IJID Regions 13 (2024) 100441

Contents lists available at ScienceDirect

IJID Regions

journal homepage: www.elsevier.com/locate/ijregi

Space-time scanning statistics in the prediction and evaluation of dengue epidemic clusters

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ARTICLE INFO

Keywords:
Scanning statistics
Dengue
Space-time
Surveillance
Epidemic

ABSTRACT

Objectives: To detect clusters of dengue hemorrhagic fever in an urbanized district of Hai Phong City, Vietnam using Poisson space-time retrospective and prospective analysis.

Methods: A cross-sectional and retrospective study analyzed dengue surveillance data in the period from January 01, 2018, to December 31, 2022. Spatial-temporal scanning statistics were performed using the free software SatScan v10.1.2.

Results: A total of 519 cases were recorded. The cumulative incidence per 100,000 inhabitants was 3.37, 127.36, 10.96, 0, and 296.04 in 2018, 2019, 2020, 2021, and 2022, respectively. By retrospective Poisson model-based analysis, seven clusters were detected. Six of these seven detected outbreaks occurred in November and December 2022. The largest cluster had a relative risk (RR) of 1539.5 (P <0.00001). The smallest cluster has a RR of 316.1 (P = 0.006). Prospective analysis using the Poisson model significantly detected four active case clusters at the time of the study. The largest cluster of cases with RR was 47.7 (P <0.00001) and the smallest cluster with RR was 18.2 (P <0.00001).

Conclusions: This study provides a basis for improving the effectiveness of interventions and conducting further investigations into risk factors in the study area, as well as in other urban and suburban areas nationwide.

Introduction

Dengue hemorrhagic fever (DHF) is a mosquito-borne disease caused by the dengue virus. It is a significant public health concern worldwide, especially in tropical and subtropical regions [1]. The World Health Organization (WHO) estimates that approximately 390 million dengue infections occur annually, with nearly half the world's population at risk of contracting the disease. Recent studies show an increasing trend in the incidence of dengue, the proportion of all consultations related to dengue [2,3]. The burden is particularly high in densely populated urban areas with inadequate sanitation and where mosquito control measures are limited [4,5]. With its wide geographic spread and severe health and economic impacts, dengue is recognized as a rapidly emerging pandemic-prone viral disease. The WHO's Health Emergencies Program actively monitors and assesses the spread of dengue on an ongoing basis, highlighting the global concern over its pandemic potential [6]. The prevention and control of dengue are largely dependent on vector control measures, as there is no specific treatment for the [7]. Strengthened dengue surveillance becomes an essential tool for detecting outbreaks early, understanding the dynamics of transmission, identifying high-risk areas, and implementing timely interventions could prevent further spread [8]. Continuous monitoring detects the emerging and the duration of disease clusters helps prioritize resources and monitors the effectiveness of targeted interventions [9,10].

Spatiotemporal analysis (SatScan) of DHF data can help health officials detect and monitor disease spread and target interventions [11,12]. In Vietnam, dengue routine surveillance data is collected according to Circular 54/2015/TT-BYT provides guidance on reporting and declaration of infectious diseases and epidemics [13]. The national electronic database generates a weekly summarized count in a weekly report on the situation of the disease by specific administrative areas, the report can be used to monitor the spread of the disease and epidemic situation. This practice is non-statistical and poorly appropriate to detect and monitor the emergence and duration of the disease clusters. We use the Spatiotemporal scan statistics implemented in SatScan (https://www.satscan.org) to detect clusters of DHF in Hai An district,

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https://doi.org/10.1016/j.ijregi.2024.100441
Received 31 May 2024; Received in revised form 29 August 2024; Accepted 30 August 2024

Table 1
Number of dengue fever cases, population, and coordinates of eight wards, Hai An district, Hai Phong.

