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Spatiotemporal characterization of the first weeks of the Chikungunya epidemic outbreak in Cienfuegos, Cuba

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Abstract
The Chikungunya virus (CHIKV) poses a significant public health threat in the Americas. Cuba, with a more epidemic than endemic transmission profile, requires detailed characterization of outbreaks to implement effective control strategies. The objective of this study was to describe the spatiotemporal dynamics of the first weeks of the CHIKV outbreak in Cienfuegos Province, Cuba. An observational, descriptive, and cross-sectional study was conducted in Cienfuegos (epidemiological weeks 33–43, 2025). Data on suspected, probable, and RT-PCR-confirmed cases were obtained from epidemiological surveillance records. Temporal trends were analyzed, and spatial analysis was performed using Moran's Global Index and kernel density to identify clusters. A total of 13.037 cases were reported (overall incidence: 3,902.3 per 100,000 population). The epidemic curve showed exponential growth, with a mean weekly incidence of 1,185 cases. The municipalities of Palmira (9,121.0*) and Cruces (8,201.3*) had the highest cumulative incidences. The spatial distribution of confirmed cases was heterogeneous, with the main clusters in Rodas (84.06*) and Cruces (80.58*). Spatial analysis revealed significant autocorrelation (Moran's Index = 0.45, $p<0.001$) and the formation of urban clusters that accounted for 79% of the cases. It is concluded that the outbreak in Cienfuegos was characterized by rapid spread and marked spatial heterogeneity, with clearly defined urban epicenters.

Keywords: Chikungunya; Cienfuegos; Spatial analysis; Temporal trend

1. Introduction

Chikungunya virus (CHIKV) is an alphavirus transmitted by mosquitoes of the genus *Aedes*, primarily the species *Aedes aegypti* and *Ae. albopictus*, representing a growing threat to global public health (WHO, 2017; Fimia *et al*., 2021; Bartholomeeusen, 2023). Since its introduction to the Americas in 2013, CHIKV has caused massive epidemic outbreaks (Fischer and Staples, 2014; Leparc *et al*., 2014; Roth *et al*., 2014), with a considerable socioeconomic impact due to associated morbidity, particularly severe and debilitating arthralgia and arthritis that can persist for months or years (Osés *et al*., 2021; Roiz *et al*., 2024; Urbanski, 2024).

Cuba, an island nation with a well-established vector control program, experiences a transmission pattern characterized by discrete epidemic outbreaks, followed by periods of low or no transmission, rather than sustained endemicity (Fimia *et al*., 2021; Sánchez *et al*., 2024; Torres *et al*., 2024). This profile makes detailed characterization of the initial outbreak phase essential for understanding the factors driving virus spread and optimizing intervention strategies (Pichardo *et al*., 2023; Sánchez *et al*., 2024; Rosales, 2025).

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The province of Cienfuegos, located in the south-central region of Cuba, was not among the provinces most affected in previous arbovirus outbreaks, classifying it as an area of historically low endemicity (Baldoquín, 2023).

The present study aimed to characterize the spatiotemporal dynamics of the initial weeks of the CHIKV epidemic outbreak in the province of Cienfuegos, Cuba between epidemiological weeks (EW) 33 to 43 of the year 2025, and thus be able to identify patterns of dispersion, high-risk municipalities and potential factors associated with intense transmission.

2. Materials and Methods

2.1. Study area

The province of Cienfuegos is geographically located between 22°36' north latitude and 80°24' west longitude, at an altitude of 65 meters. It has an estimated population of 334,804 inhabitants and a land area of 4,771.2 km², and is divided into eight municipalities: Abreus, Aguada de Pasajeros, Cienfuegos, Cruces, Cumanayagua, Lajas, Palmira, and Rodas.

2.2. Study type

An observational, descriptive, and cross-sectional study was conducted in the province of Cienfuegos, Cuba, during epidemiological weeks (EW) 33 to 43 of 2025. The study period was selected based on the inflection point in the increase of suspected cases (EW 33).

2.3. Data sources and case definitions

Data were obtained from the database of suspected and confirmed CHIKV cases of the Deputy Directorate of Epidemiology of the Provincial Center for Hygiene, Epidemiology, and Microbiology (CPHEM) of Cienfuegos, and were triangulated with the records of the Department of Epidemiological Surveillance of the General Directorate of Public Health. The PAHO/WHO case definition (2023) was adopted: suspected case (nonspecific febrile syndrome), probable case (febrile syndrome with severe arthralgia/arthritis and negative IgM for dengue) and confirmed case (detection of CHIKV by real-time RT-PCR at the "Pedro Kourí" Institute of Tropical Medicine - IPK).

2.4. Data Analysis

The analysis was performed using Microsoft Excel and QGIS v.3.40.7. Frequencies, proportions, and incidence rates (per 100,000 inhabitants) were calculated. The epidemic curve was constructed by symptom onset date. For spatial analysis, the residence of each confirmed case was geocoded. Moran's Global Index (I) was applied to assess spatial autocorrelation, and Kernel density analysis was used to identify clusters (areas of concentration and dispersion). The spatial analysis unit included municipalities, local councils, and city blocks.

