



# Malaria and the Epidemiological Triad: Strategic Pathways to Elimination in Gujarat, India

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**Abstract** – Malaria remains a formidable public health and economic challenge in Gujarat, India, acting as a persistent barrier to regional productivity. Despite the national mandate for elimination by 2030, Gujarat presents a unique sub-national landscape defined by the intersection of rapid industrialization, diverse topography—from the arid Rann of Kutch to the tribal forest belts of the Dangs—and high internal migration. This paper utilizes the Epidemiological Triad—comprising the Agent (*Plasmodium*), the Host (Humans and *Anopheles* mosquitoes), and the Environment—to analyze the disease's persistence. The paper identifies significant hurdles, including insecticide resistance and the rise of asymptomatic carriers. However, it also highlights strategic opportunities: the use of GIS-based digital surveillance for real-time outbreak mapping, genomic surveillance to track parasite origins, and public-private partnerships to integrate private clinics into the reporting net. By disrupting the equilibrium of the triad through these targeted interventions, Gujarat can transition from a high-burden state to a global model for malaria elimination in a developing economy.

**Keywords:** Malaria, Public Health, Gujarat, Prevention

## 1. Introduction: The Burden of a Persistent Pathogen

Malaria is far more than a simple biological infection; it is a profound socio-economic indicator. In Gujarat, the "Golden Corridor" of industrial growth—stretching from Ahmedabad to Vapi—has paradoxically created fertile ground for the disease. While the state has successfully transitioned from the high-mortality epidemics of the late 20th century into a "Pre-elimination" phase, the "last mile" of eradication remains the most difficult.

The epidemiological landscape of Gujarat is marked by heterogeneity. Transmission is not uniform; it is a mosaic of high-risk forest pockets in the Dangs, irrigated agricultural plains in Kheda, and dense urban construction sites in Ahmedabad. Traditionally, malaria follows a bimodal peak in the state: a minor rise in the spring (March–April) and a major surge post-monsoon (September–November). However, human-made environmental changes, such as the expansion of

the Narmada canal network and the rise of "Urban Heat Islands," are blurring these seasonal lines. To effectively combat this, public health officials must move beyond generalized interventions toward a "stratified" response that addresses the specific imbalances within the Epidemiological Triad.

## 2. The Epidemiological Triad: The Gujarat Context

### 2.1 The Agent: Evolutionary Persistence

In Gujarat, the "Agent" is a moving target. While *Plasmodium falciparum* remains the focus of mortality prevention due to its severity, *Plasmodium vivax* accounts for more than 50-60% of the state's total malaria burden in several districts.

- **The Relapse Phenomenon:** Unlike *falciparum*, *P. vivax* can lie dormant in the human liver as hypnozoites. In the arid regions of Kutch and Saurashtra, this is a survival strategy for the parasite; it "overwinters" during the dry months when mosquito populations are low and reappears during the rains, sparking new outbreaks without the need for an immediate external reservoir.
- **Antimalarial Resistance:** There is increasing vigilance regarding the efficacy of Chloroquine against *P. falciparum* in the eastern tribal belt (Dahod, Panchmahal). This has necessitated a shift to Artemisinin-based Combination Therapy (ACT), yet the threat of "partial resistance" looms as a major challenge for state health monitors.

### 2.2 The Host: The Human-Vector Interface

The "Host" component in Gujarat is defined by high mobility and biological adaptation.

- **The Migrant Vector:** Gujarat is a major economic hub, attracting millions of laborers from Odisha, West Bengal, and Chhattisgarh—states with traditionally high malaria endemicity. These laborers often inhabit temporary shelters near construction sites (e.g., the GIFT City or Surat's industrial zones) that lack basic

vector barriers like window screens. This creates a "parasite spillover" where workers unknowingly introduce new strains into urban populations.

- **Vector Adaptation:** The primary vectors, *Anopheles stephensi* (urban) and *Anopheles culicifacies* (rural), have shown remarkable plasticity. In urban centers like Vadodara, *An. stephensi* has adapted to breed in "clean" water stored in overhead tanks and cement curing tanks, directly contradicting the public perception that malaria only comes from "dirty" stagnant water.

### 2.3 The Environment: The Industrial and Climatic Facilitator

Environmental factors in Gujarat act as the ultimate catalyst for the Triad.

- **Hydrological Changes:** The Narmada Canal Project has revolutionized agriculture but created unintended consequences. Seepage and stagnant water in canal distributaries in North Gujarat have introduced malaria into previously desert-like areas where the vector was not previously established.
- **Urban Heat Islands (UHI):** Large cities create micro-climates where temperatures remain **2–4°C higher** than surrounding rural areas. This allows mosquitoes to remain active and parasites to develop within the vector even during the cooler winter months, leading to "perennial" transmission in cities like Rajkot and Bhavnagar.

## 3. Critical Challenges to Elimination

### 3.1 The Asymptomatic and Sub-microscopic Reservoir

A major hurdle in Gujarat is the "silent" carrier. In high-transmission pockets, many individuals develop a partial immunity that suppresses symptoms but does not eliminate the parasite. These individuals do not visit clinics, yet they provide the "seed" for mosquitoes to infect others. Current microscopy-based surveillance often misses these low-density infections, requiring more sensitive molecular tools.

### 3.2 Insecticide Resistance and Behavioral Change

Long-term use of synthetic pyrethroids in Long-Lasting Insecticidal Nets (LLINs) and Indoor Residual Spraying (IRS) has led to "behavioral avoidance" in mosquitoes. Instead of resting on walls where they would contact poison, vectors are increasingly biting outdoors (exophily) or early in the evening

before people go under their nets. This "biological pushback" makes traditional vector control less effective over time.

### 3.3 Urbanization and "Hidden" Breeding Sites

In rapidly growing cities, construction sites provide thousands of small, temporary water collections (e.g., plastic sheets, discarded cups, curing tanks) that are difficult for health workers to monitor. The sheer scale of urbanization in Gujarat makes traditional "larviciding" labor-intensive and easy to bypass.

## 4. Opportunities for the Future

### 4.1 Digital Intelligence (E-Health) and GIS Mapping

Gujarat has the infrastructure to lead India in **Predictive Modeling**. By integrating the Integrated Health Information Platform (IHIP) with GIS mapping, the health department can map "fever clusters" in real-time. This allows for "pre-emptive" fogging and the deployment of "Rapid Response Teams" within 24 hours of a confirmed case.

### 4.2 Public-Private Partnerships (PPP)

Since a large portion of Gujarat's population seeks care in the private sector, there is a massive opportunity to integrate private practitioners into the national reporting system. Implementing "Mandatory Notification" and providing private labs with government-grade RDTs can ensure that no case goes unrecorded.

### 4.3 Genomic Surveillance

By analyzing the DNA of the parasites found in Gujarat, scientists can track where the malaria is coming from (migration vs. local) and whether the parasite is evolving to evade current diagnostic tests (HRP2/3 gene deletions). This "parasite fingerprinting" is essential for the final phase of elimination.

## 5. Conclusion

Eliminating malaria in Gujarat requires more than just distributing nets; it requires a disruption of the **Epidemiological Triad**. By focusing on the **Host** through culturally sensitive IEC (Information, Education, and Communication), the **Agent** through radical 14-day treatment of *P. vivax*, and the **Environment** through better urban planning, Gujarat can serve as a global model for malaria elimination in industrializing states. The path forward is not just medical, but social and environmental.



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