Wards	Number of dengue fever cases	Population	Latitude	Longitude
Dong Hai 1	56	21.676	20.859630756975456	106.74098195935022
Dong Hai 2	11	10.525	20.81891166383983	106.78618864737932
Dang Lam	160	21.469	20.830028955068297	106.71500620827706
Thanh To	76	13.354	20.82343438680632	106.72074391888235
Dang Hai	53	15.598	20.83843713699793	106.723884448923
Nam Hai	9	9.486	20.834054921184954	106.74656537415393
Cat Bi	135	16.167	20.824404339740024	106.70909465084016
Trang Cat	19	10.290	20.80144937619376	106.73969365048697

an urbanized district of Hai Phong City, Vietnam using Poisson space-time retrospective and prospective analysis.

Material and method

Study setting

Hai An district is situated in the southeastern part of Hai Phong City. The district is surrounded by the Lach Tray and Cam river systems, with the Nam Trieu estuary connecting to the Gulf of Tonkin. Being located in the Red River Delta, Hai An experiences a typical hot and humid tropical climate. The average annual temperature is 32.6°C, with peak heat occurring from June to August (with an average temperature of 29°C) and colder temperatures prevailing from November to February (with an average temperature of 16.8°C). Due to its geographical features and natural conditions, Hai An district is particularly susceptible to dengue fever (DF) epidemics, given the favorable conditions for their occurrence.

Study design and population

A cross-sectional and retrospective study was conducted in Hai An district consisting of eight communes, in Hai Phong City, Vietnam. Dengue surveillance data was collected in the period from January 01, 2018, to December 31, 2022.

According to the Vietnamese Ministry of Health, suspected cases of dengue infection are defined as individuals experiencing an acute febrile illness lasting from 2 to 7 days, with a minimum of two clinical symptoms: retro-orbital pain, headache, myalgia, rash, arthralgia, hemorrhagic manifestations, and leucopenia [14]. To confirm a suspected dengue case, a single blood sample might be collected and sent to laboratory analysis using a non-structural protein 1 (NS1) antigen rapid test, serology testing (immunoglobulin enzyme-linked immunosorbent assay), or molecular methods [14].

Data collection methods and instruments

Two-dimensional geodetic coordinates, such as latitude and longitude were the averaged coordinates calculated from the publicly accessible Database of Global Administrative Areas (gadm.org). Population data according to the results of the 2019 population and housing census of the General Statistics Office.

All the data on DF cases were collected from the national database of Circular 54/2015/TT-BYT [13] and medical records of Hai An district medical center the data were then reviewed by a team of two medical doctors. For all the dengue-notified cases in our study, we obtained the following individual case information, which was routinely collected by the dengue control program of Vietnam through the Hai Phong Preventive Medical Center: age, gender, household address, and date of disease onset.

Statistical analysis

Weekly report data was aggregated and processed by MS Access 365 software. Spatial-temporal scanning statistics were performed using the free software SatScan v10.1.2 (www.satscan.org). Case cluster maps and geographic coordinates, coordinate reference systems, and base maps are managed and analyzed using QGIS 3.14 software. The spatial-temporal Poisson model was used for retrospective and prospective analysis of the concentration of cases in both high-risk and low-risk areas in the surveillance area. The number of Monte Carlo simulations (10,999 times) was used, and the relative risk (RR) was calculated between the inner and outer regions of the cluster. The statistically significant cluster was set with a P-value < 0.05.

We used a Poisson-based spatial-temporal scanning model to identify clusters, with a threshold set for detecting clusters based on a minimum of two cases and a maximum window size of 14 days. Relative risks were calculated by comparing the observed number of cases within the cluster to the expected number based on the background rate.

Parameter setting for statistics program

The threshold for detecting case clusters when there is a signal beyond the background was established from two cases within the statistical areas. The maximum period of time for cluster detection was established to be 14 days equal to the duration of an outbreak in a locality according to the Guidelines for Surveillance and Prevention of DHF [15]. The minimum time for cluster detection was set from 0 to 7 days, respectively. The spatial window is set with a radius of the maximum distance within the flight range of 200m and 400m, respectively, of the dengue vector, *A. aegypti* mosquito. The time to aggregate the number of cases by moving average is 1-14 days. The optimal set of parameters will be selected from the combination of the parameter ranges, ensuring the most suitable parameters for the data in this study.

