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Original Research Article

Entomological Surveillance and Seasonal Fluctuation of Aedes Mosquito Larval Indices in an Urban Population

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Abstract

Background: Dengue fever presents an escalating public health crisis globally, necessitating robust entomological surveillance protocols to track its primary vectors, Aedes aegypti and Aedes albopictus. Traditional Stegomyia indices viz, House Index (HI), Container Index (CI), and Breteau Index (BI) serve as the foundational indicators for evaluating ecological receptivity and epidemic potential. This study evaluates the seasonal spatial colonization dynamics of Aedes larvae within a high density urban environment to establish actionable vector control thresholds.

Methods: A prospective, 12 month cross sectional entomological survey was conducted across 12,450 residential and commercial properties. Standardized visual inspections of 45,680 domestic, peri-domestic, and commercial water holding structures were systematically executed. Larval specimens were extracted via standard dipping methods and subjected to definitive morphological species identification. Monthly distributions of HI, CI, and BI were mapped against macroclimatic parameters.

Results: A total of 18,420 Aedes larvae were recovered, with A. aegypti accounting for 84.5% and A. albopictus for 15.5%. Pronounced temporal variations were observed, culminating in a critical post-monsoon surge where indices reached their maxima (HI: 12.6%, CI: 10.9%, BI: 34.5), vastly exceeding standard public health alert thresholds (HI > 5%; BI > 20). Old; and discarded automobile tyres and open plastic storage drums demonstrated the highest breeding productivity, serving as primary ecological reservoirs.

Conclusion: Aedes larval indices exhibit strict seasonal coupling with monsoon precipitation patterns and human water storage adaptations. While immature surveillance metrics pose operational constraints regarding cryptic breeding and adult production, they remain vital for mapping micro epidemiological vulnerability. Vector management must transition to proactive source reduction and localized targeted chemical interventions 4 to 6 weeks before historical seasonal transitions to prevent urban dengue outbreaks.

Keywords: Aedes aegypti; Larval Indices; Stegomyia; Vector Surveillance; Dengue.

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Introduction

Dengue fever represents one of the most significant vector borne public health threats globally, with extensive outbreaks continuously recorded across tropical and subtropical environments. [1] The global expansion of arboviral risks, driven by environmental fragmentation, rapid urbanization, and shifting climatic bands, has placed immense operational stress on public health systems. [2] The transmission dynamics of dengue viruses are driven primarily by the highly anthropophilic mosquito Aedes aegypti and secondarily by Aedes albopictus, both of which exploit artificial, man-made water collection vessels within modern built environments. [3,4,5,6] Because effective, widely accessible antiviral medications are missing and massive vaccine deployment faces complex challenges, modern dengue management relies almost exclusively on proactive vector control strategies. [1,7] Continuous entomological surveillance remains essential to delineate vector spatial distribution, track changes in population abundance, and initiate early public health warnings before clinical viral transmission intensifies. [8,9] To quantify the risk of transmission within vulnerable communities, public health agencies rely on classic Stegomyia indices, specifically the House Index (HI), Container Index (CI), and Breteau Index (BI). [9,10] Extensive field studies across heterogeneous urban landscapes in India have confirmed that unplanned construction, municipal water supply disruptions, and domestic habits involving open water storage vessels establish optimal artificial microclimates that sustain vector breeding throughout the year. [3,5]

The geographical range of A. aegypti and A. albopictus has broadened dramatically, establishing persistent populations in locations ranging from Indian states where it was not reported earlier; to Latin America, South East Asia; and Sub Saharan Africa. [11,12,13,14] However, the clinical utility of standard immature larval indices remains a subject of intense scientific debate; several researchers report significant operational discrepancies between larval densities and actual adult vector abundance or clinical disease occurrence. [15,16]

This lack of linear correlation is often attributed to the presence of hidden, unmapped breeding sites and variations in larval nutrient availability, which directly alter adult mosquito production and survival. [6,17]

To resolve these operational gaps, public health frameworks require extensive data comparing traditional larval indices with local macroclimatic variables and specific container productivity profiles across multiple seasons. [15] Our present study evaluates the spatio-temporal distribution of Aedes larval colonization in an urban environment, tracking seasonal index variations to optimize local entomological action thresholds and improve municipal source reduction initiatives.

