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Review Article

Transforming Dengue Control: Scientific Challenges, Operational Gaps, and Elimination Prospects

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A B S T R A C T

Dengue has evolved into the most widespread arboviral disease, now threatening nearly half the world's population. Despite the availability of diverse control tools—from insecticides and Wolbachia-based methods to improved surveillance and vaccines—the global burden of dengue continues to rise. This review dissects the scientific and operational roadblocks undermining control efforts, including silent transmission by asymptomatic carriers, serotype co-circulation, antibody-dependent enhancement (ADE), and growing insecticide resistance. These challenges are compounded by rapid urbanisation, climate change, fragmented surveillance, and weak intersectoral coordination. The authors advocate for a paradigm shift: integrating real-time entomological surveillance, climate-informed predictive models, and next-generation diagnostics within a strengthened Integrated Vector-borne Disease Management (IVDM) framework. Emphasizing community engagement, cross-sectoral governance, and transdisciplinary research, this paper outlines a forward-looking strategy that aligns innovation with implementation. Transforming dengue control from a reactive response into a proactive public health mission is critical to achieving the long-standing goal of dengue elimination.

Keywords: Dengue, asymptomatic conundrum, serotype co-circulation, climate change, Urbanisation, ecological expansion, fragmented surveillance, delayed response.

Introduction

Dengue, a mosquito-borne viral infection caused by four antigenically distinct serotypes (DENV-1 to DENV-4), remains a formidable and escalating global health challenge. With an estimated 390 million infections annually—of which nearly 96 million presents with clinical symptoms—dengue has significantly outpaced existing public health interventions. [1] Once endemic to select tropical regions, dengue now threatens nearly half of the world's population and has established transmission in over 125 countries, making it the most widespread arboviral disease. [2,3]The World Health Organization (WHO) classifies dengue as a high-priority disease with epidemic potential. [4] This designation, however, contrasts sharply with the persistent rise in disease burden despite the availability of key control tools, including insecticide-based interventions[5], Wolbachia-infected mosquito releases[6], improved surveillance systems[7], and even a licensed vaccine[8]. This paradox highlights a disconnect between scientific advancements and field-level impact.

The reasons for this failure are multifactorial—fragmented surveillance, reactive interventions, inadequate community engagement, weak infrastructure, and insufficient political commitment.[9] These systemic weaknesses are further exacerbated by climate change[10], rapid urbanisation, insecticide resistance[11], and the silent transmission driven by asymptomatic carriers.[12]

As the global health community aspires toward dengue elimination, it is imperative to critically examine the unresolved scientific and operational challenges that keep dengue control at a crossroads—where the promise of elimination remains both urgent and elusive.

The Asymptomatic Conundrum

A major impediment to dengue control is the high prevalence of asymptomatic and subclinical infections, estimated to constitute 50–80% of all DENV cases.[12,13] Although clinically silent, many of these individuals remain viraemic for several days, enabling Aedes mosquitoes to acquire and transmit the virus unknowingly. This cryptic reservoir fuels sustained transmission, particularly in hyperendemic settings where multiple serotypes co-circulate. Traditional surveillance systems—largely dependent on passive reporting of febrile illnesses—fail to capture this hidden burden, leading to underestimation of transmission intensity and misinformed vector control responses. Population-wide serological or molecular screening, while ideal, remains logistically daunting and cost-prohibitive in resource-limited settings. Additionally, the lack of rapid, highly sensitive, and field-deployable diagnostic tools limits the feasibility of early detection and containment strategies targeting asymptomatic carriers. Without integrating this silent fraction into surveillance frameworks, dengue control efforts will continue to fall short of breaking the chain of transmission and achieving elimination.

Serotype Co-Circulation and Antibody-Dependent Enhancement

The concurrent circulation of all four-dengue virus (DENV) serotypes create a complex immunological landscape that heightens the risk of severe disease and challenges public health strategies. Although a primary DENV infection provides durable immunity to that specific serotype, the transient cross-protective immunity to heterologous serotypes wanes within months, rendering individuals vulnerable to secondary infections. Antibody-dependent enhancement (ADE) is central to this phenomenon, whereby sub-neutralising antibodies from a prior infection bind but do not neutralise a different serotype, instead promoting viral uptake via Fcγ receptors on monocytes and macrophages. This leads to higher viraemia, exaggerated immune responses, and severe manifestations such as dengue haemorrhagic fever and shock syndrome.[14] ADE also complicates vaccine development, as demonstrated by the Dengvaxia rollout in the Philippines. The vaccine's poor safety profile in seronegative recipients led to severe outcomes and sparked intense public backlash, regulatory restrictions, and broader hesitancy toward dengue vaccination efforts.[8]Insecticide Resistance: A Vector Control Crisis

