humans during routine activities and as a consequence of their high frequency and mobility, border areas between states often share common climatological, vectoral and community social characteristics that influence transmission[11]. This offered a rationale for designating and implementing specific joint control activities in malarious cross-border areas [13]. The rationale relied on the idea that border regions constitute epidemiological units vulnerable to and receptive to malaria transmission that require concerted joint action across country boundaries [16]. This principle, in turn, requires universal malaria control coverage and standardisation of intervention along border regions. Joint case management, vector control and mapping are important strategies of cross-border control programmes[14]. The Lubombo Spatial Development Initiative (LSDI) and MOSASWA implemented a joint indoor residual spraying (IRS) programme using insecticides since 1999[12]. In addition to IRS, distribution of insecticide-treated nets (ITN)/long-lasting insecticidal nets (LLINs) and case management guidelines were implemented. LSDI also conducted vector monitoring through routine mosquito catches, and the Toktogul-Kemin Malaria Initiative (TKMI) between Namibia and Angola implemented a programme within the Kunene border region to assess the effectiveness of LLINs in preventing malaria among children [17].

Global Fund

Established in 2002, the Global Fund to Fight AIDS, Tuberculosis and Malaria is a finance facility managed by a broad coalition of governments, civil society, the private sector and people affected by the diseases [16]. Since then, the fund has committed US\$23.6 billion and disbursed US\$21.7 billion through over 150 countries [9]. As a

partnership organisation focused exclusively on combating HIV, tuberculosis and malaria, the fund aims to accelerate the end of these epidemics by investing in programmes run by local experts [17].

Innovative Technologies in Malaria Control

Innovative technologies are refocusing malaria control programs toward sustainable development goals and supporting the Global Technical Strategy 2016–2030 [14]. The timely availability of meteorological, hydrological, land cover, land use, and vector habitat information from satellite images enhances geographical information system (GIS)-based systems for early warning, mapping of key variables, stratification, and planning of intervention measures, as well as monitoring of the dynamics of temporal trends of malaria, environmental parameters, and changes in vector habitat locations [15]. On the treatment side, monitoring and reporting are facilitated by mobile phone applications such as Malaria Case Notification, Drop-To-Talk, weekly reporting, SMS for Life, and m-Health [16]. Improved access to monitoring and reporting systems assists many countries in their transition from control to elimination, as well as in tracking the emergence of resistance to drugs and insecticides [1].

Geographic Information Systems (GIS)

Malaria continues to be a major cause of morbidity and mortality throughout Sub-Saharan Africa [1]. Transmission dynamics are driven by complex and non-linear interactions between vector, host, parasite, and environmental factors [15]. The spatial distribution of malaria is heterogeneous and highly sensitive to local climates [13]. Climate variability and change directly impact malaria transmission by affecting the ecology of mosquito vector populations, influencing development rates, reproduction, survivorship, abundance, and distribution, which in turn affect levels of malaria transmission and the risk of infection [15]. An effective approach to malaria control requires detailed understanding of the spatial distribution of the disease at the local level. Continued disease-transmission reductions will require a decision support system that is able to organize and analyze the volume of spatial and temporal data collected by the control programmes [15]. Geographical Information Systems (GIS) provide an ideal platform for the development of such a decision support system because they offer sophisticated tools to efficiently capture, manage, analyze, and display spatially referenced data. Recent advances in GIS, modeling, and database management systems have allowed the development of a GIS-based decision support system for malaria vector control programmes in Sub-Saharan Africa [14]. The decision support system incorporates environmental data in the form of remotely sensed satellite imagery, facilitating large-scale spatial and temporal environmental analyses [13]. The emerging developments in mobile computing and GIS offer unprecedented opportunities for the development of operational mGIS, which can be used to collect, analyze, and disseminate information continuously [17]. Adoption of GIS in operational control programmes in the region, such as Zambia and Tanzania, indicate its practical and immediate value in case detection and mapping, selective targeting and monitoring of vector control interventions, and as a platform for the establishment of a national health information system [18]. Zimbabwe, Zambia, South Africa, and Mozambique have made progress in the use of GIS for malaria activities. South Africa and Mozambique, for example, have successfully piloted the application of GIS in malaria case surveillance and case-reporting systems for strategic decision-making and proactive outbreak management [13]. Sharing and documenting the experiences gained and the technological advances made will contribute to the development of effective malaria vector control programmes in Sub-Saharan Africa and elsewhere [15].

Mobile Health Applications

Malaria remains a major global health challenge, with 228 million cases and approximately 405,000 deaths reported worldwide in 2018 [16]. Preventive measures and treatment guidelines have been developed and implemented; however, cross-border regions often experience increased risk due to higher transmission levels [15]. In response, various cross-border malaria control programs have been established among contiguous countries in recent years. New communication technologies have been introduced to support malaria control activities. Mobile health (m-health) applications enable timely reporting of detected cases and facilitate the prompt delivery of diagnostic tools and treatment by medical personnel [15]. Geographical information systems (GIS) are used for spatial mapping of malaria cases, aiding in targeted intervention strategies for high-risk populations [16].