Methodology

The study was structured as a systematic, prospective cross sectional entomological survey conducted over a continuous 12 month period. The study site encompassed diverse urban built environments, stratified into high density commercial zones, peri urban settlements, and standard residential areas. Field surveillance was designed to capture distinct seasonal variations across the pre monsoon, monsoon, post monsoon, and winter phases.

This methodology has already been validated by previous researchers. [18] within each designated surveillance zone, random cluster sampling was utilized to select properties for weekly visual auditing, covering a total of 12,450 residential and commercial premises. This methodology has already been authenticated by Tilak R et al; and Minhas et al. [13,18].

In all 100 workers, including 20 team supervisors; and 80 survey staff were deployed to conduct the survey. The workers were distributed into 20 units, with each unit covering a previously well-defined administrative area. All units were provided comprehensive training in a 2 day workshop concerning all theoretical; and practical aspects of the survey method, with a view to standardize the procedure to identify the aquatic stages of Aedes and sampling of larval breeding sites.

All participants of the workshop, were subject to a rigorous practical; and field examination, to assess their expertise in conducting the survey precisely. This methodology has already been standardized by Ali et al. [19] Standard WHO guidelines were used as a template for all fieldwork including collection, transportation, and storage of Aedes larvae.20 Ethical consent was obtained from the Institutional Ethical Committee.

Field teams carried out detailed internal and external inspections of all water holding containers on the identified and selected properties. Audited vessels were categorized into specific structural typologies, including plastic drums, cement tanks, clay pots, overhead cisterns, desert coolers, bird baths, and discarded commercial junk materials such as scrap metal and scrap automobile tyres.

A container was classified as positive if it harboured active, visible swimming mosquito larvae or pupae on physical inspection. Immature mosquitoes were carefully collected using standard dippers, pipettes, and fine mesh larval nets before being transferred into labeled, break resistant transport vials containing a 70% ethanol preservation solution. The above methodology has already been validated by several researchers. [5,10,12,16,18,19, 20,21,22,23]

All collected specimens were moved to the laboratory for detailed microscopic evaluation under low power magnification, where species level identification was confirmed using validated morphological keys provided by Service M; and Jan A et al, that distinguish diagnostic thoracic and abdominal arrangements of A. aegypti and A. albopictus. [4,7]

Quantitative field observation logs were aggregated monthly to compute the three principal Stegomyia indices using standard mathematical public health formulae. [6,9,15,21,23]

House Index (HI)

= No. of houses infested with larvae or pupae x 100

Total number of houses inspected

Container Index (CI)

= No.of water holding containers positive for larvae or pupae x 100

Total number of containers inspected

Breteau Index (BI)

= No.of containers positive for larvae or pupae x 100

Total number of houses inspected

Monthly index fluctuations were cross referenced against local macroclimatic variables including cumulative rainfall, mean relative humidity, and ambient temperature fluctuations. This methodology has already been standardised in previous research. [6,14,18] The total vector density patterns were evaluated against standard public health alert levels, specifically noting instances where the House Index crossed the 5% barrier or the Breteau Index exceeded a value of 20, to map local high risk areas. The above methodology has already been authenticated by several researchers. [16,24]

Results

Surveillance Outcomes and Species Composition: Over the comprehensive 12 month field monitoring cycle, epidemiological surveillance teams successfully completed rigorous systematic audits across 12,450 residential and commercial premises. During these targeted inspections, field staff physically examined a total of 45,680 individual wet or water holding containers to assess aquatic habitat viability. In total, 18,420 Aedes larvae were successfully collected, safely transported to the facility, and morphologically verified under controlled laboratory conditions. Species level taxonomic classification revealed a pronounced dominance of Aedes aegypti, which accounted for 84.5% (n = 15,565) of the total collected larval population. Aedes albopictus comprised the remaining 15.5% (n = 2,855). This distribution underscores a highly urbanized, anthropophilic vector profile within the study area. Aedes aegypti heavily exploits indoor and peri domestic artificial habitats closely associated with human activity, while the minority presence of Ae. albopictus suggests secondary exploitation of outdoor, vegetation adjacent ecological interfaces.

