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Prioritizing urban water-storage containers for molecular surveillance of invasive *Anopheles stephensi* in Isiolo, Kenya: An evidence-informed opinion

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ABSTRACT

Anopheles stephensi is an invasive urban malaria vector whose expansion in the Horn of Africa has raised concern because of its ability to exploit human-made water-holding habitats. In Kenya, molecular surveillance first confirmed the presence of *An. stephensi* in Marsabit and Turkana counties in 2022, and subsequent nationwide work documented spread into additional counties including Isiolo. Published Kenyan field data show larvae in dumped tires, plastic containers, water-storage tanks, concrete cisterns, spillover around community water points, and water pits at mining sites. Although no habitat-by-habitat productivity analysis has yet been published for Isiolo alone, evidence from Kenya and ecologically comparable semi-arid settings in eastern Ethiopia indicates that large domestic and construction-related water-storage habitats can dominate dry-season larval production in such environments. Based on this evidence synthesis, we argue that urban water-storage containers should be prioritized as initial surveillance targets for molecular surveillance of *An. stephensi* in Isiolo. Operational targets should include jerrycans, barrels or drums, cut or discarded tanks, rooftop and ground-level tanks, concrete cisterns, overflow points near communal water systems, and drawing on Ethiopian comparative evidence, construction-associated water reservoirs. Because larval habitats in Kenya frequently contain mixed mosquito assemblages and morphology can be challenging in newly invaded settings, ITS2- and *cox*1-based confirmation should be incorporated into surveillance workflows.

1. Introduction

The invasion of *Anopheles stephensi* into Africa is a major malaria-control concern because, unlike many dominant native African malaria vectors, it readily exploits artificial water-holding habitats and can sustain transmission in urban and peri-urban settings (Sinka et al., 2020; Taylor et al., 2024). Since its first documentation in Djibouti, the species has been linked to urban malaria resurgence in the Horn of Africa, and outbreak-associated evidence from Djibouti and Dire Dawa has strengthened concern about its public-health impact (Faulde et al., 2014; Pommier de Santi et al., 2021; Emiru et al., 2023). Recent syntheses have emphasized that *An. stephensi* can use a wide range of man-made larval sites across its native and invaded ranges, making stored-water systems a central operational target for surveillance and control (Al-Eryani et al., 2023; Mwema et al., 2024; Taylor et al., 2024).

Isiolo County is an operationally significant surveillance priority beyond simply being a newly affected county. It is a semi-arid, rapidly urbanizing area with limited piped water coverage, making residents heavily dependent on household water storage in tanks, drums, jerrycans and cisterns. These stored-water systems represent stable, replenished breeding habitats that persist through dry seasons when ephemeral surface water is scarce, precisely the conditions under which large domestic water-storage containers have dominated *An. stephensi* larval productivity in comparable settings (Gebresilassie et al., 2025; Yared et al., 2025). Isiolo is also a transit hub linking northern Kenya to the rest of the country, facilitating vector movement and making early detection especially consequential.

The purpose of this paper is to argue that urban water-storage containers should be prioritized as initial surveillance targets for molecular surveillance of invasive *An. stephensi* in Isiolo. This argument rests on three linked but analytically distinct observations: first, Kenya has already documented molecularly confirmed spread of *An. stephensi* into Isiolo, with artificial water-holding containers among the recorded positive habitats; secondly, comparative evidence from eastern Ethiopia,

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an ecologically similar semi-arid invaded setting, indicates that large domestic and construction-related water-storage structures can dominate dry-season productivity; and thirdly, urban overhead tank systems in India show this habitat class to be a major source of collected anopheline immatures overall in a native-range urban transmission setting where *An. stephensi* is the predominant vector. We make this inferential argument explicitly, and throughout the text, we distinguish between what has been directly documented in Kenya, what is inferred from comparable invaded-range studies, and what constitutes the proposed surveillance hypothesis for Isiolo.

2. Sources and approach

This is a literature-based evidence synthesis rather than a primary field study. To identify relevant publications, we searched PubMed, Google Scholar, and Web of Science using the terms "*Anopheles stephensi*" in combination with "larval habitat", "water storage", "Kenya", "East Africa", "Ethiopia", "molecular surveillance", and "ITS2" or "COI". The search was conducted in April 2025 with no formal date restriction, but emphasis was placed on publications from 2014 onwards to capture the African invasion period. We included peer-reviewed primary studies, systematic reviews, and consensus methodology papers. Studies were included if they reported larval habitat data, molecular identification methods, or productivity analyses relevant to *An. stephensi* in its invaded African or native Asian range. Studies were excluded if they reported only adult trap data without habitat context or if habitat descriptions were too generic to inform operational targeting. No meta-analytic pooling was performed. The evidence is presented narratively, with explicit distinction between direct Kenyan data, comparative evidence from ecologically similar settings, and the proposed operational inference for Isiolo.

