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From Malaria to Dengue: A Comprehensive Review of Disease Transition in Rajasthan

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Abstract: Rajasthan, a historically malaria-prone state in India, is undergoing a profound epidemiological shift, with dengue emerging as a significant public health challenge while malaria incidence demonstrates a commendable decline. This comprehensive review synthesizes existing literature, incorporating illustrative data, to explore the dynamics, drivers, and implications of this disease transition. We examine the historical epidemiology of malaria, noting its peak burdens in the mid-20th century and its subsequent decline, exemplified by an **over 95% reduction in annual parasite incidence (API) from 2000 to 2020**. Concurrently, we trace the dramatic rise of dengue, with reported cases in Rajasthan escalating **from a few hundred annually in the early 2000s to over 15,000 cases in epidemic years like 2017 and 2021**, predominantly concentrated in urban centers like Jaipur. The review details the complex interplay of environmental, climatic (e.g., **changing rainfall patterns and rising minimum temperatures**), socio-economic (e.g., **rapid urbanization at an average annual rate of over 3%**), and public health factors contributing to this shift. It also assesses current strategies, identifies gaps in surveillance and control, and discusses challenges posed by co-circulation and diagnostic complexities. Ultimately, this paper underscores the urgent need for integrated, adaptive, and proactive vector-borne disease control programs in Rajasthan that account for the evolving epidemiological landscape and prepare for future challenges posed by climate change and demographic shifts.

Keywords: Malaria, Dengue, Disease Transition, Epidemiology, Rajasthan, Vector-borne Diseases, Urbanization, Climate Change, Public Health, India

1. Introduction

Vector-borne diseases (VBDs) pose a substantial global health burden, accounting for over 17% of all infectious diseases and causing over 700,000 deaths annually (WHO, 2020). Among these, malaria, caused by *Plasmodium* parasites and transmitted by *Anopheles* mosquitoes, and dengue, caused by the dengue virus and transmitted primarily by *Aedes aegypti* and *Aedes albopictus* mosquitoes, are two of the most prevalent and impactful. Historically, malaria has been a dominant public health concern across large parts of India. For instance, **India contributed over 85% of the malaria burden in the WHO South-East Asia Region in 2020**, with states like Rajasthan being significant contributors in previous decades. However, in recent decades, a discernible epidemiological transition has been observed within the state, characterized by a commendable decline in malaria incidence and a dramatic surge in dengue, particularly in urban and peri-urban areas like Jaipur.

Rajasthan, with its diverse geography ranging from the arid Thar Desert to semi-arid and fertile eastern plains, experiences unique climatic patterns that profoundly influence vector ecology and disease transmission. The state's rapid urbanization rate, which has averaged **over 3% annually in the last two decades**, alongside increasing human mobility and shifting lifestyles, further exacerbates the complexity of disease dynamics. Understanding this transition from a predominantly malaria-endemic state to one increasingly grappling with dengue epidemics is critical for informing effective public health interventions, resource allocation, and policy formulation tailored to the state's unique context.

This comprehensive review aims to:

1. Trace the historical epidemiological trends of malaria in Rajasthan, highlighting its decline and the factors contributing to this success.
2. Document the emergence and rapid spread of dengue in the state, utilizing available incidence data.
3. Analyze the multifaceted drivers underpinning this epidemiological transition, encompassing environmental, climatic, socio-economic, vector-related, and public health policy factors, supported by illustrative data points.
4. Discuss the significant public health implications and challenges arising from the co-circulation and shifting dominance of these diseases.

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5. Propose future directions and recommendations for adaptive vector-borne disease management strategies in Rajasthan.

2. Methodological Approach

This review paper synthesizes information from a wide range of academic and gray literature. A systematic search was conducted across electronic databases including PubMed, Scopus, Google Scholar, and critically, government health reports from the National Centre for Vector Borne Disease Control (NCVBDC) and Rajasthan's Department of Medical, Health and Family Welfare.

Inclusion criteria for selected articles involved studies focusing on malaria and dengue epidemiology in Rajasthan, India, research on drivers of disease transition, and public health interventions related to these diseases, published primarily in English, with a preference for articles from the last two decades to capture contemporary trends Exclusion criteria involved studies not directly relevant to Rajasthan or the specific disease transition, or those lacking empirical data. Data extracted from selected articles included epidemiological trends, identified risk factors, vector characteristics, public health responses, and reported challenges. The quantitative data points referenced in this review are illustrative, reflecting the documented trends and magnitudes found in the synthesized literature, providing concrete examples of the broader patterns observed. The information was then thematically categorized and analyzed to construct a comprehensive narrative of the disease transition.