Seasonal Dynamics of Stegomyia Indices: The computed Stegomyia indices exhibited severe, distinct temporal fluctuations that closely tracked local meteorological transitions. Absolute baseline levels of vector infestation remained comparatively low during the dry pre monsoon period, sustained almost entirely by human driven domestic water storage. However, populations expanded rapidly with the onset of the monsoon rains, eventually reaching their highest epidemiological peaks in the post monsoon phase as receding rains left thousands of stagnant, nutrient rich microhabitats. The post monsoon phase recorded the highest overall vector abundance. Most notably, the Breteau Index (BI) peaked at 34.5, a critical metric that falls well above the standard transmission alert threshold (BI > 20) established by regional health authorities. [16,24]

Table 1: Seasonal Distribution and Dynamics of Stegomyia Larval Indices

Surveillance Season	Houses Inspected (N)	Containers Inspected (N)	House Index (HI %)	Container Index (CI %)	Breteau Index (BI)
Pre Monsoon	3100	10240	01.8%	01.2%	03.4
Monsoon	3250	12180	06.4%	05.8%	18.2
Post Monsoon	3050	11820	12.6%	10.9%	34.5
Winter	3050	11440	02.1%	01.5%	04.1

Container Breeding Preferences and Productivity: Subsequent analysis of container breeding preferences indicated that the structural typology and spatial location of the container significantly influenced localized larval productivity. Discarded automobile tyres left exposed to rainfall and environmental elements showed the highest absolute positivity, accounting for 42.1% of all positive breeding sites. The dark, thermally insulated, and curved interior of tyres provides an optimal, evaporation resistant incubator for Aedes eggs to mature.

Large, uncovered plastic storage drums followed closely at 31.8%. Cement storage cisterns, domestic desert coolers, and smaller miscellaneous commercial junk items accounted for 14.3%, 8.5%, and 3.3% of positive collections, respectively.

Table 2: Proportional Distribution of Positive Larval Breeding Sites

Container Typology	Proportion of Positive Sites	Primary Seasonal Driver
Discarded Automobile Tyres	42.1%	Monsoon & Post Monsoon
Plastic Storage Drums	31.8%	Year round (Pre Monsoon stable)
Cement Storage Cisterns	14.3%	Year round (Pre Monsoon stable)
Domestic Desert Coolers	08.5%	Pre Monsoon & Monsoon
Miscellaneous Junk / Debris	03.3%	Monsoon & Post Monsoon

Crucially, uncovered plastic storage drums and large permanent cement structures remained the primary stable vector breeding sites during the dry pre monsoon intervals. This dynamic suggests that structural deficits in municipal water infrastructure which force residents to chronically store water indoors inadvertently sustain the baseline vector population when natural rainfall is absent.

Discussion

Regarding common breeding sites of Aedes, the results of our study are similar to those carried out by Sharma et al, Mahadev et al; and Singh et al, wherein they reported preferred breeding sites as discarded tyres; and plastic drums. [10,11,12] The findings of our study as regards breeding of Aedes are not in consonance with the studies conducted by Katyal et al, wherein they Minhas et al; and Sharma et al, wherein they reported no breeding in discarded tyres. [25] The findings of our study as regards species of Aedes are in contrast to findings in studies conducted by Minhas et al; and Sharma et al, wherein they reported Aedes albopictus; and five different species of Aedes respectively. [9,10]

The range of house index; and container index across various seasons in our study mimics the indices, in a study by Minhas et al. [9] However, the house index; and container index in our study, are not in sync with the indices reported by Katyal et al. [25] Conversely, the range of Breteau index across various seasons in our study, is similar to the Breteau index in a study conducted by Katyal et al. [25] Aedes larval indices reported by Tezzo et al in their study conducted in 2018 are much higher, as compared to the Aedes larval indices in our study. [13] Our comprehensive 12 month surveillance data indicate a clear temporal relationship between seasonal rain patterns, domestic water conservation habits, and Aedes larval production in the urban environment. The substantial rise in all three Stegomyia indices during the post monsoon transition period highlights how accumulated rainwater in outdoor junk materials, combined with persistent indoor water storage, expands available vector breeding niches, which closely mirrors observations documented in global and regional vector profiles. [3,19 ,24,26,27] Uncovered plastic storage drums and discarded automobile tyres emerged as the primary drivers of vector population expansion, a finding that directly aligns with entomological assessments where tyres and artificial containers consistently yielded the highest breeding productivity. [9,11,13,18,19,20,21,22, 23,24] These findings reflect structural challenges in municipal water delivery infrastructure, where intermittent supply forces residents to store water in large domestic vats, inadvertently creating highly productive, semi-permanent breeding microhabitats as highlighted in regional structural surveys. [3,9,11,13,18,19,21,24,25] The thermal stability and reduced evaporation rates within these shaded, indoor containers provide optimal conditions for prolonged vector survival, effectively bridging the dry season gap and maintaining a robust baseline adult population year-round.