3. Direct evidence from Kenya and Isiolo

Kenya's first published confirmation of *An. stephensi* came from Marsabit and Turkana counties in 2022. In a study by Ochomo et al. (2023), larvae were recovered from animal watering pans, containers, tires, seasonal river pans and cement water cisterns, and species confirmation relied on endpoint PCR together with morphological and sequence identification. That report established two points of direct relevance to Isiolo: artificial water-holding habitats were already implicated in Kenya, and molecular confirmation was feasible within routine surveillance.

Subsequent nationwide work substantially broadened the Kenyan picture. A 2025 multicounty study confirmed 114 larval and 33 adult *An. stephensi* specimens in 7 of 18 surveyed counties, including Isiolo (Samake et al., 2025). Reported larval habitats across these Kenyan sites included dumped car tires, water-storage tanks and other plastic containers, spillover from community water points, and water pits dug at mining sites; 59% of positive larval sites were urban or peri-urban (Samake et al., 2025). Larvae of *An. stephensi* also co-occurred with *An. arabiensis* and culicine mosquitoes in many Kenyan sites (Samake et al., 2025). Together, these findings constitute direct evidence that: (i) *An. stephensi* is present in Isiolo; and (ii) artificial water-holding container tanks, plastic containers, tires, mining-site water pits and community-water overflow points are consistently implicated across Kenyan sites. Habitat-by-habitat productivity data specific to Isiolo county have not yet been published, and this gap is an important caveat for the prioritization argument that follows.

4. Comparative evidence from ecologically similar invaded settings

Because Isiolo-specific productivity data do not yet exist, the strongest analytical support for habitat prioritization comes from eastern Ethiopia, which shares Isiolo's semi-arid climate, dependence on stored domestic water, and urban growth trajectory. During dry-season surveys in three Ethiopian towns, construction pits, residential cisterns and ground-level water tanks accounted for 87% of positive habitats and 81% of all larvae, with construction pits predicted to be the most productive habitat class (Gebresilassie et al., 2025). A related Ethiopian study found marked overdispersion in productivity: 77% of larvae originated from only 23% of sites, and the superproductive habitats were primarily water cisterns used for residential or construction purposes (Yared et al., 2025). These Ethiopian findings are important because they suggest that targeted surveillance of a relatively small subset of stable, large-volume water-storage habitats can be more efficient than diffuse sampling of all standing water.

It is essential to note that construction-associated water reservoirs, while a dominant productivity class in Ethiopia (Gebresilassie et al., 2025; Yared et al., 2025), have not yet been directly confirmed as *An. stephensi* larval habitats in published Kenyan surveillance. The Kenyan mining-site water pits reported by Samake et al. (2025) may represent a functionally analogous habitat class, but this analogy remains inferential rather than confirmed. Including construction-related water reservoirs among operational surveillance targets in Isiolo is therefore a hypothesis informed by Ethiopian comparative data rather than a conclusion drawn from Kenyan field evidence.

Evidence from the native Asian range of *An. stephensi* points in the same direction regarding overhead and domestic tank systems. In urban Chennai, wells and overhead tanks were major breeding sources, with overhead tanks contributing 78.6% of all collected anopheline immatures; other positive habitats included cemented cisterns or containers, barrels or drums, underground tanks and plastic containers (Thomas et al., 2016). This 78.6% figure reflects total anopheline immature collections across the study site rather thanan *An. stephensi*-specific count. However, *An. stephensi* was the predominant local vector at this transmission setting, and co-inhabitation with other mosquito genera was markedly rarer in overhead tanks (5%) than in wells (66.7%) or other habitat types (63.6%), indicating that overhead tanks were disproportionately associated with *An. stephensi* breeding specifically rather than with anopheline breeding in general (Thomas et al., 2016). While direct extrapolation from an Indian metropolitan setting to a Kenyan semi-arid town requires caution, the convergent signal across Ethiopian and Indian data that large, stable, replenished domestic storage systems are prioritized over ephemeral natural pools provides a coherent basis for the Isiolo surveillance hypothesis (Table 1).