Ethics

This study was approved by the Ethical Committee of Thai Binh University of Medicine and Pharmacy (No. 49, January 10, 2023). The study results are based on the analysis of DF surveillance data, following Circular 54/2015/TT-BYT [13], and did not require informed consent from participants. The privacy of the patient information was respected and kept confidential, with only the researcher involved in data analysis having full access to the information.

Results

Characteristics of the included population

During the period time of study, 519 cases of DF were recorded. Of those, 253 (48.7%) were male, 266 (51.3%) were female, hence the sex ratio was 0.95. The median age of patients was 37 years, interquartile = 22-50 years, range = 1-86 years.

Table 1 shows the distribution of cases in eight wards of Hai An district. Most of the DF patients were recorded in two wards: Dang Lam and Cat Bi with 160 and 135 cases, respectively. Of note, these two wards are geographically adjacent to each other.

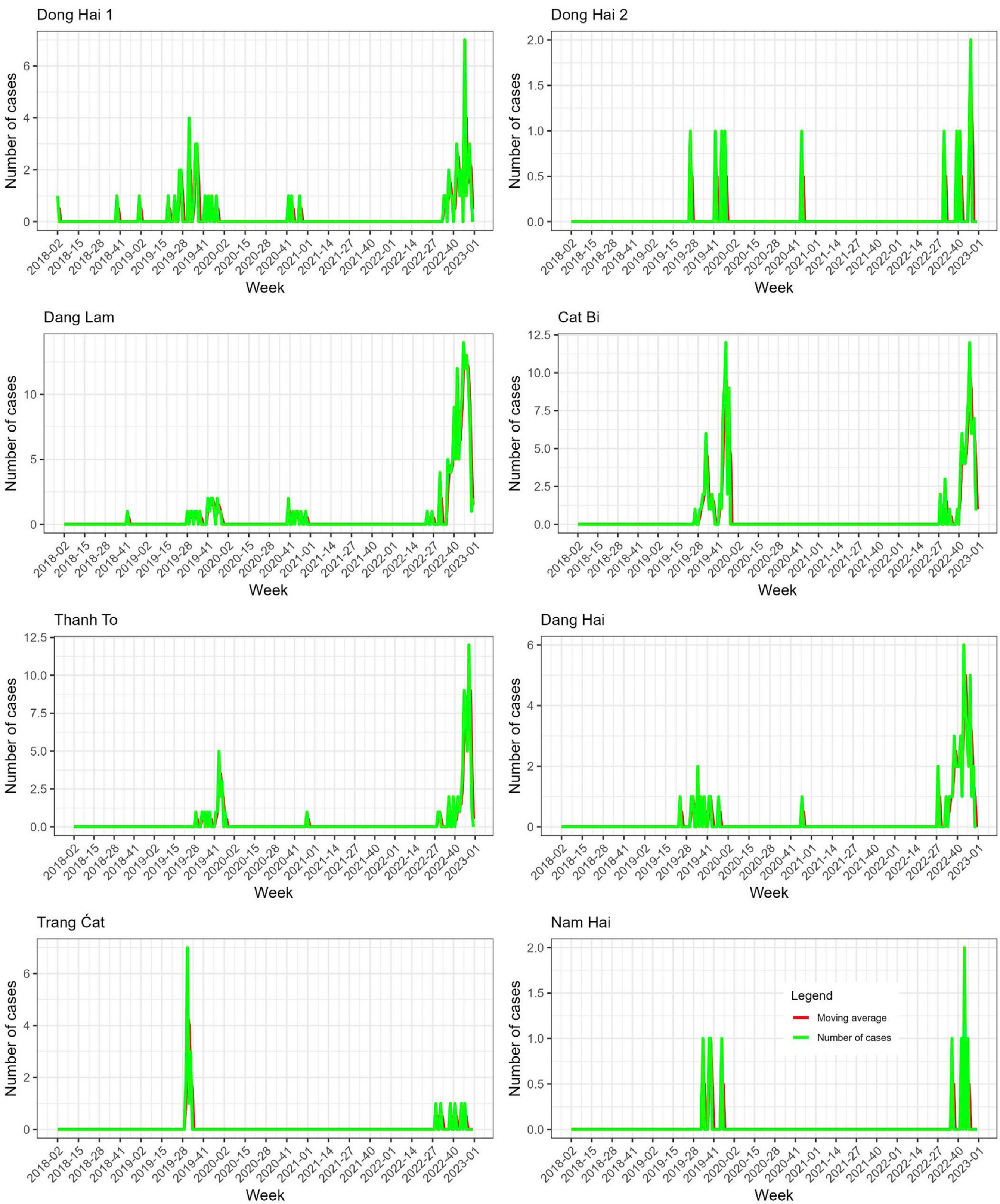

Figure 1. Moving average and number of cases in eight wards (N = 519).