A key point of discussion is the operational mismatch often observed between immature larval indices and actual clinical dengue transmission rates within public health programs, a phenomenon also observed during major historical outbreaks. Although larval indices are effective for mapping baseline ecological receptivity, they do not directly reflect the abundance, survival, or flight dynamics of adult female vectors, as noted in comparative operational investigations. For instance, in high density urban core areas, a study done by investigators during localized outbreaks found that even a low House Index can support rapid viral transmission due to high human population density and constant vector host contact. [28,29] Conversely, high larval indices in peri urban or industrially zoned areas with lower human density often fail to trigger corresponding epidemiological spikes, as the biting frequency and viral amplification cycles are constrained by the lack of available human hosts. This disconnect underscores the inherent limitations of relying solely on traditional Stegomyia indices as predictive early warning systems. [28,29]

To bridge this surveillance gap, modern epidemiological frameworks advocate for the integration of pupal productivity surveys and adult vector trapping alongside traditional larval metrics. Because pupal mortality in the aquatic environment is generally lower and more predictable than larval mortality, pupal demographic counts offer a much closer proxy for the impending adult female population capable of disease transmission. [5,20,28,29] Furthermore, focusing public health interventions exclusively on the most productive container types, specifically large, unsealed water storage units and discarded vehicle tyres can yield disproportionately high reductions in overall vector density. This targeted intervention approach is highly critical in resource limited municipal settings where widespread, indiscriminate larviciding is both economically and logistically unfeasible. [4,7,28,30,31,32]

Ultimately, these findings emphasize that effective Aedes management requires a structural paradigm shift from reactive outbreak response to proactive, ecologically integrated control. While biological and chemical vector control remain essential tools, the root causes of urban Aedes proliferation are profoundly environmental and behavioural. [5,18,20,21,32,33,34] Long term suppression of dengue transmission will depend on intersectoral collaboration aimed at improving the reliability of piped municipal water, implementing stringent solid waste management protocols for non-biodegradable refuse, and mobilizing community led source reduction campaigns. [18,19, 21,22,30,31,35,21]

Strengths

This investigation possesses several methodology strengths in sync with previous literature on the subject that enhance its validity. Our study maintains an extensive spatial sampling framework covering a diverse range of urban microclimates, reducing local selection bias. It also features multi season longitudinal monitoring over a complete annual weather cycle, which allows for precise identification of seasonal transition peaks. All recovered samples underwent direct laboratory confirmation using specialized taxonomic keys rather than field approximations, ensuring highly accurate species distinction. The simultaneous evaluation of three separate Stegomyia indices (HI, CI, and BI) provides a multidimensional perspective on both property infestation rates and absolute container productivity.

Limitations

Several limiting operational factors of our present study must be taken into account when interpreting these results. Ground level visual surveys naturally exclude cryptic, inaccessible vertical spaces such as multi storey roof drains or elevated construction structures, potentially underestimating true vector presence. Stegomyia indices measure the presence of immature life stages but do not track adult survival rates, physiological resistance, or flight distributions, creating gaps between larval abundance patterns and actual localized clinical transmission risks. Operational resource constraints restricted adult trapping confirmations, precluding direct mathematical correlations between larval indices and adult vector densities across all audited sectors.

Recommendations

To improve current public health intervention capabilities, the authors recommend a few important actions. Municipal vector control units should transition from reactive treatments to proactive, localized targeted source reduction interventions should be initiated 4 to 6 weeks prior to known historical post monsoon transmission peaks. Public health agencies should integrate alternative adult mosquito trapping systems such as ovitraps or light traps alonagside traditional larval indices to address hidden cryptic breeding dynamics. Local authorities should implement structural container management policies, including distribution of specialized tight fitting storage covers and routine legal checks on high risk commercial tyre yards. Community led communication programs should be established to train residents in identifying and eliminating micro breeding sites within their own domestic properties on a weekly basis.

Conclusion

This evaluation confirms that Aedes larval indices show a clear, predictable seasonal surge peaking during the post monsoon phase in urban environments. Artificial domestic storage containers and discarded commercial waste items remain the primary drivers of vector population growth. While standard larval indices face logistical and structural constraints, they still serve as vital indicators for public health planning. Transitioning towards targeted, preventive source reduction strategies and incorporating multi stage vector monitoring will significantly strengthen urban epidemic preparedness programs.

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