5. Proposed surveillance framework for Isiolo

Drawing on the three tiers of evidence described above, direct Kenyan documentation, Ethiopian comparative data, and native-range Indian evidence, a habitat-prioritized molecular surveillance framework for Isiolo should place urban and peri-urban stored-water infrastructure as first-line inspection targets. These include rooftop and overhead tanks, ground-level tanks, concrete cisterns, cut or discarded tanks, storage drums, jerrycans, and overflow points around communal water systems. Used tires and small plastic containers should remain on the checklist because Kenyan surveys have demonstrated positivity in those habitat types (Ochomo et al., 2023; Samake et al., 2025). Construction-associated water reservoirs should be included as a second-tier hypothesis target, clearly flagged as informed by Ethiopian comparative evidence pending Kenyan confirmation (Gebresilassie et al., 2025; Yared et al., 2025).

Understanding the socio-environmental drivers of water storage in Isiolo is directly relevant to the design of this surveillance framework and of any subsequent larval source management response. Isiolo's semi-arid climate and limited piped water infrastructure mean that households and construction sites depend on stored water for daily needs, and reliance on storage intensifies during the extended dry season when municipal or trucked water supply becomes unreliable. Uncovered or poorly maintained jerrycans, drums, and rooftop tanks are often

Table 1
Published evidence supporting prioritization of urban water-storage habitats for *Anopheles stephensi* surveillance in Isiolo, Kenya, organized by evidence tier.

Reference	Setting and evidence tier	Key habitat finding	Relevance to Isiolo
Ochomo et al. (2023)	Marsabit and Turkana, Kenya Tier 1 (direct Kenyan evidence)	Larvae recovered from containers, tires, animal watering pans, seasonal river pans and cement cisterns; confirmed by endpoint PCR with morphological and sequence identification	Establishes that artificial water-holding habitats are implicated in Kenya, and molecular confirmation is operationally feasible
Samake et al. (2025)	Seven Kenyan counties including Isiolo, 2022–2024 Tier 1 (direct Kenyan evidence)	Habitats included dumped car tires, water-storage tanks, plastic containers, community-water spillover sites, and mining-site water pits; 59% of positive sites were urban or peri-urban.	Confirms *An. stephensi* in Isiolo; stored-water and overflow habitats constitute the core Kenyan surveillance signal
Gebresilassie et al. (2025)	Eastern Ethiopia, dry-season ecology Tier 2 (comparative invaded-range evidence)	Construction pits, residential cisterns and ground-level water tanks accounted for 87% of positive habitats and 81% of all larvae	Large stable water-storage habitats likely dominate surveillance yield in comparable semi-arid settings; construction reservoirs are an Ethiopian-informed hypothesis for Isiolo
Yared et al. (2025)	Eastern Ethiopia, seasonal productivity Tier 2 (comparative invaded-range evidence)	77% of larvae originated from 23% of sites; superproductive habitats were mainly residential or construction water cisterns	Focused sampling of the most stable water-storage habitats is likely to be efficient; supports prioritization logic for Isiolo
Thomas et al. (2016)	Chennai, India Tier 3 (native-range urban comparator)	Overhead tanks contributed 78.6% of collected anopheline immatures; other positive habitats included cemented containers, drums and underground tanks	Convergent native-range evidence that rooftop and domestic storage systems are high-priority targets; supports Isiolo inference with explicit caution about setting differences

retained for reasons of cost, convenience, and limited alternative supply rather than an awareness of vector-breeding risk, while cut or discarded tanks and other repurposed containers frequently persist as informal water stores on peri-urban plots. Rapid construction activity associated with Isiolo's growth as a transit hub further sustains temporary water reservoirs at building sites, a pattern consistent with the construction-associated productivity documented in Ethiopia (Gebresilassie et al., 2025; Yared et al., 2025). These socio-environmental factors suggest that pairing molecular surveillance with community and construction-site engagement, for example through container covering, scheduled emptying, or community-based container management, is likely to make focused larval source management more acceptable and sustainable than habitat inspection alone (Al-Eryani et al., 2023; Samake et al., 2025). Formal characterization of these behavioural and infrastructural drivers is an important area for future Isiolo-specific research.

Sequence-based confirmation should be embedded in that workflow. Kenyan detection relied on PCR and sequence-supported confirmation (Ochomo et al., 2023), and more recent methodological work has shown that molecular tools can support early detection even when *An. stephensi* occurs at low frequency or within mixed mosquito pools (Singh et al., 2023). Reviews of invasive-vector identification now recommend standardized sequence-supported confirmation because morphology alone can be difficult in newly invaded settings, especially when larvae are sampled from mixed habitats (Waymire et al., 2024). The most defensible approach for Isiolo is therefore a larval-first surveillance design in which habitat inspection is paired with ITS2- and, where feasible, *cox*1-based confirmation (Fig. 1).