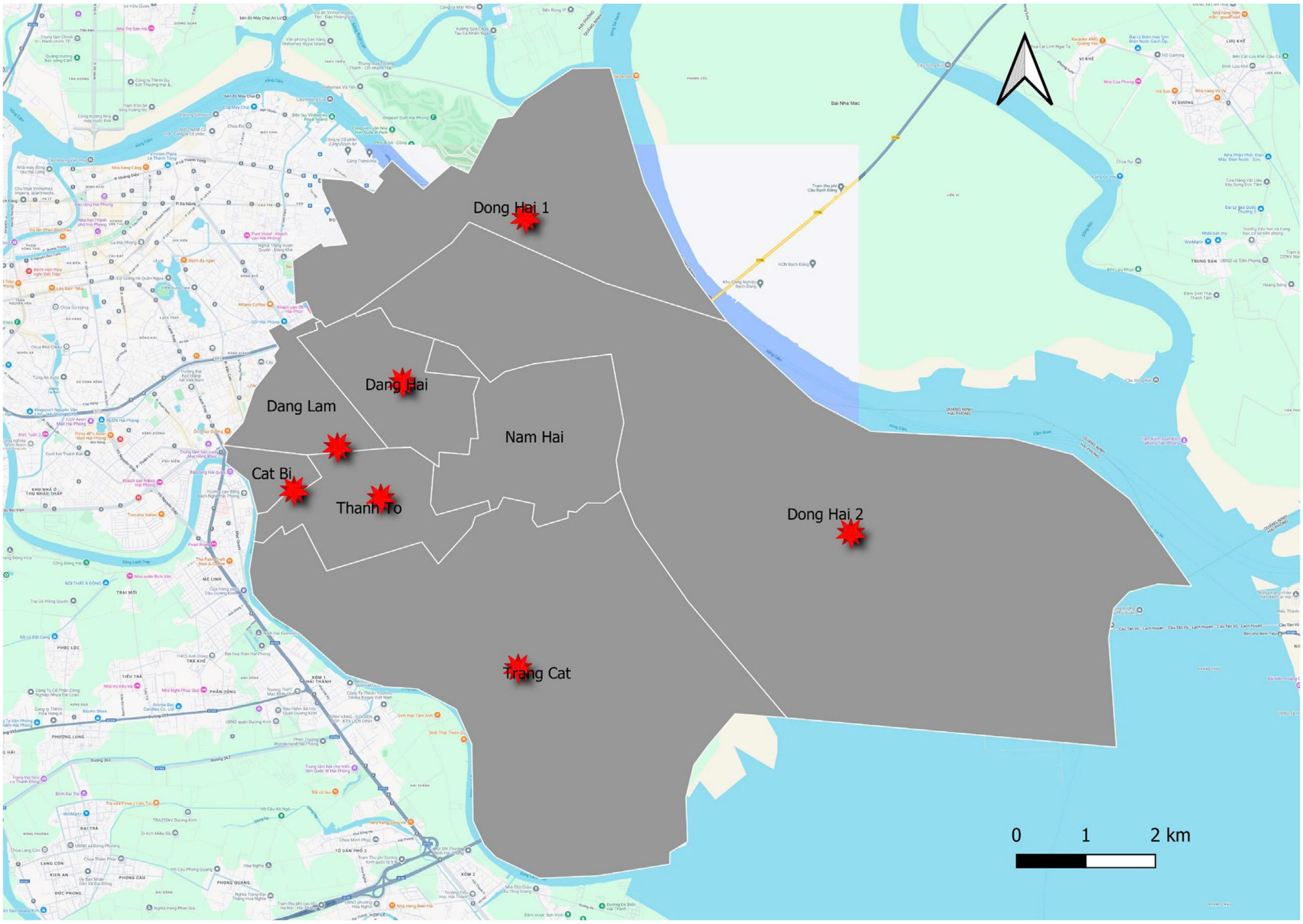

Figure 2. Distribution of seven clusters of cases in Hai An district, Hai Phong, week 2/2018-week 53/2022.

