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Strengthening surveillance and vector control for a malaria-free India: A comprehensive review

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Abstract
Malaria remains a major public health challenge worldwide, with India accounting for a significant proportion of cases in the WHO South-East Asia Region. Despite this burden, India has achieved remarkable progress, with an 85% reduction in cases and a 78% reduction in deaths between 2015 and 2022. Guided by the National Framework for Malaria Elimination (NFME, 2016) and the National Strategic Plan (NSP) 2023–2027, India aims to interrupt local transmission and achieve zero indigenous cases by 2027, moving toward elimination by 2030. The NSP emphasizes transforming surveillance through real-time, case-based systems; ensuring universal access to diagnosis and treatment; optimizing vector control; strengthening program management and multisectoral coordination; and fostering research and innovation. However, challenges persist, including data discrepancies, fragmented surveillance, limited entomological capacity, and the need for tailored interventions for high-risk populations such as migrants, urban communities, forest dwellers, and tribal districts. Addressing these gaps through integrated strategies, community engagement, and robust supply chain and human resource management is essential. By leveraging lessons from recent public health responses and sustaining political and technical commitment, India is poised to advance toward a malaria-free future.

Keywords: Malaria elimination India, National Strategic Plan (NSP) 2023–2027, surveillance and vector control, public health challenges, integrated intervention strategies

Introduction
Malaria continues to pose a substantial public health challenge globally, particularly in Africa and South Asia, including India1. While the global incidence saw a decline from 71 to 57 cases per 1,000 population at risk between 2010 and 2018, the pace of reduction slowed from 2014 to 2018. In 2018, approximately 228 million malaria cases occurred worldwide, with the WHO South-East Asia region contributing 3.4% of this burden. By 2022, the South-East Asia Region accounted for about 2% of the estimated global malaria cases, having reduced cases by 77% (from 22.8 million in 2000 to 5.2 million) and deaths by 77.1% (from 35,000 in 2000 to 8,000). India alone is a significant contributor, bearing almost half (47%) of all *Plasmodium vivax* cases globally and 65.7% of the estimated malaria cases in the South-East Asia Region in 2022. Despite this, India has demonstrated remarkable progress, reporting 176,522 cases and 83 deaths in 2022, alongside an 85% decline in total malaria cases and a 78.3% decline in deaths compared to 2015 data. The Annual Parasite Incidence (API) in India also drastically reduced from 2.09 in 2000 to 0.13 in 2022.

India's Malaria Elimination Ambition and Progress
As malaria-endemic countries transition from controlling morbidity and mortality to achieving zero indigenous cases, there is an imperative need for approaches and strategies to evolve4. India launched its National Framework of Malaria Elimination (NFME) in 2016, with an overarching goal of achieving zero indigenous cases nationwide by 2030. The National Strategic Plan (NSP) for Malaria Elimination 2023-2027, developed by the National Center for Vector Borne Disease Control (NCVBDC) with WHO support, consolidates previous achievements and aims to strengthen efforts towards this goal. The plan specifically targets interrupting local transmission and achieving zero indigenous cases across the country by 2027, while also establishing an enabling environment to prevent the re-establishment of malaria.

India has shown significant strides in malaria reduction, recognized globally by WHO World Malaria Reports. Key achievements from the previous NSP (2017-2022) include a 79% reduction in malaria cases and a 57% reduction in malaria deaths by 2022 compared to 2017. In 2022, 128 districts reported zero indigenous cases, and 603 districts maintained an API below 1. Furthermore, 34 States/Union Territories (UTs) have made malaria a notifiable disease, reinforcing surveillance efforts. The country surpassed the Global Technical Strategy (GTS) target of a 40% reduction in malaria cases by 2020, achieving an 85% reduction compared to 2015. This progress is reflected in the movement of districts from higher endemicity categories (Category 3, API $\ge$ 2) to lower ones, with districts reporting API $\ge$ 2 reducing from 110 in 2015 to just 18 in 2022.