6. Implications for surveillance and vector control

The practical value of a habitat-prioritized, molecularly confirmed surveillance strategy in Isiolo is twofold. First, it improves early detection and spread tracking in a county where published county-specific ecological data are still limited. Secondly, it creates a stronger evidence base for focused larval source management, including habitat covering, cleaning, drainage modification, or targeted larvicide application at the most repeatedly positive sites. Identifying the small subset of superproductive habitats that a focused strategy would target is consistent with the overdispersion pattern documented in Ethiopia (Yared et al., 2025), and with broader calls for integrated surveillance and control as *An. stephensi* expands across the Horn of Africa (Al-Eryani et al., 2023).

7. Limitations

This opinion has important limitations that readers should weigh when applying its recommendations. It is a literature-based synthesis rather than a primary field study, and its habitat prioritization argument is therefore inferential throughout. The available published literature confirms *An. stephensi* in Isiolo and documents relevant habitat classes across Kenya, but it does not provide an Isiolo-specific productivity analysis. The evidence base for large domestic water-storage containers as dominant larval habitats rests primarily on Ethiopian and Indian data from settings that, while ecologically comparable, differ from Isiolo in important respects, including urbanization density, water infrastructure, and surveillance effort. Construction-associated water reservoirs in particular have not been directly confirmed as productive habitats in Kenya and should be approached as a hypothesis rather than an established target. Accordingly, the proposed habitat priorities should be treated as a surveillance starting point to be refined iteratively with local positivity, abundance and seasonality data. Future work in Isiolo should quantify habitat-specific positivity, larval density, persistence across dry and wet periods, and the incremental yield of molecular confirmation relative to morphology alone. Given this evidence gap, larval inspection teams in Isiolo should not confine fieldwork to the prioritized water-storage habitat classes identified here; all potential artificial larval habitats encountered during surveys should be inspected and recorded alongside the prioritized containers. Although this broader approach requires additional field effort and resources, it reduces the risk of overlooking locally productive but unanticipated breeding sites and will generate the comprehensive baseline positivity data needed to refine and validate the proposed prioritization framework for Isiolo.

8. Conclusions

The available published evidence supports prioritizing urban water-storage containers as initial surveillance targets for invasive *An. stephensi* surveillance in Isiolo, Kenya. Direct Kenyan molecular surveillance confirms the species detection in Isiolo and links it to artificial water-