Aedes aegypti's escalating resistance to pyrethroids and other commonly used insecticides poses a significant barrier to effective dengue control. This resistance stems largely from the indiscriminate and prolonged use of insecticides, particularly in fogging and ultra-low volume spraying campaigns that are often deployed without adequate entomological surveillance or efficacy assessments. [15] Such reactive and non-targeted applications frequently fail to suppress mosquito densities below epidemic transmission thresholds. While larviciding is conceptually more targeted and efficient, its operational success is constrained by the widespread presence of cryptic breeding habitats and the inconsistent involvement of communities in source reduction. Compounding the issue is the limited pipeline of novel insecticides with new modes of action, undermining the sustainability of chemical control interventions. [5,15] In this context, insecticide resistance is not just a technical challenge but a critical vulnerability in current vector control programmes that urgently demands innovation, strategic rotation, and integration with non-chemical approaches.

Urbanisation and Habitat Explosion

The rapid pace of urbanisation in low- and middle-income countries has created ideal conditions for the proliferation of Aedes aegypti mosquitoes, the primary dengue vector. Urban sprawl, especially in informal settlements and peri-urban slums, leads to dense human populations living amid poorly managed environments. Discarded containers, rooftop water tanks, and flowerpots become abundant larval habitats. Compounding this, inadequate municipal infrastructure, unreliable water supply systems, poor waste disposal, and lack of regulatory enforcement undermine source reduction efforts. Community participation in vector control remains minimal, further diminishing the effectiveness of interventions aimed at eliminating breeding sites and controlling dengue transmission. [16]Climate Change and Ecological Expansion

Climate change is fundamentally reshaping the ecological landscape for dengue transmission, enabling the expansion of Aedes mosquitoes into previously non-endemic,

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temperate regions. [10,17] Rising ambient temperatures accelerate mosquito development, prolong adult survivability, and enhance virus replication and transmission efficiency. Additionally, unpredictable rainfall patterns and urban flooding generate abundant and persistent breeding habitats, often in densely populated areas. These dynamic environmental changes render traditional static vector control strategies insufficient. Despite the growing recognition of these risks, the integration of real-time entomological, virological, and meteorological data into predictive models remains limited, curtailing the operational utility of climate-informed early warning systems. [18]Fragmented Surveillance and Delayed Response

Surveillance systems in many dengue-endemic countries remain passive, delayed, and poorly integrated. Entomological, clinical, and laboratory data are often collected in silos and rarely synthesised, resulting in fragmented responses that lack precision and timeliness. Fogging operations and other vector control measures are typically reactive rather than anticipatory, commencing only after outbreaks are already in progress. [7,9] Modern tools such as GIS mapping, real-time case-based reporting, and syndromic surveillance remain underutilised due to persistent capacity constraints and the lack of sustained financial and institutional investment. Additionally, cross-border data sharing is negligible, despite the growing role of human mobility and transnational transmission in dengue epidemiology. [19] A major limitation in entomological surveillance is the absence of efficient adult mosquito traps [20, 21], which are essential for accurately estimating vector density thresholds and calculating the minimum infection rate (MIR)—critical metrics for early outbreak detection and evidence-based intervention planning.

Operational and Research Gaps in Novel Strategies Although novel vector control tools like Wolbachia-infected mosquitoes and genetically modified vectors offer considerable promise, their real-world implementation faces several operational and research barriers. [6,23] Scaling up these interventions requires significant logistical coordination, sustained funding, and regulatory approval frameworks that are often underdeveloped in endemic regions. Concerns about ecological impacts and unintended consequences, such as species replacement or altered transmission dynamics, persist. Furthermore, public perception and community acceptance remain fragile, especially in areas with limited scientific literacy or distrust in authorities. On the therapeutic front, antiviral drug development remains stagnant due to the challenges posed by antibody-dependent enhancement (ADE) and the need for pan-serotype efficacy. These scientific barriers are compounded by weak market incentives and limited pharmaceutical investment, given dengue's status as a neglected tropical disease. [20] Addressing these gaps demands transdisciplinary research, long-term financial commitment, and inclusive public engagement to translate innovation into impactful and sustainable public health outcomes.