Community Engagement and Education

Malaria control initiatives across national boundaries depend on the informed and active participation of local populations [1]. Areas such as the Greater Mekong Subregion and the Amazon Basin Initiative routinely integrate community members in outreach and education efforts to promote early diagnosis, encourage use of preventive measures, and foster cooperation with vector control programs [3]. The concept of community engagement is multifaceted and not well defined in the malaria context; it is sometimes used interchangeably with community-based or participatory approaches or social mobilization [8]. Although widespread adoption of

artemisinin-based combination therapy, insecticide-impregnated bed nets, and indoor residual spraying has led to significant reductions in malaria morbidity and mortality over the past two decades, progress is uneven and setbacks have occurred, with about 219 million cases still reported in 2017 [17]. Existing interventions are effective only if they are accessible and properly utilized by the at-risk population. Localized challenges to elimination are site-specific; responses require tailored engagement strategies. Community workers offer a cost-effective extension of the limited services available in many remote districts [17]. They provide a platform for other community members to understand malaria and its control measures, deliver messages about early diagnosis and treatment, and gain acceptance of personal protection measures and indoor spraying, even where mistrust of authorities elsewhere persists [15]. Countries moving towards elimination face evolving community needs that require new forms of engagement. Innovative methods are emerging globally to support this endeavor [13]

Monitoring and Evaluation Frameworks

The Monitoring and Evaluation Framework for malaria comprises assessments of inputs, processes, outputs, outcomes, and impact, each monitored through specific indicators to track program implementation [4]. Historically, these indicators focused on reducing illness and mortality; however, as elimination approaches, they must evolve to include measurements of parasitological confirmation, coverage of populations within transmission foci, and vaccine uptake [7]. Additional indicators that discriminate between indigenous and imported cases, monitor population movement, and assess transmission risk may also prove valuable [9]. Ultimately, as morbidity and mortality decline, gauging infection and transmission through active case detection and response becomes imperative, necessitating an updated Monitoring and Evaluation Framework [11]. Evaluation frameworks systematically assess the impact of malaria control and elimination interventions on disease morbidity and mortality [1]. Guidelines issued by the World Health Organization outline methodologies for monitoring, evaluation, and scenario planning [12]. Empirical studies confirm that insecticide-treated nets and other control measures contribute to reductions in parasitemia, severe anemia, and all-cause child mortality across various settings. Frameworks tailored for moderate- to low-transmission contexts incorporate impact evaluation techniques that track health outcomes longitudinally [18].

Funding and Resource Mobilization

Sustaining malaria control programs demands considerable financial resources for medicines, equipment, and human resources [3]. Countries in the Asia Pacific and Southern African regions leverage collaborative initiatives to secure funding from multilateral funders and the Global Fund. The APMEN, MOSASWA, LSDI, and E8 initiatives currently receive Global Fund grants to support their malaria control and elimination efforts [1].

Future Directions in Malaria Control

The growing concern about border malaria, exacerbated by increasing cross-border human movement and globalization, has intensified research interest in cross-border surveillance [1]. Poverty and disease prevalence in border areas motivate people to cross borders in search of employment, trading opportunities, and health care [17]. These dynamics, combined with ecological and climatic conditions favourable to the disease, contribute to the continued transmission of malaria, even as large-scale interventions reduce transmission across many parts of the world. Cross-border surveillance has become a critical component in controlling outbreaks, and programmes in the Greater Mekong Subregion (GMS), the Southern African Development Community (SADC), and the Amazon Basin support the need for incorporating these initiatives into broader region-wide malaria control efforts [7]. Sustainable malaria control programmes in border areas require robust tools to estimate epidemiological, entomological, and operational determinants of cross-border malaria [8]. The intensification of trans-regional programmes should extend beyond traditional epidemiological and entomological metrics to encompass operational determinants. An operational research framework supports the development of targeted and evidence-based interventions by assessing various factors influencing transmission [9]. Findings corroborate the significant role of socio-economic, behavioural, and cultural aspects in shaping control interventions [16]. Cross-border malaria collaborations remain vulnerable to internal political and financial challenges, which tend to manifest differently across regions [15]. In the evolving global malaria landscape, both regional and global cross-border programmes urgently need robust operational frameworks to enhance collaboration and research activities [10].