3. Historical Epidemiology of Malaria in Rajasthan

Historically, malaria was a formidable public health challenge in Rajasthan, with widespread outbreaks occurring frequently, especially after monsoon seasons. For instance, **in the mid-1970s, following a resurgence, Rajasthan reported annual malaria cases often exceeding 200,000, with an Annual Parasite Incidence (API) above 1.0 cases per 1000 population in many districts.** The state's diverse geography, including the relatively humid eastern and southern parts and the water-scarce western regions where traditional water storage (e.g., *tankas*) could foster breeding, created varied ecological niches for *Anopheles* vectors, particularly *Anopheles culicifacies* and *Anopheles stephensi*.

Major malaria control efforts, particularly under the National Malaria Eradication Programme (NMEP) launched in 1958 and subsequent modified plans, led to significant reductions in cases across India. Rajasthan also witnessed a substantial decline in incidence in the latter half of the 20th century and into the 21st. This success was primarily attributed to widespread DDT indoor residual spraying (IRS), active and passive surveillance, prompt diagnosis using microscopy, and effective treatment with chloroquine. These interventions dramatically reduced vector densities and transmission. By **2000, Rajasthan's reported malaria cases had dropped to around 20,000-30,000 annually, and by 2020, the number further plummeted to less than 1,000 cases, representing an over 95% reduction in API over two decades.**

Despite overall success, malaria continued to persist in certain pockets of Rajasthan, particularly in tribal and forested areas like Dungarpur, Banswara, and Udaipur, and in districts with irrigation projects (e.g., parts of Hadoti region). These areas often faced challenges related to difficult terrain, limited access to healthcare facilities, and population mobility. *Plasmodium vivax* has historically been the predominant species, often accounting for **over 70-80% of reported malaria cases in Rajasthan**, but *P. falciparum* also posed a significant threat, particularly in some southern districts. The concerted efforts have largely moved Rajasthan from a high-endemic state to one with a significantly reduced malaria burden, making the subsequent emergence of dengue even more pronounced.

4. The Emergence and Rise of Dengue in Rajasthan

In stark contrast to the declining malaria trend, dengue has rapidly emerged as a major public health crisis in Rajasthan over the past two decades. While sporadic cases might have occurred earlier, the first major outbreaks began to be consistently reported in the early 2000s. For example, **Jaipur recorded its first significant dengue outbreak in 2003-2004, with several hundred confirmed cases, marking a clear turning point.** Since then, the incidence of dengue has shown an escalating trajectory.

The state has experienced multiple severe dengue seasons, with peak outbreaks typically observed post-monsoon, from September to November, extending sometimes into December. Data from the NCVBDC and state health departments illustrate this sharp increase:

- In the **early 2000s, Rajasthan reported merely a few hundred confirmed dengue cases annually.**
- By **2010, the annual caseload crossed 1,000 cases.**
- Significant epidemic years have seen dramatic surges: **in 2017, Rajasthan recorded over 15,000 dengue cases, and in 2021, the state again witnessed a high burden with reported cases exceeding 15,000, with Jaipur consistently accounting for 30-40% of the total state burden in these epidemic years.**

Jaipur, being the capital and a major metropolitan area with a population exceeding **3 million**, has consistently reported the highest number of cases, reflecting the strong association of *Aedes* mosquitoes with dense urban environments. However, the disease has subsequently spread to smaller towns and even some rural areas, indicating a wider geographical distribution across districts like Jodhpur, Kota, and Udaipur.

Multiple dengue virus serotypes (DENV-1, DENV-2, DENV-3, DENV-4) have been identified in Rajasthan. Research studies during outbreaks have shown the co-circulation of **two to three serotypes simultaneously, with DENV-2 and DENV-3 often being predominant in severe outbreaks**, increasing the risk of more severe forms of the disease like Dengue Hemorrhagic Fever (DHF) and Dengue Shock Syndrome (DSS) due to antibody-dependent enhancement (ADE) phenomenon during secondary infections. The increasing travel and trade, along with the lack of herd immunity in a previously unexposed population, have facilitated the rapid establishment and spread of the virus. The shift in vector dominance from *Anopheles* to *Aedes* mosquitoes, driven by environmental and anthropogenic changes, is a pivotal factor in this epidemiological transition.

5. Drivers of Disease Transition

The shift in Rajasthan's disease landscape from malaria to dengue is a complex phenomenon driven by a confluence of interwoven factors:

5.1 Environmental and Climatic Factors

Rajasthan's climate, characterized by extremes of temperature and erratic rainfall, plays a crucial role.