Key Challenges to Malaria Elimination in India

Despite the notable progress, India faces several significant challenges in its journey towards malaria elimination:

- **Data Discrepancy and Surveillance Limitations:** A substantial discrepancy exists between cases and deaths reported by India's National Programme and estimates by WHO and research studies. For example, in 2017, the National Programme reported 0.84 million cases and deaths, while WHO estimated 9.6 million cases and 7 thousand deaths for the same year. This divergence highlights limitations in the existing surveillance system, which suffers from a time-lag due to paper-based data, poor coverage of mobile populations (such as forest workers, transitory urban slum populations, refugees, and tourists), and inefficiency in representing data from remote and inaccessible tribal and hilly regions.
- **Fragmented Data Landscape:** The multiplicity of malaria stakeholders in India, including public sector agencies, private healthcare providers, defense forces, railways, industries, and independent researchers, often operate in silos, leading to fragmented data inputs and interpretation. Notably, malaria cases treated by the private healthcare sector, which provides approximately 70% of healthcare, are often not accounted for in national figures. Similarly, armed forces, railways, and organized industries with their own healthcare systems are missing from national surveillance data.
- **Lack of Real-time Aggregation and Granularity:** The routinely collected data within the national program scope lacks real-time aggregation and the desired level of resolution, such as household-level data. This restricts the ability to identify infection foci and adopt timely corrective actions. Data are also not publicly available with granularity by age, gender, or month, hindering comprehensive analysis.
- **Missing Surveillance Components:** Critical elements like drug and insecticide efficacy surveillance, entomological surveillance, and commodity and stock management are not fully integrated into the existing surveillance systems, leading to scattered and disintegrated data.
- **Institutional and Human Resource Gaps:** Challenges include the need for strengthened institutional mechanisms for **multi-sector** coordination and increased focus on urban malaria issues, including data sharing between state health services and municipal corporations. A significant challenge is the vacant posts of entomologists in states and UTs, crucial for vector surveillance and management.
- **Behavioral and Research Needs:** Evidence-based community engagement and Social and Behaviour Change Communication (SBCC) activities are highly variable and need tailoring to local contexts, especially for vulnerable populations. There is a need for increased research into new diagnostic tools, basic entomological parameters in different eco-epidemiological situations, drug resistance monitoring, vector behavior changes due to climate change, insecticide resistance monitoring, outdoor transmission control, and the usage/durability and bio-efficacy of Long-Lasting Insecticidal Nets (LLINs). Ensuring compliance with the 14-day radical treatment for *P. vivax* cases also requires special focus.

Strategic Approaches for Malaria Elimination (NSP 2023-2027)

To overcome these challenges, the NSP 2023-2027 outlines five strategic approaches aimed at achieving a "Malaria Free India":

1. Transforming Malaria Surveillance as a Core Intervention

The plan emphasizes a shift from aggregated data to **near real-**time case-based surveillance. This will be achieved through the rollout of the Integrated Health Information Portal (IHIP)-malaria, enabling web-based reporting across the country. Surveillance will be strengthened at all levels, including case-based and foci-based investigations, and entomological surveillance.

A "1-3-7 day timeline" approach will be adopted: case reporting within 1 day of diagnosis, case investigation within 3 days, and completion of all preventive measures within 7 days. Accurate case classification (indigenous, imported, relapse, recrudescence, induced, introduced) is crucial for targeted interventions. Reactive Case Detection (RACD) will be performed around confirmed index cases, typically within a 1km radius, especially in low endemic areas. Foci investigation will categorize areas as "active," "residual," or "cleared" based on transmission evidence, guiding tailored responses.

The system will support outbreak preparedness and response, leveraging Geographical Information Systems (GIS) for identifying clusters.

Mandatory reporting from the private sector will be emphasized to ensure comprehensive data capture. Surveillance indicators like Annual Blood Examination Rate (ABER) will continue to be monitored, with efficiency measured by the timeliness of blood smear collection/examination or RDT performance. Mass Surveillance and Treatment (MSaT) may be considered in specific, hard-to-reach areas, although cost-effectiveness remains a consideration.

