Tropical Biomedicine 43(2): 211-218 (2026)
https://doi.org/10.47665/tb.43.2.011
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RESEARCH ARTICLE

Temporal and spatial distribution of dengue in an urban setting: evidence from Hanoi, Vietnam (2018-2022)

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ARTICLE HISTORY

Received: 14 April 2026
Revised: 22 May 2026
Accepted: 04 June 2026
Published: 30 June 2026

ABSTRACT

Dengue fever remains a major mosquito-borne disease in Southeast Asia, with increasing incidence in rapidly urbanizing settings. In Vietnam, Hanoi has experienced recurrent outbreaks; however, comprehensive analyses of recent dengue epidemiology in northern regions remain limited. This study aimed to characterize the spatiotemporal dynamics of dengue in Hanoi from 2018 to 2022. A retrospective descriptive study was conducted using routine dengue surveillance data collected by the Hanoi Center for Disease Control. All clinically diagnosed and laboratory-confirmed dengue cases reported between January 2018 and December 2022 were included. Temporal trends were examined using descriptive analysis of monthly and annual incidence rates. District-level incidence rates were calculated and visualized using a geographic information system (GIS) mapping. Serotype distribution was examined using available virological data. A total of 46,650 dengue cases were reported during the study period. Dengue transmission occurred annually, with substantial inter-annual variability; the highest incidence was recorded in 2022 (236 per 100,000 population), while the lowest occurred in 2021 (41 per 100,000 population). A clear seasonal pattern was observed, with cases increasing from June and peaking between September and November. Spatial analysis revealed marked heterogeneity, with higher incidence consistently observed in peri-urban districts. All four dengue virus serotypes co-circulated, with DENV-1 and DENV-2 predominating and a shift toward DENV-2 dominance in later years. Dengue transmission in Hanoi exhibits pronounced seasonal and spatial patterns influenced by urbanization and ecological factors. Strengthening pre-season vector control activities and district-level surveillance may help reduce outbreak risk and maintaining integrated epidemiological and virological surveillance is essential to mitigate future outbreaks.

Keywords: Dengue; spatial distribution; temporal trends; seasonal variation; surveillance data.

INTRODUCTION

Dengue is one of the most rapidly expanding mosquito-borne viral diseases worldwide and represents a major public health challenge in tropical and subtropical regions (WHO, 2024; Zheng *et al.*, 2025). The disease is caused by four antigenically distinct dengue virus serotypes (DENV-1, DENV-2, DENV-3, and DENV-4), which are primarily transmitted by *Aedes aegypti* mosquitoes and, to a lesser extent, by *Aedes albopictus* (Smartt *et al.*, 2017). Infection with one serotype confers lifelong immunity to that specific serotype but only temporary cross-protection against the others, increasing the risk of subsequent infections and severe disease (Reich *et al.*, 2013). Globally, dengue has increased dramatically in both incidence and geographic distribution over the past decades (Stanaway *et al.*, 2016). The World Health Organization estimates that approximately 390 million dengue infections occur annually, of which about 100 million are clinically apparent. Nearly half of the global population now lives in areas at risk of dengue transmission (WHO, 2024). This expansion has been driven by several interconnected factors, including rapid urbanization, population growth, increased international travel, and climate change (Lee *et al.*, 2021; Stanaway *et al.*, 2016). Urban environments in particular provide favorable conditions for mosquito breeding and human–vector contact, facilitating sustained transmission.

Southeast Asia remains one of the regions most heavily affected by dengue worldwide. Countries such as Thailand, Indonesia, the Philippines, and Vietnam experience recurrent outbreaks that impose substantial morbidity and economic burden on health systems (Weng *et al.*, 2025). In many countries in the region, dengue has become a leading cause of hospitalization among children and adults. Transmission dynamics in Southeast Asia are shaped by complex interactions between climatic conditions, vector ecology, demographic factors, and urban development (Lee *et al.*, 2021; Weng *et al.*, 2025).

Vietnam is considered a dengue-endemic country where transmission occurs annually with periodic large-scale outbreaks (Cuong *et al.*, 2013). Dengue cases have been reported throughout the country, although the epidemiological characteristics vary across regions. In southern Vietnam, particularly in Ho Chi Minh City and the Mekong Delta, dengue transmission often occurs year-round

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with seasonal peaks during the rainy season. In contrast, northern Vietnam typically experiences more pronounced seasonal outbreaks (Cuong *et al*., 2013).

Hanoi, the capital city located in northern Vietnam, frequently reports dengue outbreaks during the summer and early autumn months when climatic conditions favor mosquito breeding and virus transmission (Do *et al*., 2014). The monsoon climate in northern Vietnam, characterized by high temperatures and heavy rainfall during the warm season, contributes to the seasonal increase in dengue incidence (Nguyen *et al*., 2020). In recent years, Hanoi has experienced several significant dengue outbreaks, placing considerable pressure on the healthcare system and public health infrastructure. Despite the increasing burden of dengue in northern Vietnam, relatively fewer epidemiological studies have examined transmission dynamics in Hanoi compared with southern regions of the country. Rapid urbanization, population growth, and changes in land use in the capital city may influence mosquito ecology and dengue transmission patterns (Do *et al*., 2014). Understanding how dengue incidence varies across time and geographic areas within the city is therefore essential for improving control strategies.