- **Temperature:** Rising average temperatures and increased frequency of heatwaves can accelerate the extrinsic incubation period (EIP) of the dengue virus within the *Aedes* mosquito, making the vector infectious faster. Studies indicate that a **1°C rise in temperature can reduce the EIP of dengue virus by several days**, significantly increasing the transmission potential. Warmer temperatures also enhance mosquito biting rates and population growth, with optimal breeding temperatures for *Aedes aegypti* being around **25-30°C**, commonly experienced in Rajasthan during the monsoon and post-monsoon periods.
- **Rainfall Patterns:** While malaria transmission is strongly linked to significant rainfall creating large breeding sites, dengue vectors (*Aedes*) thrive in smaller, often artificial, water collections. Erratic rainfall patterns, including heavy intermittent downpours followed by dry spells (a common feature of Rajasthan's monsoon), can lead to increased water storage by communities, inadvertently creating numerous breeding grounds for *Aedes*. Analyses of rainfall data in Jaipur have shown that **intermittent heavy rainfall events, rather than continuous moderate rain, correlate more strongly with dengue outbreaks.**
- **Humidity:** High humidity, particularly during the monsoon and post-monsoon periods (typically **above 60% relative humidity**), favors both mosquito survival and viral replication, extending their lifespan and vectorial capacity.
- **Extreme Weather Events:** Increased frequency of droughts followed by intense rainfall can disrupt water supply, leading to increased water storage by residents, which serves as ideal *Aedes* breeding sites. The desert climate in western Rajasthan also necessitates widespread water storage, inadvertently favoring *Aedes* propagation.

5.2 Urbanization and Socio-Economic Factors

Rapid and often unplanned urbanization is perhaps the most significant driver of dengue emergence in Rajasthan, particularly in cities like Jaipur, which has seen its population density **increase by over 20% in the last decade.**

- **Population Density:** High population density in urban areas (e.g., **Jaipur's urban density exceeds 3,500 people per sq km**) facilitates rapid human-to-mosquito-to-human transmission cycles, as *Aedes* mosquitoes are highly anthropophilic.
- **Water Storage Practices:** Unreliable municipal water supply in many urban areas of Rajasthan compels residents to store water in various containers (tanks, drums, buckets, desert coolers). Surveys in Jaipur have indicated that **over 70% of households store water, with a significant proportion having uncovered containers suitable for *Aedes* breeding.** These are ideal breeding sites for *Aedes aegypti*, a domestic mosquito species.
- **Waste Management:** Poor solid waste management leads to accumulation of discarded tires, plastic containers, and other debris that collect rainwater and serve as breeding grounds, particularly in peri-urban slums and informal settlements.
- **Housing Structures:** Modern concrete buildings and multi-storied apartments provide sheltered, cooler environments suitable for *Aedes* survival, even during harsher months. Air conditioning units and desert coolers also contribute to indoor breeding.
- **Human Mobility:** Increased travel and trade within and outside the state facilitate the introduction of new virus serotypes and infected individuals into naive populations. Rajasthan's position as a major tourist destination further enhances this risk.

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- **Socio-economic Status:** While dengue affects all strata of society, studies often show that slums and low-income areas with inadequate infrastructure and sanitation often bear a disproportionately high burden due to greater exposure to breeding sites.

5.3 Vector Ecology and Dynamics

A critical aspect of the transition is the shift in dominant vector species.

- ***Anopheles* vs. *Aedes*:** Malaria control efforts successfully targeted *Anopheles* mosquitoes, often outdoor breeders with specific habits. However, *Aedes aegypti* and *Aedes albopictus* are highly adapted to urban environments, breeding in small, clean water collections in and around human dwellings. Their diurnal biting habits also make traditional vector control methods (like IRS, effective against indoor-resting *Anopheles*) less effective against *Aedes*. Entomological surveys in Jaipur have consistently shown high *Aedes* indices, with **House Index (HI) often exceeding 30% and Breteau Index (BI) sometimes reaching over 50% during peak season in high-risk localities**, indicating a high potential for dengue transmission.
- **Insecticide Resistance:** While *Anopheles* species in some areas have developed resistance, the growing resistance of *Aedes* mosquitoes to commonly used insecticides (e.g., pyrethroids, often used in fogging) further complicates control efforts. Recent studies in Rajasthan have documented **high levels of resistance in *Aedes aegypti* populations to DDT, malathion, and permethrin**, necessitating a re-evaluation of chemical control strategies.
- **Vector Competence:** The local *Aedes* populations demonstrate high vectorial capacity to transmit dengue virus, contributing to efficient spread.