The Socio-Political Dimension

Dengue control is not merely a biomedical challenge but a socio-political issue rooted in fragmented governance, short political cycles, and siloed bureaucracies. Ministries of health, urban development, and sanitation frequently operate without synergy, resulting in disjointed vector control and reactive outbreak responses. [9] Political short-termism often prioritises visible but ineffective measures like fogging over sustained surveillance and prevention. Community participation—a cornerstone of integrated vector management—is weakened by misinformation, intervention fatigue, and the perception that dengue is non-fatal.[9] Despite this, the socioeconomic cost is immense, driven by healthcare expenses, loss of income, and strain on public health systems.[9] The controversy surrounding Dengvaxia—stemming from inadequate risk communication and early deployment without full safety clarity—has significantly damaged vaccine confidence, complicating future immunization campaigns.[10] Overcoming these socio-political barriers requires strong leadership, intersectoral governance, transparent risk communication, and long-term investments that prioritise

The way forward

Dengue control must evolve from reactive, mosquito-centric interventions to forward-looking, evidence-based strategies rooted in Integrated Vector Management (IVM).[24,25] Integrated Vector Management (IVM) can be evolved into Integrated Vector-Borne Disease Management (IVBDM), emphasising the parallel control of both vectors and diseases. This approach offers a sustainable framework by harmonising diverse strategies for vector-borne disease control through intersectoral collaboration, policy integration, and community empowerment. Crucially, vector control should be embedded within a broader public health system that prioritises early-warning surveillance using real-time entomological and epidemiological data, remote sensing, and climate-informed predictive modelling.[26-28] Investment in innovative, affordable point-of-care diagnostics and pathogen detection in vectors can bridge the gap between surveillance and response.[29] Furthermore, strategies must be hyper-localised-tailored to reflect spatial heterogeneity in transmission dynamics, socio-economic vulnerabilities, urban infrastructure, and cultural behaviors.[30,31] Transdisciplinary research linking virology, vector biology, human behaviour, and systems thinking will be pivotal to designing adaptive interventions.[32,33] By shifting from short-term control to long-term prevention and resilience, dengue management can transform from a fragmented response into an integrated, context-aware public health paradigm.[34,35]

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Summary

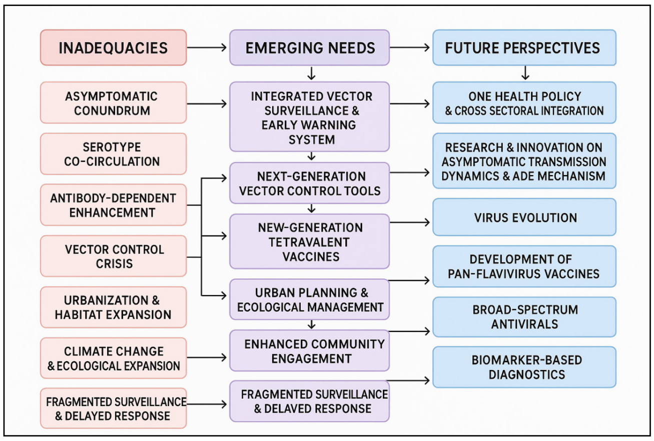

Figure 1.Summary

Conclusion

The transformation of dengue control stands at a critical crossroads, shaped by persistent scientific challenges, entrenched operational gaps, and a complex ecological and socio-political landscape. The high burden of asymptomatic infections, co-circulating serotypes, and the immunological paradox of antibody-dependent enhancement (ADE) continue to obscure disease dynamics and thwart conventional control strategies. Meanwhile, rapid urbanisation, expanding mosquito habitats, and climate-driven ecological shifts exacerbate vector proliferation and virus transmission. These are further compounded by fragmented surveillance systems, delayed outbreak responses, and gaps in both implementation and research of novel interventions.

To overcome these multifaceted barriers, a paradigm shift is essential—one that transitions from reactive containment to anticipatory, integrated, and adaptive control. Future success will depend on the establishment of robust, integrated vector surveillance coupled with real-time early warning systems, deployment of next-generation vector control tools, and investment in tetravalent vaccines and pan-flavivirus candidates. Urban planning must align with ecological management, supported by sustained community engagement and cross-sectoral governance under a One Health framework. Additionally, deeper research into asymptomatic transmission, ADE mechanisms, viral evolution, and host-pathogen interactions must guide the development of broad-spectrum antivirals and biomarker-based diagnostics. Only through such a comprehensive, scientifically grounded, and systemically integrated approach can the vision of dengue elimination shift from a distant aspiration to a tangible public health milestone.