2. Ensuring Universal Access to Malaria Diagnosis and Treatment

This approach is foundational for elimination, requiring universal coverage of parasitological confirmation for all suspected malaria cases using quality-assured microscopy or Rapid Diagnostic Tests (RDTs). Microscopy remains the gold standard, particularly in elimination settings for detailed parasite analysis.

While *Plasmodium falciparum* and *P. vivax* are predominant in India, the plan acknowledges the reporting of *P. malariae*, *P. ovale*, and *P. knowlesi*. Molecular tools (PCR) are considered for confirmation in complex cases. A reliable real-time supply chain system for diagnostics and drugs will be implemented to prevent stock-outs and minimize wastage.

Continuous capacity building of frontline health workers and laboratory technicians is crucial for quality-assured service delivery. Ensuring treatment availability and compliance with national guidelines is paramount, with follow-up for all cases to ensure complete radical cure. The plan advocates for the inclusion of public, private, and informal healthcare providers in program activities and their capacity building on national treatment guidelines and reporting. Monitoring of relapse, recrudescence, early treatment failures, drug effects, and pharmacovigilance will be integrated into surveillance activities. Therapeutic Efficacy Studies (TES) are vital for the early detection and management of antimalarial drug resistance.

3. Ensuring Universal Access to Malaria Prevention by Enhancing and Optimizing Vector Control

Vector control is an essential component of malaria elimination, with strategies based on understanding vector bionomics, surveillance, incrimination, and community awareness.

- **Entomological Surveillance:** This will be tailored to different transmission settings, encompassing routine and regular monitoring of adult vector density, establishment of sentinel sites, and targeted spot checks in known persistent transmission areas. An entomologist's participation is crucial in foci investigations to identify vector species, breeding sites, and insecticide resistance status.
- **Insecticide Resistance Monitoring (IRM):** Regular IRM is critical for guiding the selection of appropriate insecticides for interventions. This involves strengthening collaboration with research bodies like the Indian Council of Medical Research (ICMR) and preparing annual maps of insecticide resistance.
- **Integrated Vector Management (IVM):** The deployment of interventions will be evidence-based, guided by Vector Control Need Assessment (VCNA). Indoor Residual Spraying (IRS): Prioritized for high-risk areas, transitioning to focal spray (in and around 50 houses of a case) as elimination progresses. Long-Lasting Insecticidal Nets (LLINs): A core strategy in high-burden areas, with distribution criteria reviewed based on epidemiology and entomology. Larval Source Management (LSM): Includes the use of Temephos, Bio-larvicides, and Insect Growth Regulators (IGRs) in urban areas, promotion of larvivorous fish (*Gambusia* and *Guppy*), and environmental engineering methods for breeding site reduction, involving community and local institutions. Emergency Vector Control: Fogging with appropriate insecticides is recommended for immediate killing of infected mosquitoes during outbreaks. Safe disposal of insecticides and public health products will adhere to the Environmental Code of Practice (ECoP).

In India, Nine *Anopheles* species are proven vectors out of 58 identified species. Primary vectors include *An. culicifacies*, *An. fluviatilis*, *An. minimus*, *An. baimaii (dirus)*, *An. stephensi*, and *An. epiroticus (sundaicus)*, while *An. annularis*, *An. philippinensis*, and *An. varuna* are secondary vectors of local importance. *An. stephensi* is notably involved in urban malaria transmission.

4. Accelerating Efforts towards Elimination and Attainment of Malaria-Free Status

This strategic approach encompasses strengthening program management and coordination at all levels, from planning and implementation to monitoring and evaluation. The NCVBDC oversees the program, with States/UTs responsible for implementation, supported by central technical and financial assistance.