Spatiotemporal analysis provides important tools for understanding dengue epidemiology (Pasaribu *et al*., 2021). Temporal analyses help characterize seasonal trends and epidemic cycles, while spatial analyses allow identification of geographic areas with higher transmission risk (Lee & Wen, 2023). Such information is critical for guiding targeted vector control interventions and optimizing the allocation of public health resources. Routine surveillance systems also play a crucial role in monitoring dengue trends and informing public health responses (Colón-González *et al*., 2021). In Vietnam, dengue is a notifiable disease and confirmed cases are routinely reported to provincial Centers for Disease Control. These surveillance datasets contain valuable information on disease occurrence over time and across geographic locations. However, such data remains underutilized for epidemiological research in many settings.

Given the continuing burden of dengue in Hanoi and the limited number of studies examining recent transmission patterns in the city, further analysis of surveillance data is needed to better understand the epidemiology of dengue in this setting. Therefore, this study aimed to analyze the spatiotemporal epidemiology of dengue in Hanoi from 2018 to 2022 using routine surveillance data. Specifically, the study sought to (1) Describe the temporal trends and seasonal patterns of dengue cases during the study period, and (2) Examine the spatial distribution of dengue across districts in Hanoi and characterize the distribution of circulating dengue virus serotypes.

MATERIALS AND METHODS

Study setting

The study was conducted in Hanoi, the capital city of Vietnam, located in the northern Red River Delta region. Hanoi is one of the most densely populated metropolitan areas in the country, with an estimated population of approximately eight million inhabitants according to the General Statistics Office of Vietnam. The city serves as the political, economic, and cultural center of Vietnam and has experienced rapid urbanization over the past two decades (Hien *et al*., 2020). Administratively, Hanoi is divided into 30 districts, including 12 urban districts, 17 rural districts, and one district-level town. This administrative structure encompasses a wide range of population densities, infrastructure conditions, and environmental settings. Urban districts are characterized by high population density, extensive construction activities, and dense residential areas, while peri-urban and rural districts have lower population density and more heterogeneous land use patterns.

Hanoi has a humid subtropical climate with four distinct seasons. Summers are typically hot and humid, with average temperatures ranging from 28°C to 35°C, accompanied by substantial rainfall between May and October. These climatic conditions are favorable for mosquito breeding and contribute to the transmission of the dengue virus, which is primarily transmitted by the mosquito vectors *Aedes aegypti* and *Aedes albopictus* (Nguyen-Tien *et al*., 2021). Seasonal rainfall often leads to the accumulation of stagnant water in containers, construction sites, and household environments, creating ideal breeding habitats for *Aedes* mosquitoes. Together with high population mobility and urban density, these ecological and demographic factors contribute to the persistence and periodic outbreaks of dengue in Hanoi. A geographic map of the study area in Hanoi, Vietnam, was generated using ArcGIS version 10.8.2 (Figure 1).

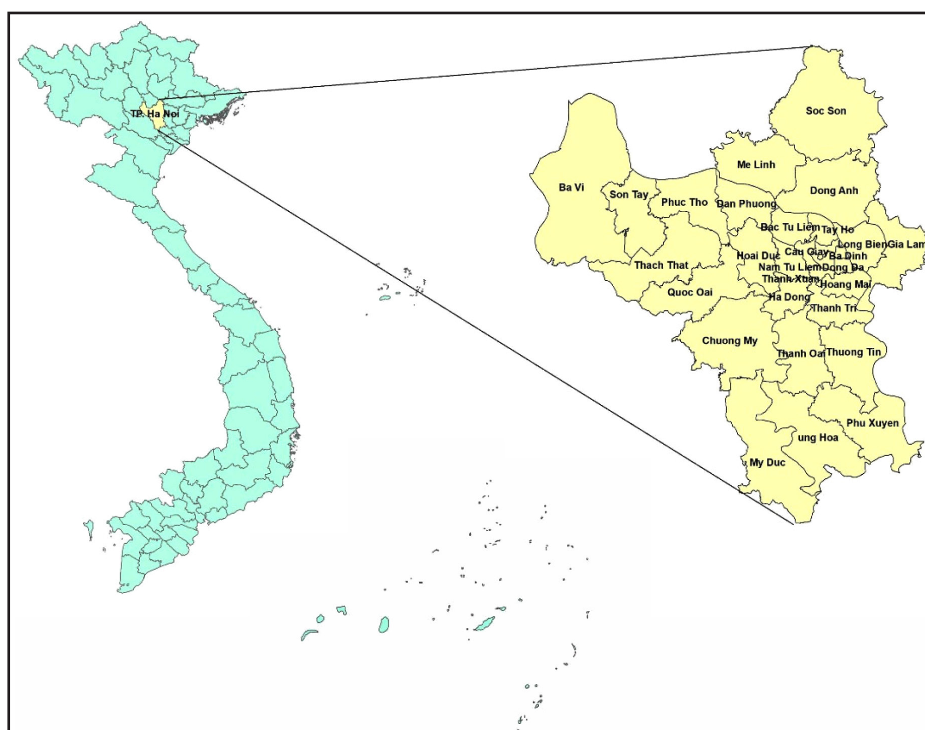

Figure 1. Map of Vietnam and the location of Hanoi capital.