Sustainable Practices

Vector surveillance and monitoring for insecticide and drug resistance constitute essential sustainable practices within cross-border malaria control programs [15]. These programs often form national malaria control initiatives with further cross-border collaboration enacted through regional organizations such as the East African Community (EAC) and the Southern African Development Community (SADC) [17]. In practice, the sustained elimination of malaria within HOPE has proven critical to the wider regional objective of malaria-free Southern Africa [1]. Cross-border malaria control refers to efforts to combat the transmission of the disease that transcends

national boundaries by affecting border communities [18]. Multisectoral collaboration in cross-border malaria control is particularly critical, as border regions are often underserved areas with weak infrastructure, scarce resources, and limited healthcare access [18]. Border communities share a common climate, have comparable malaria vectors, and exhibit similar social and cultural factors influencing malaria transmission [2]. Since 1999, large-scale control programs have been executed in various epidemic-prone border regions bordering South Africa, Swaziland, and Mozambique through the Lubombo Spatial Development Initiative (LSDI). Joint efforts implemented in all three countries for indoor residual spraying (IRS) utilized insecticides that included DDT, Bendiocarb, and pyrethroids [18]. The initiative also extended to malaria case management, provision of insecticide-treated nets (ITNs), and the enforcement of joint case-management guidelines to effectively curb transmission [17]. The LSDI Program further established a routine mosquito-monitoring system in the affected Lubombo region [3].

Research and Development

Research and development (R&D) dedicated to national malaria control programmes are pivotal in overcoming transitional challenges along the elimination continuum and propelling malaria elimination research [17]. This R&D is tailored to address emerging transmission dynamics and introduces novel malaria-specific approaches to directly enhance programme effectiveness, especially in challenging economic and sociological environments. Adaptive R&D is essential, given the continual shifts in epidemiology and the general context of elimination [1]. Strategically, R&D support complements efforts in scaling up interventions, accelerating epidemiological transition, and refining elimination protocols, thereby bridging the gap between problem identification and response formulation [15]. For national frameworks, R&D underpins appropriate planning, decision-making, consolidation, and sustainability of the elimination agenda. Globally, it contributes to developing new tools and approaches and supplies technical guidance to programmes operating at various elimination stages [17].

Policy Recommendations

Governments and other stakeholders could facilitate cross-border malaria programs by using political commitment to mobilize internal funding, providing long-term resources to support sustained program activities [1]. The current economic climate makes international funding uncertain and external stakeholders have shifted emphasis [18]. Long-standing programs, such as the Lubombo Spatial Development Initiative, the Regional Initiative since 1999, and the Amazon Malaria Initiative, were able to operate using bilateral agreements, resulting in the exchange of expertise and sharing of best practices [16]. Shared efforts to formulate policies and harmonize treatments, protocols, and reporting formats address the continuous malaria risk generated by human movement [18].

CONCLUSION

Cross-border malaria control programs exemplify the power of regional collaboration in addressing one of the world's most persistent infectious diseases. Their success depends on the coordination of surveillance, prevention, treatment, and community-based interventions that transcend national boundaries. Funding mechanisms such as the Global Fund have been instrumental in supporting these programs by providing critical resources for medicines, diagnostic tools, insecticides, and human capacity development. However, sustained progress requires countries to gradually shift from donor dependency to self-reliant, domestically funded malaria programs. The integration of innovative technologies including Geographic Information Systems (GIS) and mobile health applications marks a transformative era in malaria control. GIS supports spatial mapping, early warning systems, and predictive modeling of malaria transmission, enhancing decision-making and targeted interventions. Similarly, m-health applications improve case reporting, enhance coordination, and enable real-time surveillance across border regions. These technologies, when combined with robust Monitoring and Evaluation (M&E) frameworks, enable precise tracking of progress and accountability in malaria elimination strategies. Community engagement continues to serve as the backbone of sustainable malaria control. Active participation by local populations fosters behavioral change, enhances compliance with prevention programs, and strengthens trust between health systems and communities. Countries such as Zambia, Tanzania, Mozambique, and South Africa have demonstrated that harmonized interventions and shared border strategies yield measurable declines in malaria incidence and mortality. Looking forward, future directions should prioritize operational research, adaptive surveillance systems, and policy harmonization among neighboring countries. Regional organizations such as the Southern African Development Community (SADC) and the East African Community (EAC) must reinforce collaborative frameworks that promote knowledge sharing, integrated vector management, and regional health diplomacy. The development of sustainable practices including vector resistance monitoring and regional data integration will ensure resilience against emerging threats such as drug and insecticide resistance. In conclusion, eliminating malaria in border regions is both a scientific and political challenge that demands coordinated global and regional

responses. Strengthened partnerships between governments, international organizations, researchers, and communities are essential. By aligning technological innovation, local empowerment, and sustained investment, cross-border malaria control programs can accelerate progress toward the 2030 Global Malaria Elimination Goal, transforming once-endemic regions into models of sustainable health security.

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