Incidence, temporal trends, and seasonality of dengue fever

Among 519 DF cases, the cumulative incidence per 100,000 inhabitants was 3.37, 127.36, 10.96, 0, and 296.04 in 2018, 2019, 2020, 2021, and 2022, respectively.

Figure 1 shows the time series distribution of patients during the period time of study. Most dengue cases recorded in eight wards of Hai An district appeared in week 15 to week 41 of 2019 and in week 27 to week 53 of 2022. Only a few cases appeared in week 41 to week 53 of 2020 (Figure 1).

Space-time clusters

By retrospective Poisson model-based analysis, seven spatially and temporally significant high-risk dengue clusters were detected, as illustrated in Figure 2. Four of these clusters are geographically adjacent to each other, located in the west of Hai An district, which borders with other districts of Hai Phong City. The other three dengue epidemic clusters were described as individual wards clusters. Six of these seven detected outbreaks occurred in November and December 2022. The largest cluster (the most likely cluster) had a RR of 1539.5 (P <0.00001). The smallest cluster (i.e., the least likely cluster) has a RR of 316.1 (P = 0.006) (Table 2).

Prospective analysis using the Poisson model significantly detected four active case clusters at the time of the study. Especially, all four clusters of these cases are in four wards that are geographically adjacent to each other. The largest cluster of cases with RR was 47.7 (P <0.00001) and the smallest cluster with RR was 18.2 (P <0.00001) (Table 3).

Discussion

In this study, we investigated the spatial and temporal patterns of DF cases in an urban district of Hai Phong City, Vietnam, from 2018 to 2022 using spatial-temporal scan statistics. Our analysis revealed several important findings, emphasizing the improvement of preventive measures and intervention and the need for further investigation of risk factors of DHF in this area.

The demographic characteristics of the DF cases in our study sample indicated a relatively balanced sex ratio. The average age of patients was 37 years, suggesting an increase in adult patients [16].

The findings of this study highlight significant disparities in the distribution of DF cases in Hai Phong, Vietnam, with clear spatial and temporal patterns. Seasonal clustering was evident in our pure temporal clustering analysis, identifying the months of November and December with the highest risk of DF from 2018 to 2022 [14,17–20]. Previous studies conducted in Vietnam consistently reported the cyclical nature of DF outbreaks occurring approximately every 3-5 years and peaking every 10 years. Importantly, our study observed a significant increase in the number of DF cases during the study period. The majority of reported cases occurred from July to November. These findings align with similar studies conducted in different regions of Vietnam, emphasizing the rainy season as the most common time for dengue transmission [14,17–20].

The favorable conditions for dengue transmission during the rainy season in Vietnam can be attributed to its tropical climate. Warm temperatures and humid environment facilitate the propagation of *Aedes agypti* contributing to more disease outbreaks [21–23]. Additionally, the

Table 2
Dengue fever case cluster detected by retrospective spatial-temporal Poisson model.

Time	Wards	Number of cases	Expected number of cases	Relative risk	*P*-value Monte Carlo
12-25/11/2022	Dang Lam	26	0.019	1405.6	<0.00001
02-15/11/2022	Cat Bi	21	0.015	1492.5	<0.00001
03-16/12/2022	Thanh To	18	0.012	1539.5	<0.00001
29/10-11/11/2022	Dang Hai	10	0.014	720.7	<0.00001
20/07-02/08/2019	Trang Cat	9	0.009	981.3	<0.00001
19/11-02/12/2022	Dong Hai 1	8	0.02	413.3	<0.00001
19/11-02/12/2022	Dong Hai 2	3	0.009	316.1	0.006

Table 3
Dengue fever case cluster detected by prospective space-time Poisson model.