Study design
This study employed a retrospective descriptive epidemiological design using dengue surveillance data collected between 1 January 2018 and 31 December 2022 in Hanoi, Vietnam.

Data sources
Data for this study were obtained from the routine dengue surveillance system managed by the Hanoi Center for Disease Control. The surveillance system is part of the national communicable disease surveillance network coordinated by the Vietnam Ministry of Health (tế, 2015).

Under national communicable disease surveillance regulations issued by the Ministry of Health, all healthcare facilities are required to report suspected and confirmed dengue cases. Reporting facilities include public hospitals, private hospitals, outpatient clinics, and diagnostic laboratories across the city. When a suspected dengue case is identified, healthcare providers report the case to the district health center, which subsequently submits the report to the Hanoi Center for Disease Control through the electronic disease surveillance platform. Data were verified and compiled at district and city levels before inclusion in the surveillance database.

The surveillance database includes demographic information, clinical characteristics, laboratory results, and epidemiological information. However, clinical variables contained substantial missing and inconsistent information across reporting years and districts and were therefore not included in the present analysis.

For this study, anonymized dengue surveillance data covering the period from January 2018 to December 2022 were extracted from the city-level database. Personal identifiers were removed before analysis to ensure patient confidentiality. Data were checked for completeness and duplicate records before analysis.

Case definition
Dengue cases were defined according to national dengue surveillance guidelines issued by the Ministry of Health and aligned with recommendations from the World Health Organization (tế, 2014).

Two categories of dengue cases were included in the analysis
Clinically diagnosed dengue fever: Patients presenting with acute febrile illness and clinical manifestations compatible with dengue infection, including headache, retro-orbital pain, myalgia, arthralgia, rash, or hemorrhagic signs, as assessed by a qualified clinician.

Laboratory-confirmed dengue infection: Cases with laboratory evidence of dengue virus infection based on at least one of the following diagnostic methods: detection of dengue virus RNA by reverse transcription polymerase chain reaction (RT-PCR), detection of dengue NS1 antigen, or positive dengue-specific IgM serology.

Both clinically diagnosed and laboratory-confirmed cases were included to reflect the total burden of dengue reported through the surveillance system.

Variables
The dataset included demographic and epidemiological variables such as age, sex, district of residence, and dengue virus serotype when available. These variables were used to describe the demographic characteristics of cases and assess temporal and spatial patterns of dengue transmission. Clinical variables were not analyzed because of incomplete reporting and data inconsistency across surveillance sites.

Data analysis

Temporal analysis
Temporal patterns of dengue transmission were assessed descriptively using monthly and annual dengue case counts and incidence rates. Because the study objective was descriptive epidemiological characterization, no formal trend test was performed. Monthly totals were used to describe seasonal variation and identify peak transmission periods.

Spatial analysis
Dengue cases were aggregated by district to examine geographic distribution. District-level dengue incidence rates were calculated as the number of reported cases per 100,000 population using population estimates obtained from the Hanoi Statistical Office. Geographic distribution maps were produced using ArcGIS version 10.8.2 to visualize spatial patterns of dengue transmission across districts.

Serotype distribution
Virological surveillance data were used to examine the distribution of dengue virus serotypes circulating in Hanoi during the study period (2018:102 cases; 2019: 448 cases; 2020: 352 cases; 2021: 240 cases; 2022: 51 cases). The proportion of each dengue virus serotype was calculated annually among laboratory-confirmed cases with available virological data.

Changes in serotype dominance across years were analyzed to identify potential shifts in circulating strains that may contribute to epidemic dynamics.

Statistical analysis
Statistical analyses were performed using Stata version 16.0 (StataCorp, USA). Figures were generated using Microsoft Excel and ArcGIS version 10.8.2. Data were entered and managed using Microsoft Excel. After data cleaning, the dataset was exported to Stata version 16.0 (StataCorp, USA) for statistical analyses.

Descriptive statistics were used to summarize the epidemiological characteristics of dengue cases. Categorical variables were presented as frequencies and percentages, while continuous variables were summarized using means and standard deviations or medians and interquartile ranges when appropriate.

Dengue incidence rates were calculated per 100,000 population using district population data obtained from the Hanoi Statistical Office. Temporal trends were examined using monthly and annual case counts. Spatial distribution of dengue cases was visualized using ArcGIS version 10.8.2.