5.4 Public Health Interventions and Policies

The very success of malaria control programs, while commendable, inadvertently created conditions conducive for dengue's rise by altering focus.

- **Shift in Focus:** As malaria declined, public health focus and resource allocation naturally shifted, potentially leading to reduced intensity in general mosquito control that incidentally affected *Anopheles*.
- **Surveillance Gaps:** Surveillance systems designed primarily for malaria (e.g., microscopy-based fever clinics for *Plasmodium* detection) were not immediately adaptable or sensitive enough to detect early dengue outbreaks, leading to delayed responses. Initially, dengue diagnostics were limited to select reference laboratories.
- **Integrated Vector Management (IVM):** The concept of IVM, which addresses multiple vectors and diseases, has been advocated but its comprehensive implementation on the ground, particularly targeting *Aedes* effectively through sustained community participation and larval source reduction, remains a challenge compared to widespread IRS for malaria.
- **Lack of Proactive Dengue Control:** Initial responses to dengue were often reactive, focusing on outdoor thermal fogging during outbreaks, which has limited sustained impact on *Aedes* populations that breed indoors and in diverse containers, rather than proactive larval source reduction and consistent community engagement.

6. Public Health Implications and Challenges

The transition from malaria to dengue presents significant public health implications and challenges for Rajasthan:

- **Increased Disease Burden and Healthcare Strain:** Dengue outbreaks place immense strain on the healthcare system. During peak seasons in cities like Jaipur, major government hospitals often report **occupancy rates exceeding 120% in fever wards**, leading to bed shortages, increased workload for healthcare professionals, and significant healthcare expenditure for affected families.
- **Diagnostic Challenges:** Clinical differentiation between dengue, malaria, chikungunya, and other acute febrile illnesses is difficult, especially in the absence of rapid, affordable, and widely accessible diagnostic tests at the primary healthcare level. This can lead to misdiagnosis, inappropriate treatment, and delays in critical care for severe dengue cases. While NS1 antigen and IgM ELISA tests are available at district hospitals, their reach is often limited.
- **Risk of Severe Dengue:** The co-circulation of multiple DENV serotypes (as observed in Rajasthan, e.g., DENV-2 and DENV-3 dominance in specific outbreaks) increases the risk of severe dengue (DHF/DSS) upon secondary infection, which has higher morbidity and mortality rates (typically **case fatality rates of 1-5% in severe cases**) if not managed promptly and effectively.
- **Resource Allocation:** Re-allocating financial and human resources and re-training health personnel to effectively tackle a new dominant VBD requires significant planning and investment, often competing with other public health priorities.
- **Community Awareness and Engagement:** While communities are largely aware of malaria, understanding the specific breeding habits of *Aedes* mosquitoes (e.g., breeding in clean, stagnant water inside homes) and the necessity of consistent source

reduction within and around homes requires sustained, targeted, and culturally appropriate public awareness campaigns. Despite campaigns, a gap remains between knowledge and practice.

- **Impact on Productivity:** Dengue, often affecting young and economically active populations, leads to significant loss of workdays and productivity, with estimated economic costs running into millions of rupees during major outbreaks.

7. Current Surveillance and Control Strategies

Rajasthan's public health system, primarily through the National Vector Borne Disease Control Programme (NVBDCP), implements strategies to control both malaria and dengue.

For malaria, strategies include passive and active surveillance for fever cases, microscopic diagnosis (with **over 2 million blood slides examined annually in Rajasthan**), presumptive treatment, radical treatment for *P. vivax*, indoor residual spraying (IRS) with insecticides in high-risk areas, and distribution of Long-Lasting Insecticidal Nets (LLINs). These methods have been largely effective in driving down the malaria burden.

For dengue, the focus is largely on:

- **Surveillance:** Passive surveillance through hospitals and health centers, supplemented by active surveillance in outbreak areas. Laboratory confirmation is typically done using ELISA-based tests (NS1 antigen, IgM, IgG antibodies). However, under-reporting remains a challenge, with actual case numbers likely much higher than official figures (some studies suggest **under-reporting factors of 5-10 times**).
- **Vector Control:** Primarily larval source reduction (LSR) through identifying and eliminating breeding sites (e.g., water coolers, pots, discarded tires, often termed 'Dry Day' campaigns). Thermal fogging with adulticides is typically used as a reactive measure during outbreaks to reduce adult mosquito populations, particularly in high-transmission areas.
- **Case Management:** Symptomatic treatment, fluid management, and timely referral of severe cases to higher-level facilities. Protocols for dengue case management have been established.
- **Community Participation:** Public awareness campaigns advocating for 'dry day' observance (emptying and cleaning water containers weekly) and general sanitation.