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References

1. Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL, Drake JM, Brownstein JS, Hoen AG, Sankoh O, Myers MF. The global distribution and burden of dengue. Nature. 2013 Apr 25;496(7446):504-7. [Google Scholar] [Pubmed]
2. World Health Organization. Dengue and severe dengue. World Health Organization. Regional Office for the Eastern Mediterranean; 2014. [Google Scholar]
3. Brady OJ, Gething PW, Bhatt S, Messina JP, Brownstein JS, Hoen AG, Moyes CL, Farlow AW, Scott TW, Hay SI. Refining the global spatial limits of dengue virus transmission by evidence-based consensus. [Google Scholar] [Pubmed]
4. World Health Organization, Special Programme for Research, Training in Tropical Diseases, World Health Organization. Department of Control of Neglected Tropical Diseases, World Health Organization. Epidemic, Pandemic Alert. Dengue: guidelines for diagnosis, treatment, prevention and control. World Health Organization; 2009. [Google Scholar] [Pubmed]
5. Achee NL, Gould F, Perkins TA, Reiner Jr RC, Morrison AC, Ritchie SA, Gubler DJ, Teyssou R, Scott TW. A critical assessment of vector control for dengue prevention. PLoS neglected tropical diseases. 2015 May 7;9(5):e0003655. [Google Scholar] [Pubmed]
6. O'Neill SL, Ryan PA, Turley AP, Wilson G, Retzki K, Iturbe-Ormaetxe I, Dong Y, Kenny N, Paton CJ, Ritchie SA, Brown-Kenyon J. Scaled deployment of Wolbachia to protect the community from dengue and other Aedes transmitted arboviruses. Gates open research. 2019 Aug 13;2:36. [Google Scholar] [Pubmed]
7. Runge-Ranzinger S, McCall PJ, Kroeger A, Horstick O. Dengue disease surveillance: an updated systematic literature review. Tropical Medicine & International Health. 2014 Sep;19(9):1116-60. [Google Scholar] [Pubmed]
8. Sridhar S, Luedtke A, Langevin E, Zhu M, Bonaparte M, Machabert T, Savarino S, Zambrano B, Moureau A, Khromava A, Moodie Z. Effect of dengue serostatus on dengue vaccine safety and efficacy. New England Journal of Medicine. 2018 Jul 26;379(4):327-40. [Google Scholar] [Pubmed]
9. Shepard DS, Undurraga EA, Halasa YA, Stanaway JD. The global economic burden of dengue: a systematic analysis. The Lancet infectious diseases. 2016 Aug 1;16(8):935-41.[Google Scholar] [Pubmed]
10. Larson HJ, Hartigan-Go K, de Figueiredo A. The Philippines is the latest victim of vaccine scares. Lancet. 2018;392(10165):620–621. doi:10.1016/S0140-6736(18)31758-0.
11. Colón-González FJ, Sewe MO, Tompkins AM, Sjödin H, Casallas A, Rocklöv J, Caminade C, Lowe R. Projecting