Ethical considerations
The study protocol was approved by the Scientific Committee of Hanoi Medical University (Decision No. 407/QD-DHYHN) and the Scientific and Technical Committee of the Hanoi Center for Disease Control (Decision No. 1992/QD-KSBT dated 21 July 2023).

Permission to access and use the surveillance dataset was granted by the Hanoi Center for Disease Control. All data were anonymized prior to analysis and used solely for research purposes. Because the study used secondary surveillance data without personal identifiers, informed consent was waived.

RESULTS

Overall dengue burden
Between 2018 and 2022, a total of 46,650 dengue cases were reported in Hanoi through the routine surveillance system (Table 1). Dengue transmission occurred every year, although the magnitude varied considerably, reflecting fluctuations in epidemic activity. The

Table 1. Distribution of Dengue Fever Cases in Hanoi from 2018 to 2022 by Year

Year	Number of Cases	Incidence Rate (per 100,000 population)
2018	4478	57
2019	12253	153
2020	6784	83
2021	3373	41
2022	19762	236

annual incidence showed alternating periods of moderate and high transmission. Notably, the number of reported cases peaked in 2022 (19,762 cases; 236 per 100,000 population), while the lowest burden was observed in 2021 (3,373 cases; 41 per 100,000 population). The average annual number of cases during the study period was 9,330 (114 per 100,000 population).

During the 2018-2022 period, the incidence rate of dengue fever in Hanoi was primarily among adults and individuals over the age of 15, accounting for more than 83% of cases annually (Table 2). Meanwhile, there was no substantial difference in incidence rates between males and females.

Temporal trends

Dengue cases were reported throughout the year; however, a clear seasonal pattern was observed (Figure 2). Case numbers remained relatively low during the early months of the year and began to increase in June, coinciding with the onset of the rainy season. A sharp rise in cases was observed during late summer, with peaks typically occurring between September and November. Following this peak, incidence declined markedly in December and remained low in the early months of the following year.

This seasonal trend was consistent across all five years and reflects the strong influence of climatic factors. Increased rainfall likely creates favorable breeding conditions for *Aedes* mosquitoes, while higher temperatures may accelerate vector development and viral replication. In addition to seasonal variation, inter-annual fluctuations were evident, with some years experiencing large outbreaks and others showing lower transmission intensity.

Spatial distribution

Figure 3 shows district-level incidence. Dengue cases were reported across all districts of Hanoi, indicating widespread geographic distribution. However, substantial heterogeneity in incidence was observed (Figure 3). Higher incidence rates were consistently recorded in peri-urban districts and areas undergoing rapid urbanization. These areas often experience increased population

Table 2. Characteristics of Dengue Fever Cases in Hanoi from 2018 to 2022 by Age and Gender

Characteristics	2018 N (%)	2019 N (%)	2020 N (%)	2021 N (%)	2022 N (%)
Age group					
>15 years old	3.908 (87.3)	10.719 (87.5)	5.915 (87.2)	2.886 (85.6)	16.562 (83.8)
≤15 years old	570 (12.7)	1534 (12.5)	869 (12.8)	487 (14.4)	3.200 (16.2)
Total	4.478 (100)	12.253 (100)	6.784 (100)	3.373 (100)	19.762 (100)
Gender					
Male	2.307 (51.5)	6.264 (51.1)	3.511 (51.8)	1.739 (49.6)	9.797 (49.6)
Female	2.171 (48.5)	5.989 (48.9)	3.273 (48.2)	1.634 (50.4)	9.965 (50.4)
Total	4.478 (100)	12.253 (100)	6.784 (100)	3.373 (100)	19.762 (100)