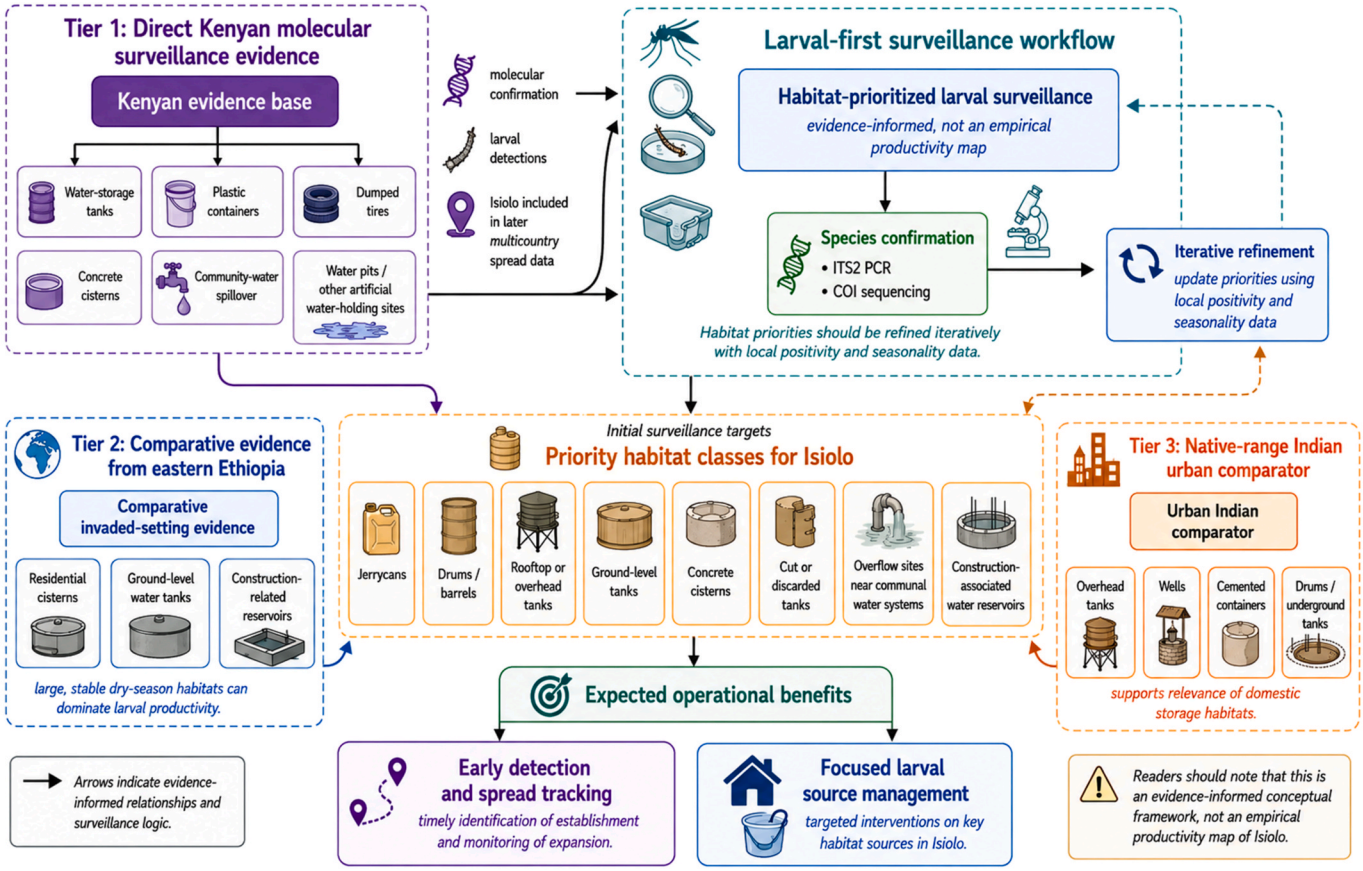


Fig. 1. Conceptual framework for habitat-prioritized molecular surveillance of *Anopheles stephensi* in Isiolo, Kenya. Habitat classes are organized by evidence tier: *Tier 1* (direct Kenyan molecular surveillance evidence), *Tier 2* (comparative evidence from eastern Ethiopia), and *Tier 3* (native-range Indian urban comparator). The figure highlights the role of ITS2- and/or *cox*1-based confirmation in a larval-first surveillance workflow and identifies two expected operational benefits, i.e. early detection and spread tracking, and focused larval source management. Readers should note that this is an evidence-informed conceptual framework, not an empirical productivity map of Isiolo. Habitat priorities should be refined iteratively with local positivity and seasonality data (Thomas et al., 2016; Ochomo et al., 2023; Singh et al., 2023; Waymire et al., 2024; Gebresilassie et al., 2025; Samake et al., 2025; Yared et al., 2025).

holding habitats across multiple counties. Comparative evidence from eastern Ethiopia shows that large domestic and construction-related water reservoirs can dominate larval productivity in dry semi-arid settings analogous to Isiolo, while Indian urban data reinforce the importance of overhead and domestic storage systems. This three-tier evidence synthesis supports a practical operational inference: short-cycle larval surveys in Isiolo should begin with stored-water habitats, pair habitat inspection with ITS2- and *cox*1-based confirmation, and treat construction-associated reservoirs as a second-tier hypothesis target pending local confirmation. This framework is offered as an evidence-informed starting point to guide early detection, spread tracking, and focused larval source management as surveillance capacity in Isiolo develops.

Ethical approval

Not applicable.

CRediT authorship contribution statement

Okechukwu Paul-Chima Ugwu: Writing - original draft, Writing - review & editing, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Chinyere Nneoma Ugwu:** Writing - original draft, Writing - review & editing, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Godson Emeka Anyanwu:** Writing - original draft, Writing - review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization. **Mariam Basajja:** Writing - original draft, Writing - review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization.

Data availability

Not applicable. No new data were generated or analyzed in this work. All statements are based on published literature cited in the manuscript.

Statement on the use of AI-assisted technologies

During the preparation of this work, the authors did not use any artificial intelligence (AI) or AI-assisted technologies to generate, analyze, or interpret scientific content. AI-assisted language-editing tools were used only to support English-language polishing and formatting prior to submission; the authors reviewed and edited all resulting content and take full responsibility for the content of the published article.

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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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