- **Multisectoral Coordination:** Recognizing the multi-factored nature of malaria, the plan mandates extensive collaboration with various ministries (e.g., Tribal Affairs, Rural Development, Home Affairs, Environment, Education, Railways, Defense), municipal corporations, Civil Society Organizations (CSOs), faith-based organizations, and CSR foundations.
- **Human Resource Management:** This involves a comprehensive analysis of HR needs, budgeting for additional personnel, and robust capacity building through training and refreshers for all cadres, from State Programme Officers (SPOs) and entomologists to Medical Officers (MOs), ASHAs, and private practitioners.
- **Advocacy and Social Behaviour Change & Communication (SBCC):** High-level political advocacy is crucial to maintain commitment and leverage resources. National, State, and District Task Forces for Malaria Elimination are established to provide strategic guidance. SBCC activities will promote community participation through mass media, local influencers (Panchayat Raj, Self-Help Groups), and targeted campaigns (e.g., World Malaria Day) to promote prevention and treatment behaviors.
- **Procurement and Supply Chain Management (PSCM):** The NSP aims to ensure a continuous supply of quality-assured antimalarial drugs, diagnostics, and insecticides through efficient planning, acquisition, storage, and distribution. This includes centralized and decentralized procurement mechanisms, buffer stock management, and regular reviews to minimize expiry and stock-outs, enhanced by online software like LMIS.
- **Finance:** The NSP has an estimated budget of ₹6249.80 Crores for 2023-2027, broadly categorized into intervention costs (preventive, diagnosis, treatment), program costs (HR, training, M&E, surveillance, communication), and governance. Funding sources include the Union Government, State Governments, local bodies, and national/international donors (including CSR activities).
- **Certification and Verification:** The plan details the process for National Certification of Malaria Elimination by WHO, which requires proof of interrupted local transmission for at least three consecutive years and a functional surveillance system. Subnational verification is also proposed to incentivize and recognize the achievements of well-performing States/UTs/Districts, involving independent assessment committees and extensive documentation.

5. Promoting Research and Innovation for Malaria Elimination and Prevention of Re-establishment of Malaria Transmission

Research and Development (R&D) is an ongoing activity to develop, test, and deploy new tools and strategies. Key focus areas include Therapeutic Efficacy Studies (TES), quality assurance of RDTs, vector control, insecticide resistance studies, and GIS mapping. The plan highlights the need for research into gender disparities to design more effective and equitable elimination approaches. Leveraging the IHIP Malaria portal's real-time data, malaria forecasting and modeling studies will be undertaken to guide the program amidst changing environmental conditions and vector distribution.

Priority research areas span disease surveillance, diagnosis, treatment, vector biology, and control, with specific studies on elimination models for islands/tribal areas, costing analyses, social benefits, climate change impacts, human migration, Knowledge, Attitudes, and Practices (KAP) studies, and chemoprevention.

The Epidemiological Triad and Vector Bionomics in India Understanding the epidemiological triad (agent, vector, host, environment) is crucial for targeted interventions.