Time	Wards	Number of cases	Expected number of cases	Relative risk	*P*-value Monte Carlo
01-14/11/2022	Dang Lam	24	0.54	47.4	<0.00001
01-14/11/2022	Cat Bi	14	0.41	35.7	<0.00001
01-14/11/2022	Thanh To	13	0.34	40.0	<0.00001
01-14/11/2022	Dang Hai	7	0.39	18.2	<0.00001

dense population concentration in urban centers and industrial areas might set an environment conducive to dengue transmission.

These results provide valuable insights into the DHF disease dynamics in Hai Phong, highlighting the need to consider both spatial and temporal dimensions when designing effective control strategies. By understanding the specific high-risk periods and areas, targeted interventions can be implemented to minimize the spread of DF and mitigate its impact on the population. Such measures may include comprehensive vector control, public awareness campaigns, and community engagement, all aimed at reducing mosquito breeding sites, promoting personal protection measures, and fostering collective efforts against DF [24,25].

The strength of this study lies in using both retrospective and prospective analysis methods to detect existing and emerging clusters, while most previous spatial-temporal studies on DF in Vietnam as well as other countries such as Australia, Bangladesh, Thailand, and Sri Lanka only employed one method [26–30]. Therefore, this study provided more detailed information on clusters for local health authorities facing different risks of DF cases. In fact, the spatial-temporal Poisson retrospective analysis was used to accurately identify statistically significant seven clusters in the study area [31].

Conversely, the spatial-temporal Poisson prospective analysis served as a powerful tool for the real-time detection of emerging DF clusters. Through continuous monitoring of incoming data, this analysis enabled early identification of newly forming clusters. During the study, this analysis method successfully identified four active outbreak clusters with a relatively high risk.

Our study has potential limitations. Firstly, the reported number of cases may be underreported due to asymptomatic infections or self-treatment at home. Secondly, the precise location (home addresses) where DF cases were reported may differ from the places where they were infected, as we did not differentiate between locally acquired and imported cases in this study. Additionally, the use of officially available surveillance data with limited parameters can impact cluster detection. The interpretation of results should also take into account other contextual factors, such as population dynamics, environmental conditions, and human mobility patterns. In this study, we did not collect and analyze weather data, such as humidity, rainfall, and sunshine duration, even though DF is known to be sensitive to climatic conditions and certain socio-economic factors. However, with minimal information—population, coordinates, and case counts—we were still able to detect and monitor the existence of clusters. The scan statistics model could incorporate these parameters in future research, and this study serves as a promising direction for applying this statistical technique in the surveillance and response to DF in Vietnam. Lastly, the small and narrow geographical area of the urban district in which this study was conducted may limit the generalizability of the results to larger populations. However, it is important to note that the primary objective of our study was to assess the effectiveness of the scanning statistical analysis method in detecting case clusters. In this context, although these limitations should be considered, they do not significantly diminish the validity and significance of the findings.

Conclusion

Our study provided important insights into the spatial and temporal patterns of DF in an urban district of Hai Phong City, Vietnam. This is a single study conducted in an urban area; however, we suggest applying this approach on a broader scale with sampling from various geographical regions across Vietnam. Despite the efforts of existing control and preventive measures, the incidence of DHF was increasing. This study provides a basis for improving the effectiveness of interventions and conducting further investigations into risk factors in the study area, as well as in other urban and suburban areas nationwide.

Declarations of competing interest

The authors have no competing interests to declare.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics statement

This study was approved by the Ethical Committee of Thai Binh University of Medicine and Pharmacy (No. 49, January 10, 2023). The study results are based on the analysis of dengue fever surveillance data, following Circular 54/2015/TT-BYT, and did not require informed consent from participants. The privacy of the patient information was respected and kept confidential, with only the researcher involved in data analysis having full access to the information.

Author contributions

TTL, HTN, KLD, TLD, and VTH contributed to experimental design, data analysis, statistics, interpretation, and writing. TTL, PTV, DCL, TKN, KLD, and TLD administered questionnaires and collected data. TTL, HTN, and TLD wrote the original draft; TTL, HTN, PTV, DCL, TKN, TLD, KLD, and VTH contributed to critically reviewing the manuscript. TLD coordinated the work.

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