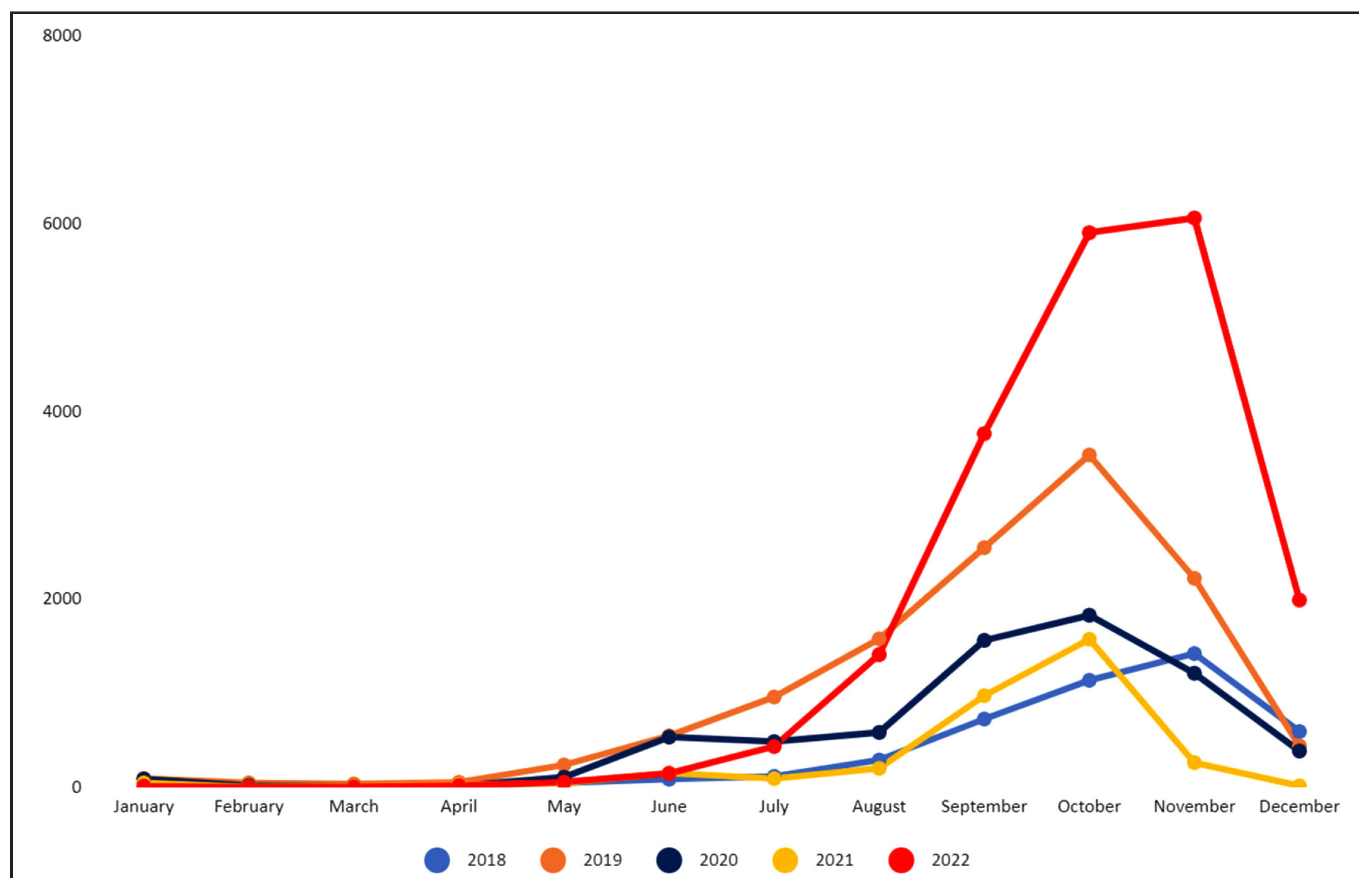

Figure 2. Distribution of Dengue Fever Cases in Hanoi from 2018 to 2022 by Month.