- **Agent Factors:** Malaria in India is primarily caused by *Plasmodium falciparum* and *P. vivax*. *P. malariae* and *P. ovale* are rarely reported, though some cases of *P. knowlesi* have also been identified in certain areas.
- **Vector Factors:** Out of 58 *Anopheles* species in India, 9 are proven malaria vectors.
- **Primary Vectors**: *An. culicifacies, An. fluviatilis, An. minimus, An. baimaii (dirus), An. stephensi,* and *An. epiroticus (sundaicus)*.
- **Secondary Vectors:** *An. annularis, An. philippinensis,* and *An. varuna*, which are of local importance in disease transmission. *An. stephensi* is particularly significant for malaria transmission in urban areas.
- **Bionomics (Feeding and Resting Habits):** The behavior of *Anopheles* species varies widely: Anthropophilic (human-preferring) species, which readily bite humans, include *An. baimaii* (very anthropophilic, exophagic/endophagic), *An. dirus* (highly anthropophilic, exophagic/endophagic, exophilic), *An. fluviatilis* (most anthropophilic and endophilic), *An. jeyporiensis* (generally anthropophilic, early biter), *An. karwari* (generally anthropophilic), *An. kochi* (readily bites man), *An. koliensis* (strongly anthropophilic, readily bites outdoors/indoors), *An. lesteri* (regarded as anthropophilic, readily attacks humans), *An. minimus* (mainly bites humans, degree of anthropophily depends on alternative hosts), *An. philippinensis* (mostly anthropophilic, mainly exophagic and exophilic), *An. pujutensis* (highly anthropophilic, exophagic/endophagic, exophilic), *An. punctulatus* (readily attacks humans outdoors and indoors), *An. sawadwongporni* (freely bites humans indoors/outdoors, appears least zoophilic), *An. sundaicus* (mainly anthropophilic, endophagic/exophagic), *An. varuna* (generally anthropophilic, readily collected in houses and cattle sheds), and *An. willmori* (anthropophilic and opportunistic, freely bites indoors/outdoors).

Zoophilic (animal-preferring) species, which show a preference for non-human blood, include *An. annularis* (primarily zoophilic, but bites humans even in presence of cattle), *An. argyropus* (more attracted to cattle than humans), *An. barbirostris* (generally prefer other animals, especially bovids), *An. dravidicus* (attracted more towards cattle than humans), *An. maculatus* (more strongly attracted to cattle than humans, but bite people freely), *An. nigerrimus* (zoophilic, but bites humans also, primarily exophilic), *An. sinensis* (predominantly zoophilic and exophilic, infrequently biting humans when preferred hosts are present), *An. splendidus* (primarily a cattle feeder, may occasionally bite man), *An. subpictus* (generally zoophilic), *An. tessellatus* (primarily zoophilic, but enters houses to bite man), *An. theobaldi* (more strongly attracted to cattle than humans), and *An. vagus* (zoophilic, exophilic, and exophagic).

Opportunistic feeders like *An. aconitus* and *An. pallidus* feed on humans in varying proportions or prefer accessible hosts, whether human or animal, respectively. Resting habits (endophily/exophily) vary significantly among species.

- **Host Factors:** Human elements influencing malaria epidemiology include age, sex, socioeconomic development, housing, population mobility, occupation, human habits, and immunity.
- **Environmental Factors:** Malaria is a seasonal disease in India, with maximum incidence typically from July to November. Optimum conditions for parasite development include temperatures between 20-30 °C and relative humidity of 60%. Rainfall is fundamentally important as it provides opportunities for mosquito breeding.
- Specific Challenges and Approaches for Vulnerable Populations. The heterogeneous nature of malaria epidemiology in India necessitates tailored strategies for specific contexts and risk groups. The NSP 2023-2027 outlines focused approaches for various vulnerable populations:
- **Malaria in Migrant Populations:** Developmental activities lead to population flow from endemic areas, potentially introducing malaria. Challenges include access to surveillance, treatment compliance, and effective vector control.
- **Key activities:** Mandating Health Impact Assessments (HIAs) for projects to track expected migrants. Strengthening surveillance and screening of mobile populations, especially those from endemic areas. Special focus on labor camps and night shelters for periodic visits. Conducting IEC and SBCC activities in appropriate languages and strengthening passive surveillance at health facilities for migrants. Prioritizing vector control measures (IRS, LLINs, anti-larval activities) in high-risk migrant camps. Ensuring active collaboration with labor, irrigation, and housing departments, and promoting interstate/intercountry cross-border consultations.
- **Urban Malaria:** Considered a marginal problem until the 1970s, urban malaria now presents a rising trend, primarily transmitted by *Anopheles stephensi*. Urbanization contributes to risk through labor migration, inadequate civic amenities, poor drainage, and large-scale construction.
- **Key activities:** Emphasizing linkages between national, state, and local urban bodies for policy, planning, and budgeting. Consistent monitoring of hotspots and mother foci. Ensuring Early Diagnosis and Prompt Treatment

