

Perspective

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Biological forms and public health implications of *Anopheles stephensi*: Addressing the urban malaria challenge

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Anopheles (An.) stephensi is one of the dominant malaria vectors in India, Bangladesh, Pakistan, Iran, Iraq and some other Asian countries[1]. It plays a crucial role in transmitting *Plasmodium falciparum* and *Plasmodium vivax* in India along with its rural counterpart, *An. culicifacies*. This mosquito species has adapted well to urban and peri-urban environments, making it a significant public health concern in the country. The presence of *An. stephensi* in urban areas contrasts with other malaria vectors that predominantly inhabit rural regions, thus complicating traditional malaria control strategies. It is well-adapted to human-made environments, breeding in various containers including tanks, cisterns, and barrels used for water storage.

An. stephensi exhibits three biological forms based on egg float ridge counts: type, intermediate, and mysorensis[2,3]. The type form is typically an urban form whereas the mysorensis and intermediate forms are primarily found in rural regions. These three forms also differ in terms of their vectorial capacities, distribution and each one has its contribution in malaria transmission in a particular region. In India, the type form is the predominant vector of urban systems which mostly breeds indoors while mysorensis form is distributed mainly in rural areas, breeds outdoors, and is a poor vector (a mosquito species that has a low capacity to transmit the malaria parasite to humans, even if it is capable of carrying the parasite). On the other hand, the role of the intermediate form is uncertain. Interestingly, in Iran, Pakistan and Afghanistan, mysorensis is recognized as a medically important vector of malaria in both urban and rural areas[4]. The variability in the vectorial capacities of these forms necessitates precise identification and characterization within specific malaria transmission foci. Understanding the geographic distribution and vectorial roles of these forms is critical for implementing effective control measures.

In the last two decades, the geographic range of *An. stephensi* has rapidly extended across the Asian and African continents as evident from the reporting of the type form from Lakshadweep islands in 2001, followed by Djibouti in 2012, Sri Lanka in 2016 and across the Horn of Africa, posing a global threat[5-7]. This spatial expansion of *An. stephensi* to new regions may have profound public health implications. Urban populations, previously considered at lower risk for malaria, are now vulnerable to the disease. A recent report by Emiru *et al.* has specifically highlighted the involvement of *An. stephensi* in the spread of "drug and diagnosis resistant malaria" in Africa[8]. This shift urgently necessitates a re-evaluation of existing malaria control programs and the development of targeted interventions for urban settings. Traditional interventions, designed for rural vectors, may prove inadequate in addressing the unique challenges posed by *An. stephensi*.

Effective control of *An. stephensi* requires a comprehensive approach through integrating several strategies to weave the threads together. (1) Environmental management: Reducing breeding sites by ensuring proper water storage in covered water containers, and eliminating stagnant water sources. Regular monitoring and cleaning of potential breeding sites are of paramount importance in this strategy. (2) Chemical control: The use of insecticides, such as indoor residual spraying (IRS) and insecticide-treated nets (ITNs), remains critical. However, resistance management is even more crucial, which may be tackled through the rotation of insecticides and exploration of alternative mosquitocidal compounds. (3) Biological control: Employing biological agents like larvivorous fish and bacteria such as *Bacillus thuringiensis israelensis* (Bti) to target mosquito larvae can dramatically reduce adult vector populations. (4) Community engagement: Public awareness campaigns to educate communities about malaria prevention, proper water storage practices, and the use of protective measures like bed nets and repellents is important for a comprehensive approach.

There are several questions that need immediate attention. The type form of *An. stephensi* is a primary vector in India while in Iran both

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type and mysorensis forms serve as vectors of malaria. A few studies have indicated that type form has invaded the African continent[9]. But, still it is important to delve deep into characterisation of the biological form of the *An. stephensi* populations that have been detected in the African continent. This will greatly help in tracking the origin of the invading species whether it is from India or Iran. Further, the three forms of *An. stephensi* differ in their vectorial capacity as well as other aspects of vector bionomics such as insecticide resistance status, breeding and biting preferences. Therefore, bionomics studies encompassing all three forms will be important for applying vector control activities. It will also be relevant to differentiate the three forms at the genetic level which will significantly enhance our understanding of the behavioural differences among them. This will also aid in the development of targeted interventions, such as gene driven technologies. Therefore, studies focused on the mosquitoes' behaviour, genetic makeup, and resistance patterns should be prioritized to add novel and innovative strategies to our control tool box.

The second compelling question is regarding the infectiousness of *An. stephensi* mysorensis from India as well as intermediate form from the globe. There is a dearth of literature on these two aspects. This lack of concrete evidence on the *Plasmodium* carrying capacity of these two forms presents a question mark of whether these two forms are really incapable of transmitting the malaria parasite. Therefore, laboratory and field studies are required to update the knowledge about the vectorial potential of all three forms simultaneously.

Furthermore, research evidence on insecticide resistance development and its mechanism in all these three forms will guide the world malaria control programme to contain the malaria transmission due to *An. stephensi* mosquitoes.

The rapid urbanization in malaria-endemic regions, combined with the invasive nature of *An. stephensi*, calls for a concerted effort to address the growing threat. We need to adopt a collaborative strategy to bring different stakeholders, like governments, public health organizations, and research institutions together to develop and implement effective control strategies in a prioritized manner. Additionally, monitoring for insecticide resistance and exploration of alternative control methods, such as biological control and genetic approaches, should be integral components of the comprehensive control program against this vector species.

In conclusion, the rise of *An. stephensi* as a dominant vector in urban and peri-urban settings marks a paradigm shift in malaria transmission dynamics. Addressing this challenge requires a holistic, multidisciplinary approach that integrates environmental, chemical, biological, and genetic tools while fostering community participation. Only through such a coordinated effort can we hope to mitigate the impact of this formidable vector and move closer to the goal of malaria eradication.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' contributions

GK and SP conceptualized, drafted the manuscript. GK, SP and HS reviewed the manuscript.

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