The coevolutionary relationship between *Plasmodium parasite*s and their hosts has led to remarkable plasticity in parasite traits that facilitate adaptation to changing environments and vector species shifts. This adaptability complicates control efforts by enabling parasites to evade interventions through altered transmission dynamics or resistance development. Understanding these biological determinants is vital for designing effective transmission-blocking strategies targeting both parasite stages in humans and vectors (Mukamurera, 2024; Sollelis et al., 2024).

3.3 Effects of climate change and human activities on transmission risk

Climate change significantly influences malaria transmission by altering environmental conditions that affect both mosquito vectors and *Plasmodium parasite*s. Rising temperatures can accelerate mosquito development rates, increase biting frequency, extend lifespan under certain humidity conditions, and shorten parasite incubation periods within vectors-all factors that enhance transmission potential. Changes in rainfall patterns create new breeding habitats or eliminate existing ones, while extreme weather events such as floods or droughts can either amplify or suppress vector populations regionally (Idani et al., 2025; Megersa and Luo, 2025).

Human activities including land use changes, urbanization, migration, and political instability further modify ecosystems in ways that impact malaria risk. Deforestation or agricultural expansion can increase vector habitats or bring humans into closer contact with vectors. Additionally, reduced funding for vector control programs due to socioeconomic factors exacerbates vulnerability to outbreaks despite climatic suitability for transmission. Integrated approaches combining climate-informed surveillance with sustainable public health interventions are essential to mitigate these evolving risks (Rossati et al., 2016; Megersa and Luo, 2025).

4 Conventional Mosquito Control Strategies and Their Limitations

4.1 Chemical control methods (insecticide-treated nets, indoor residual spraying)

Chemical control remains the cornerstone of malaria vector management, primarily through the use of insecticide-treated nets (ITNs) and indoor residual spraying (IRS). These interventions have significantly reduced malaria incidence by targeting mosquitoes that feed and rest indoors, thereby interrupting transmission cycles. However, their effectiveness is increasingly compromised by the widespread emergence of insecticide resistance among Anopheles vectors, which diminishes mortality rates and reduces the protective efficacy of these tools (Benelli and Beier, 2017; Namias et al., 2021). Additionally, ITNs and IRS mainly target indoor-biting mosquitoes, leaving outdoor and early-evening biting vectors less affected, which sustains residual transmission despite high coverage (Benelli and Beier, 2017).

Innovations such as insecticidal paints are being explored to enhance chemical control by providing longer-lasting residual effects and easier application compared to conventional spraying. These paints may improve cost-effectiveness and acceptability in endemic regions like India but still face challenges related to resistance development and environmental safety (Singh et al., 2024). Despite these advances, reliance on chemical methods alone is insufficient for sustainable malaria control due to ecological complexities and evolving vector behaviors that reduce contact with treated surfaces (Benelli and Beier, 2017).

4.2 Environmental management and biological control approaches

Environmental management strategies aim to reduce mosquito breeding sites through habitat modification or manipulation, such as drainage of stagnant water or improved water management practices. These approaches can be effective in limiting vector populations but often require sustained community engagement and infrastructure support, which may be challenging in resource-limited settings (Benelli and Beier, 2017). Biological control methods offer eco-friendly alternatives by utilizing natural predators like larvivorous fish, entomopathogenic fungi, bacteria (e.g., *Bacillus thuringiensis israelensis*), or genetically modified mosquitoes to suppress vector populations without chemical insecticides (Benelli et al., 2016; Hamed et al., 2022).

Biocontrol strategies are gaining attention due to their potential sustainability and reduced risk of resistance development. However, their implementation faces limitations including variable efficacy under field conditions,