the risk of mosquito-borne diseases in a warmer and more populated world: a multi-model, multi-scenario intercomparison modelling study. The Lancet Planetary Health. 2021 Jul 1;5(7):e404-14. [Google Scholar]
12. Huong LT, Hung NH, Dai DN, Tai TA, Hien VT, Satyal P, Setzer WN. Chemical compositions and mosquito larvicidal activities of essential oils from Piper species growing wild in Central Vietnam. Molecules. 2019 Oct 27;24(21):3871.[Google Scholar]
13. Duong V, Lambrechts L, Paul RE, Ly S, Lay RS, Long KC, Huy R, Tarantola A, Scott TW, Sakuntabhai A, Buchy P. Asymptomatic humans transmit dengue virus to mosquitoes. Proceedings of the National Academy of Sciences. 2015 Nov 24;112(47):14688-93. [Google Scholar] [Pubmed]
14. Yoon, I. K., et al. (2012). Underrecognized mildly symptomatic viremic dengue virus infections in rural Thai schools. PLoS Neglected Tropical Diseases, 6(1), e1732. [Pubmed]
15. Halstead SB. Neutralization and antibody-dependent enhancement of dengue viruses. [Google Scholar] [Pubmed]
16. Moyes CL, Vontas J, Martins AJ, Ng LC, Koou SY, Dusfour I, Raghavendra K, Pinto J, Corbel V, David JP, Weetman D. Contemporary status of insecticide resistance in the major Aedes vectors of arboviruses infecting humans. PLoS neglected tropical diseases. 2017 Jul 20;11(7):e0005625. [Google Scholar] [Pubmed]
17. Bowman, L. R., et al. (2016). Barriers to implementation of sustainable vector control in urban settings. BMC Public Health, 16, 635.
18. Messina, J. P., et al. (2019). The impact of climate change on dengue. eLife, 8, e48421.
19. Samy AM, Thomas SM, Wahed AA, Cohoon KP, Peterson AT. Mapping the global geographic potential of Zika virus spread. Memórias do Instituto Oswaldo Cruz. 2016 Sep;111(9):559-60. [Google Scholar] [Pubmed]
20. Tatem AJ, Jia P, Ordanovich D, Falkner M, Huang Z, Howes R, Hay SI, Gething PW, Smith DL. The geography of imported malaria to non-endemic countries: a meta-analysis of nationally reported statistics. The Lancet Infectious Diseases. 2017 Jan 1;17(1):98-107. [Google Scholar] [Pubmed]
21. Sivagnaname N, Gunasekaran K. Need for an efficient adult trap for the surveillance of dengue vectors. Indian Journal of Medical Research. 2012 Nov 1;136(5):739-49. [Google Scholar] [Pubmed]
22. Sivagnaname N, Yuvarajan S, De Britto RL. Urgent need for a permanent dengue surveillance system in India. Current Science. 2012 Mar 10;102(5):672-5. [Google Scholar]
23. Utarini A, Indriani C, Ahmad RA, Tantowijoyo W, Arguni E, Ansari MR, Supriyati E, Wardana DS, Meitika Y, Ernesia I, Nurhayati I. Efficacy of Wolbachia-infected mosquito deployments for the control of dengue. New England Journal of Medicine. 2021 Jun 10;384(23):2177-86. [Google Scholar] [Pubmed]
24. World Health Organization. Handbook for integrated vector management. World Health Organization; 2012. [Google Scholar]
25. Wilson AL, Courtenay O, Kelly-Hope LA, Scott TW, Takken W, Torr SJ, Lindsay SW. The importance of vector control for the control and elimination of vector-borne diseases. PLoS neglected tropical diseases. 2020 Jan 16;14(1):e0007831. [Google Scholar] [Pubmed]
26. Reiner Jr RC, Stoddard ST, Forshey BM, King AA, Ellis AM, Lloyd AL, Long KC, Rocha C, Vilcarromero S, Astete H, Bazan I. Time-varying, serotype-specific force of infection of dengue virus. Proceedings of the National Academy of Sciences. 2014 Jul 1;111(26):E2694-702. [Google Scholar] [Pubmed]
27. Semenza JC, et al. Environmental suitability of climate-sensitive infectious diseases: an index-based approach to assess the potential impact of climate change. Environ Health Perspect. 2012;120(7):881–889.
28. Eisen L, Moore CG. Aedes (Stegomyia) aegypti in the continental United States: a vector at the cool margin of its geographic range. Journal of medical entomology. 2013 May 1;50(3):467-78. [Google Scholar] [Pubmed]
29. Yohana E, et al. Innovations in point-of-care diagnostics for vector-borne diseases: Barriers and opportunities. Trends Parasitol. 2023;39(2):103–117.
30. Salje H, Lessler J, Endy TP, Curriero FC, Gibbons RV, Nisalak A, Nimmannitya S, Kalayanarooj S, Jarman RG, Thomas SJ, Burke DS. Revealing the microscale spatial signature of dengue transmission and immunity in an urban population. Proceedings of the National Academy of Sciences. 2012 Jun 12;109(24):9535-8. [Google Scholar] [Pubmed]
31. Louis VR, Phalkey R, Horstick O, Ratanawong P, Wilder-Smith A, Tozan Y, Dambach P. Modeling tools for dengue risk mapping-a systematic review. International journal of health geographics. 2014 Dec 9;13(1):50. [Google Scholar] [Pubmed]
32. Tatem AJ, Huang Z, Narib C, Kumar U, Kandula D, Pindolia DK, Smith DL, Cohen JM, Graupe B, Uusiku P, Lourenco C. Integrating rapid risk mapping and mobile phone call record data for strategic malaria elimination planning. Malaria journal. 2014 Feb 10;13(1):52. [Google Scholar] [Pubmed]
33. Bowman LR, Donegan S, McCall PJ. Is dengue vector control deficient in effectiveness or evidence?:

ISSN: 0019-5138
DOI: https://doiorg/10.24321/0019.5138.2026109

Systematic review and meta-analysis. PLoS neglected tropical diseases. 2016 Mar 17;10(3):e0004551. [Google Scholar] [Pubmed]

34. McGraw EA, O'neill SL. Beyond insecticides: new thinking on an ancient problem. Nature Reviews Microbiology. 2013 Mar;11(3):181-93. [Google Scholar] [Pubmed]
35. Wilder-Smith A, Gubler DJ, Weaver SC, Monath TP, Heymann DL, Scott TW. Epidemic arboviral diseases: priorities for research and public health. The Lancet infectious diseases. 2017 Mar 1;17(3):e101-6. [Google Scholar] [Pubmed]

ISSN: 0019-5138
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