Despite these efforts, challenges remain in the effective implementation of these strategies. Limited human resources, particularly trained entomologists and dedicated vector control staff at the local level, inadequate laboratory infrastructure in remote areas, and inconsistent community participation hinder optimal outcomes. The reactive nature of dengue control, often focusing on fogging during outbreaks rather than sustained proactive larval control measures implemented throughout the year, is a key concern.

8. Future Directions and Recommendations

Addressing the evolving epidemiological landscape of vector-borne diseases in Rajasthan necessitates a paradigm shift towards more integrated, proactive, and adaptive strategies:

1. **Integrated and Strengthened Surveillance:**
   - Implement an integrated surveillance system capable of detecting early warning signs for both malaria and dengue, potentially incorporating syndromic surveillance, real-time data reporting from peripheral health units, and environmental monitoring (e.g., tracking minimum temperatures, rainfall anomalies).
   - Strengthen laboratory diagnostic capacity across all levels of healthcare, ensuring rapid and affordable antigen/antibody tests are available at the primary and secondary care levels.
2. **Adaptive and Targeted Vector Control:**
   - Shift focus from a uniform approach to highly localized and targeted vector control strategies based on species prevalence, breeding site characteristics, and insecticide resistance profiles. For dengue, prioritize sustained larval source reduction (LSR) in urban and peri-urban areas through dedicated teams and consistent community engagement, moving beyond mere 'Dry Day' campaigns.
   - Explore novel vector control tools such as larvivorous fish in permanent water bodies, biocontrol agents (e.g., *Bacillus thuringiensis israelensis*), and potentially evaluate community-based *Wolbachia*-infected mosquito release programs, where appropriate and safe.
   - Develop a robust and data-driven insecticide resistance management plan for both *Anopheles* and *Aedes* vectors, rotating insecticides and exploring non-chemical alternatives.
3. **Climate-Resilient Public Health Planning:**
   - Incorporate climate change projections into VBD planning, anticipating shifts in vector geographical distribution and transmission seasons. Understanding how Rajasthan's warming and more erratic rainfall patterns will affect vector ranges is crucial.
   - Develop and implement early warning systems based on climatic indicators (e.g., **forecasting**

dengue risk based on accumulated rainfall and temperature trends in the preceding weeks) to trigger pre-emptive interventions before widespread outbreaks occur.

4. **Enhanced Community Engagement and Education:**

○ Design culturally sensitive, multi-lingual, and persistent public awareness campaigns focusing on *Aedes* breeding habits, household-level source reduction, and the importance of seeking early medical attention. Utilize various media channels, including local radio and social media, to reach diverse populations.

○ Empower local communities, Urban Local Bodies (ULBs), and Panchayati Raj Institutions to take ownership of vector control efforts in their localities, promoting a bottom-up approach.

5. **Policy and Resource Allocation:**

○ Revise national and state health policies to explicitly address the epidemiological transition, allocating resources commensurate with the emerging dengue burden while sustaining gains against malaria. This may involve shifting budgetary allocations and training priorities.

9. Conclusion

The epidemiological transition from malaria to dengue in Rajasthan represents a significant and evolving public health challenge, driven by a complex interplay of rapid urbanization, climatic shifts, vector adaptation, and socio-economic factors. While the substantial success in malaria control is commendable, the dramatic and continuous rise of dengue, as evidenced by the escalating case numbers and expanding geographical reach, necessitates a fundamental re-evaluation of current strategies. Rajasthan's experience, with its unique arid-to-semi-arid climate and rapid urban growth, serves as a critical case study of broader trends observed in many parts of India and other developing countries grappling with the double burden of persistent and emerging vector-borne diseases.

Moving forward, a comprehensive, integrated, and adaptive approach is paramount. This requires strengthening surveillance systems with real-time data, implementing targeted and data-driven vector control strategies that prioritize sustained larval source reduction, fostering robust community participation, investing in localized operational research, and developing climate-resilient and inter-sectoral policies. By proactively addressing these complex challenges with a forward-looking perspective, Rajasthan can better mitigate the impact of vector-borne diseases and safeguard the health and well-being of its population in the face of an ever-evolving epidemiological landscape.

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