(EDPT) and tailored control activities. Implementing environmental management, judicious use of larvicides (chemical, biological, IGR), and effective legislative measures. Strengthening intersectoral collaboration with municipal departments (finance, planning, housing, sanitation). Targeted SBCC involving Resident Welfare Associations (RWAs) and Self-Help Groups (SHGs). Promoting modern technologies like GIS mapping for health resources and breeding sites. Enforcing civic bylaws (e.g., covering water storage, proper waste management) and building bylaws (e.g., mosquito-proofing, preventing water accumulation during construction).

- **Forest Malaria:** Areas with large forest cover are ecologically more receptive to malaria, linked to high burden and deaths due to favorable conditions for vector breeding and difficult terrain.
- **Key activities:** Advocating with the Ministry of Environment, Forest and Climate Change (MoEFCC) for resource pooling. Building technical capacity of stakeholders for prevention and control. Fostering community participation through Joint Forest Management Committees (JFMCs) and Eco-development Committees (EDCs), identifying "Malaria Elimination Mitra" volunteers to bridge health and forest departments. Supporting monitoring and evaluation of malaria elimination efforts in targeted forest areas. Promoting traditional knowledge of forest dwellers for mosquito breeding control. Augmenting digital facilities and connectivity in interior areas, including telemedicine and strengthening IHIP for real-time data monitoring.
- **Tribal Malaria Elimination Plan:** In 2022, 59% of India's malaria cases were reported from identified tribal districts, facing challenges like multiple vectors, insecticide resistance, scattered populations, and high mobility.
- **Key strategies:** Providing hamlet-wise ASHAs and training Anganwadi Workers, faith healers, local medical providers, and village headmen for case identification and referral. Strengthening PHCs with quality microscopy facilities. Ensuring free and traditional transport services for cases in inaccessible areas. Implementing patient cards for treatment completion tracking and utilizing mobile technology for early communication and follow-up. Prioritizing IHIP-malaria portal implementation.

Vector control includes advance stocking of insecticides, IRS planning with community consultation, and supply of LLINs with proper IEC. Promoting community-owned bed nets and involving contractors/owners of development projects to mandate bed nets for laborers. Implementing minor environmental engineering through Village Health, Sanitation and Nutrition Committees (VHSN&C).

Ensuring efficient supply chain management of RDTs, ACTs, and insecticides, maintaining buffer stocks, and using mobile technology for rapid communication. Developing community-specific IEC/SBCC activities leveraging weekly markets, local festivals, skits, and folk media to ensure desired and sustainable results.

Malaria in Project and Border Areas: Development projects can introduce malaria through incoming labor, while border areas pose unique challenges due to population movement and varying endemicity. Key activities for project areas: Screening all incoming labor and their families from endemic areas. Providing prompt and effective treatment. Promoting mosquito nets and Larval Source Management (LSM). Establishing epidemic preparedness and alert systems. Key activities for border areas: Developing joint surveillance plans to synchronize disease management, vector control, and public awareness campaigns. Exchanging real-time case information and cross-notification of outbreaks between bordering districts. Strengthening epidemic preparedness and response, and collaborating on monitoring insecticide susceptibility and drug-resistant parasites.

Conclusion: Towards a Malaria-Free Future

India's ambitious target of malaria elimination by 2030 requires a multifaceted and integrated approach. The National Strategic Plan 2023-2027 provides a robust roadmap, emphasizing enhanced surveillance, universal access to quality diagnosis and treatment, optimized vector control, accelerated program implementation through multisectoral coordination and robust HR management, and continuous research and innovation. The lessons learned from the COVID-19 pandemic regarding real-time data sharing and public health mobilization provide a valuable precedent for malaria elimination efforts. By consistently addressing the identified challenges and diligently implementing these strategies, particularly in vulnerable populations, India aims to consolidate its achievements and move towards a "MALARIA FREE FUTURE"

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