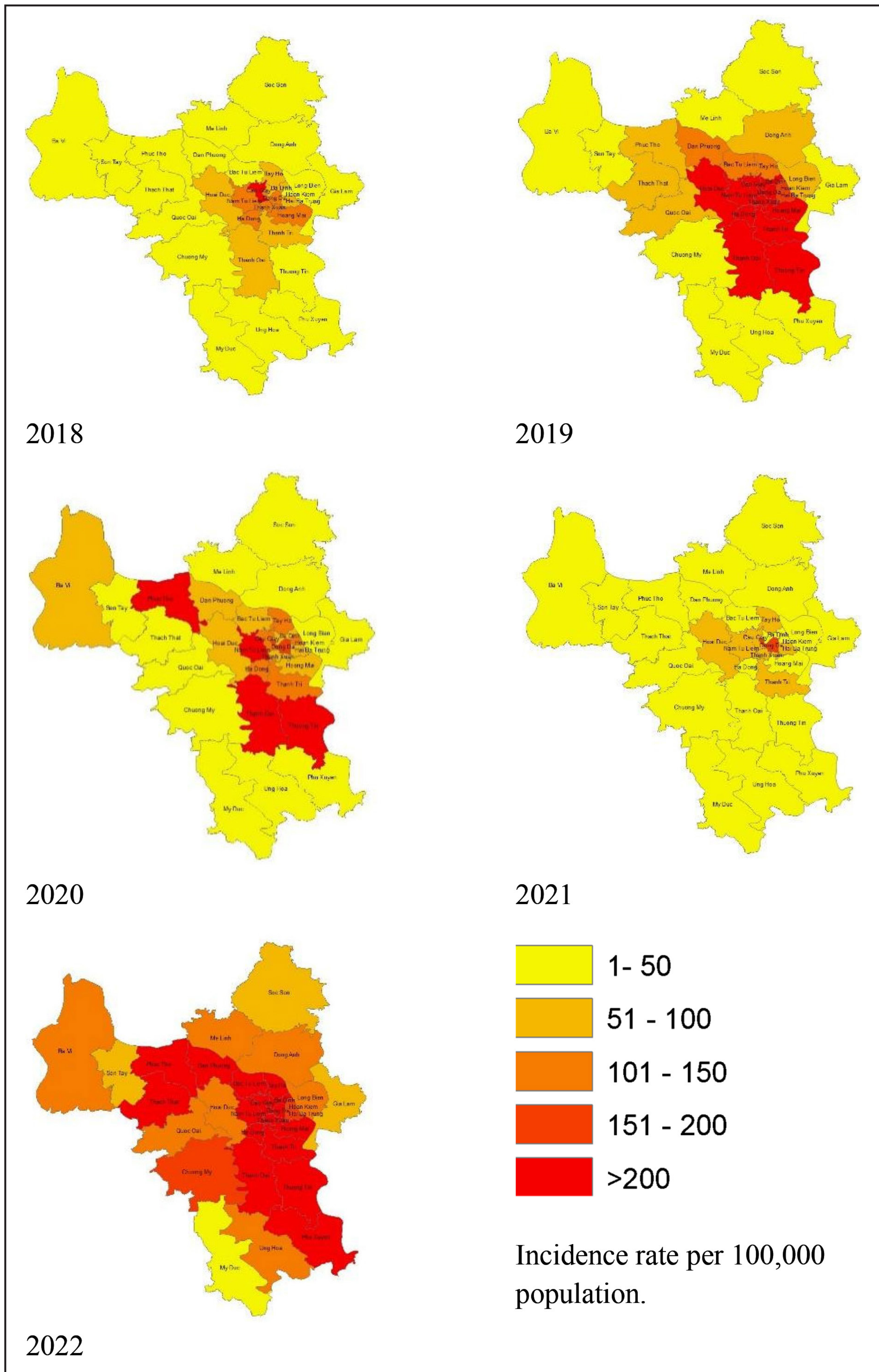

Figure 3. Dengue Fever Incidence Rate per 100,000 Population in Hanoi by District, Suburban Districts, and Towns, 2018-2022.

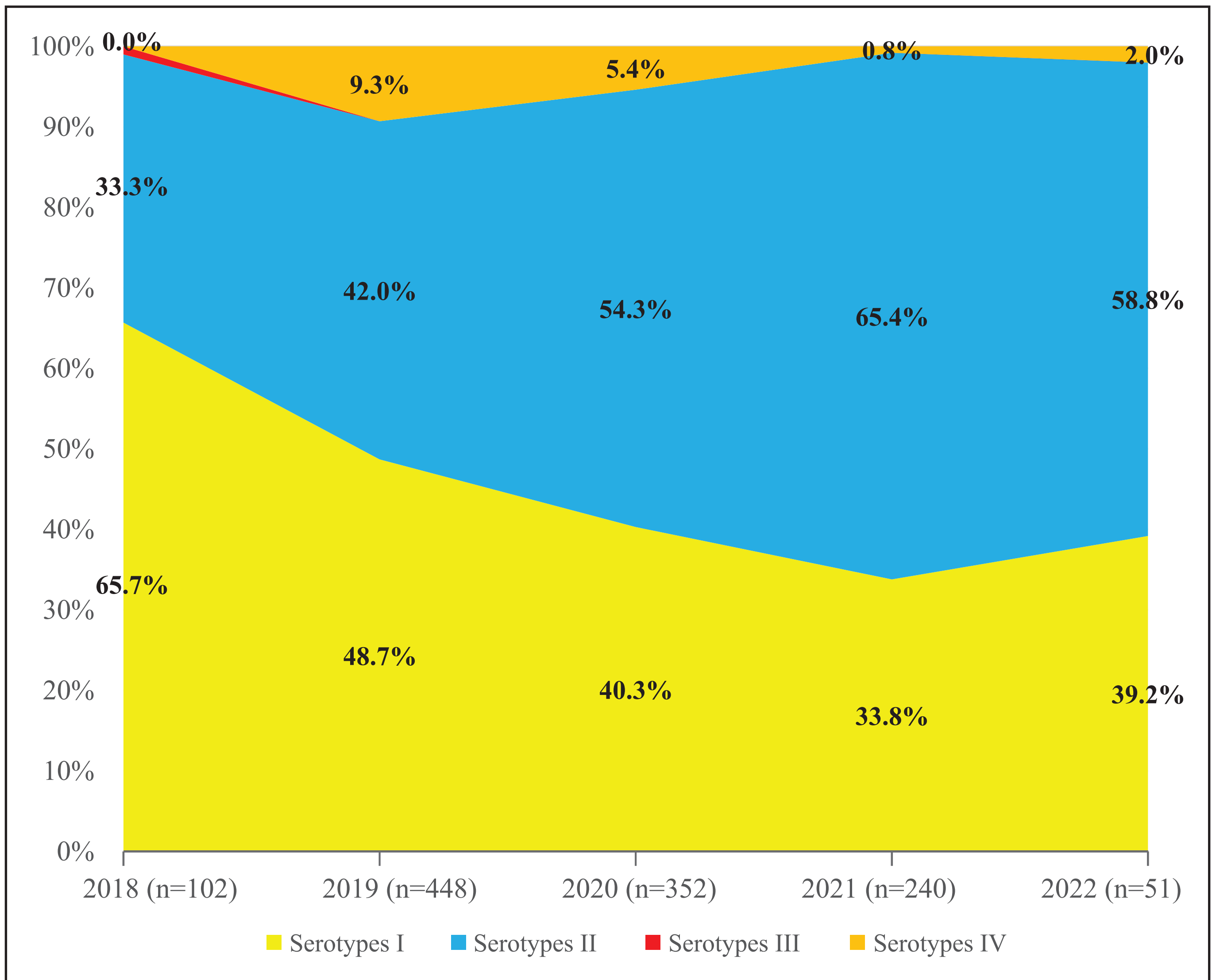

Figure 4. Distribution of Dengue Virus Serotypes in Hanoi from 2018 to 2022.

density, construction activities, and water storage practices, which may create favorable conditions for mosquito breeding. In contrast, some central urban districts reported relatively lower incidence rates, possibly due to better infrastructure, improved sanitation, and more effective vector control measures. In 2022, the most widespread outbreak was observed, with 19 out of 30 districts exceeding 150 cases per 100,000 population. Meanwhile, in 2021, only one district exceeded this threshold. These findings highlight the importance of localized environmental and demographic factors in shaping dengue transmission patterns and suggest the need for targeted interventions in high-risk areas.

Serotype distribution

Virological surveillance revealed the co-circulation of all four dengue virus serotypes (DENV-1 to DENV-4) in Hanoi during the study period. Among these, DENV-1 and DENV-2 were the most frequently detected. A temporal shift in dominant serotype was observed, with DENV-1 more common in earlier years and DENV-2 becoming increasingly predominant in later years. The co-circulation of multiple serotypes is characteristic of endemic settings and may contribute to periodic outbreaks. It also increases the risk of secondary infections, which are associated with more severe disease outcomes.

DISCUSSION

Key findings

This study provides a comprehensive description of dengue epidemiology in Hanoi over a five-year period using routine surveillance data. The findings highlight three key features: pronounced seasonal transmission, substantial spatial heterogeneity, co-circulation with shifting dominance of dengue virus serotypes.

Seasonal transmission and comparison with previous studies

The pronounced seasonal pattern observed in this study, with dengue incidence increasing from June and peaking between September and November, is highly consistent with previous research conducted in Hanoi and northern Vietnam. A study analyzing dengue data from 2002 to 2009 reported that approximately 72% of cases occurred between June and November, with epidemic peaks typically observed in September and October (Do *et al*., 2014). This seasonal pattern is also consistent with findings from other Southeast Asian countries, including Thailand, Indonesia, and the Philippines, where dengue transmission is strongly associated with the rainy season (Do *et al*., 2014). However, compared with southern Vietnam, where transmission can occur year-round with less pronounced seasonality, the pattern observed in Hanoi is more sharply defined. This difference reflects regional climatic variation, particularly the

subtropical climate in northern Vietnam characterized by cooler winters that limit mosquito activity (Xuan le *et al*., 2014).

Previous studies have suggested that climatic factors such as rainfall and temperature may contribute to dengue seasonality in Vietnam and other endemic settings. Previous studies have demonstrated that temperature, rainfall, and humidity are strongly associated with dengue incidence, often with a lag of several weeks. Increased rainfall and temperature have been reported in previous studies to be associated with increased mosquito breeding and dengue transmission. The lag between climatic variables and dengue incidence reflects the time required for mosquito population growth and virus transmission cycles.

Inter-annual variability and epidemic cycles

In addition to seasonal variation, this study identified substantial fluctuations in dengue incidence between years, with major outbreaks occurring in 2019 and 2022. Similar inter-annual variability has been widely reported in dengue-endemic regions (Thai *et al*., 2010). These epidemic cycles are likely driven by a combination of factors. One key mechanism is population immunity. Following large outbreaks, a substantial proportion of the population may develop immunity to the circulating serotype, leading to a temporary decline in transmission. Over time, as immunity wanes and new susceptible individuals enter the population, conditions become favorable for subsequent outbreaks (Aguiar *et al*., 2022).

Another important factor is the interaction between dengue virus serotypes. The co-circulation of multiple serotypes increases the likelihood of secondary infections, which can both amplify transmission and contribute to more severe disease. Mathematical and epidemiological studies have shown that such interactions can generate cyclical epidemic patterns in endemic settings (Aguiar *et al*., 2022).

Environmental variability may also contribute to inter-annual differences. Changes in rainfall patterns, temperature anomalies, and large-scale climatic phenomena such as El Nino have been associated with dengue outbreaks in multiple regions, including Vietnam (Tipayamongkholgul *et al*., 2009).

Spatial heterogeneity and urbanization

The study demonstrates clear spatial heterogeneity in dengue incidence across districts, with higher incidence consistently observed in peri-urban areas. This finding is consistent with a growing body of literature highlighting the role of urbanization in shaping dengue transmission. Peri-urban districts often represent transitional zones characterized by rapid population growth, expanding infrastructure, and mixed land use. These areas may have inadequate water supply systems, leading to increased water storage practices, which create breeding sites for *Aedes* mosquitoes. Construction activities and poor waste management can further contribute to the proliferation of mosquito habitats (Wilke *et al*., 2019).

Similar spatial patterns have been reported in other rapidly urbanizing cities in Southeast Asia (Weng *et al*., 2025). Studies in Indonesia and Brazil, for example, have shown that dengue incidence is often higher in areas undergoing rapid urban expansion, where environmental conditions and population density favor transmission (Leandro *et al*., 2024; Weng *et al*., 2025). In contrast, central urban districts in Hanoi tended to report lower incidence rates. This may reflect better infrastructure, improved sanitation, and more effective vector control programs. However, it is important to note that dengue transmission was still observed across all districts, indicating that the risk is widespread and not confined to specific geographic areas.

Serotype dynamics and implications for transmission

The co-circulation of all four dengue virus serotypes observed in this study is characteristic of hyperendemic transmission. The predominance of DENV-1 and DENV-2 is consistent with previous reports from Vietnam, where these serotypes have frequently been identified as dominant (Pham *et al*., 2024; Vaddadi *et al*., 2017).

The observed shift toward DENV-2 dominance in later years is particularly noteworthy. Changes in dominant serotypes have been reported in many endemic regions and are often associated with changes in epidemic patterns (Begum *et al*., 2024). These shifts may reflect complex interactions between viral evolution, population immunity, and transmission dynamics (Begum *et al*., 2024).

From an epidemiological perspective, serotype dynamics are critically important. Infection with one serotype confers lifelong immunity to that serotype but only partial and temporary protection against others. As a result, populations previously exposed to one serotype remain susceptible to infection with another, and secondary infections are associated with increased risk of severe disease (Shih *et al*., 2024).

Monitoring serotype distribution is therefore essential for understanding epidemic risk and guiding public health responses. The findings of this study underscore the need for continued virological surveillance in Hanoi.

Public health implications

The findings of this study have several important implications for dengue prevention and control in Hanoi. First, the strong seasonal pattern suggests that vector control interventions should be implemented proactively before the onset of the transmission season. Intensifying mosquito control activities between April and June could help reduce vector populations before peak transmission occurs. Second, the identification of high-incidence districts highlights the importance of targeted interventions. Peri-urban areas should be prioritized for vector control, community engagement, and surveillance efforts. Third, the observed serotype dynamics emphasize the need for integrated surveillance systems that combine epidemiological and virological data. Such systems can provide early warning of potential outbreaks and support more effective response strategies. Finally, public awareness campaigns should be strengthened to promote community participation in vector control, particularly during high-risk periods.

In addition, increasing insecticide resistance among *Aedes* mosquitoes has emerged as an important challenge for sustainable dengue prevention programs. Continuous monitoring of insecticide susceptibility and the development of integrated vector management strategies are therefore essential for long-term dengue control (Kasman *et al*., 2025).

Strengths and limitations

This study has several strengths. It utilizes a large, population-based dataset covering all districts of Hanoi over a five-year period, providing a comprehensive overview of dengue epidemiology in the city. The integration of temporal, spatial, and virological data allows for a multidimensional analysis of transmission dynamics. However, several limitations should be acknowledged. First, the study relies on routine surveillance data, which may be subject to underreporting, particularly for mild or asymptomatic cases. Second, the inclusion of clinically diagnosed cases may introduce some degree of misclassification. Third, serotype data were only available for a subset of cases, which may limit the generalizability of findings related to viral circulation. Clinical severity outcomes and mortality data were not comprehensively available in the surveillance dataset. Finally, the present study did not directly assess climatic or environmental variables; therefore, causal interpretations regarding climate and dengue transmission cannot be made.

Despite these limitations, the study provides valuable insights into dengue transmission patterns in Hanoi and contributes to the limited body of literature on dengue epidemiology in northern Vietnam.

CONCLUSION

This study described the temporal and spatial patterns of dengue cases in Hanoi during 2018–2022. Dengue transmission showed clear seasonal variation, with most cases occurring during the rainy season. Spatial analysis indicated that dengue cases were unevenly distributed across districts, suggesting the presence of localized transmission hotspots.

These findings highlight the importance of strengthening dengue surveillance and implementing targeted vector control measures in high-risk areas, particularly before and during peak transmission periods. Continuous monitoring of dengue trends is essential to support early warning systems and improve the effectiveness of prevention and control strategies in urban settings. Future studies should integrate climatic and environmental data with surveillance systems to better understand drivers of dengue transmission in Hanoi. Expanded virological and entomological surveillance, together with analysis of clinical severity and mortality outcomes, would further strengthen dengue early warning and control strategies.

ACKNOWLEDGMENTS

The authors would like to thank the Hanoi Center for Disease Control for providing surveillance data for this study.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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