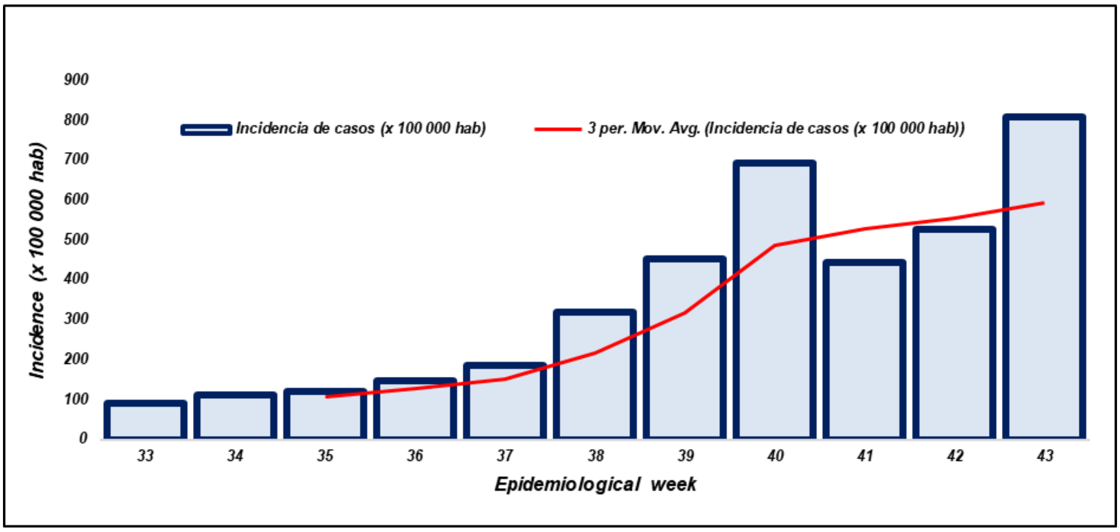
2.5. Ethical Considerations

The study protocol was reviewed and approved by the Ethics Committee of the Cienfuegos CPHEM. Only aggregated and anonymized data were used to ensure confidentiality, all in accordance with the norms and principles of the latest Declaration of Helsinki (DHAMM, 2024).

3. Results

3.1. Temporal dynamics of the outbreak

During the study period (EW 33-43), a total of 13,037 cases of nonspecific febrile syndrome were reported, of which 5,119 (39.2%) were classified as probable CHIKV and 321 (2.4%) were confirmed by RT-PCR. The overall cumulative incidence was 3,902.3 per 100,000 populations. The epidemic curve showed an exponential increase in weekly incidence, from 91.9 per 100,000 populations in EW 33 to a peak of 810 per 100,000 populations in EW 43, with a mean of 1.185 cases per week (Figure 1).



Source: Database of Nonspecific Febrile Syndrome. Deputy Directorate of Epidemiology of the CPHEM 2025.

Figure 1 Temporal distribution of the incidence of suspected, probable, and confirmed cases of CHIKV (per 100,000 inhabitants) according to statistical weeks. Cienfuegos Province, Cuba. epidemiological weeks 33-43/2025

The municipal distribution of the cumulative incidence of suspected and probable cases was heterogeneous. The municipalities of Palmira (9,121.0*), Cruces (8,201.3*), Aguada de Pasajeros (6,077.6*), and Lajas (4,080.8*) presented rates well above the provincial average. The peak of weekly incidence also varied among municipalities, occurring in epidemiological week 39 (Palmira), epidemiological week 40 (Aguada de Pasajeros), and epidemiological week 43 (Cruces and Lajas) (Table 1).

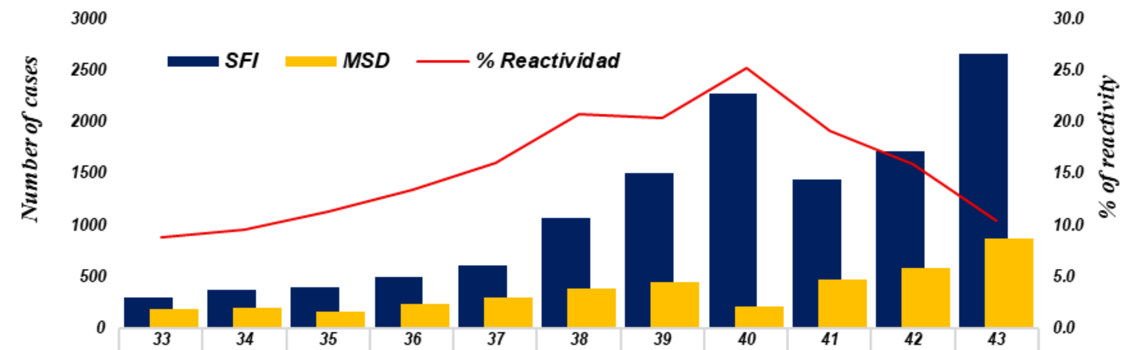
Table 1 Temporal distribution of the weekly and cumulative incidence of suspected, probable and confirmed cases of CHIKV according to municipalities and epidemiological weeks. Cienfuegos, week 33-43/2025

Municipalities/se	33	34	35	36	37	38	39	40	41	42	43	Cumulative incidence
Abreus	90.1	49.2	69.6	151.6	77.8	102.4	168.0	356.4	295.0	508.0	520.3	2388.6
Aguada de Pasajeros	122.5	283.0	249.2	384.3	401.2	696.9	561.7	950.3	899.6	764.5	764.5	6077.6
Cienfuegos	98.0	101.5	114.2	134.3	139.5	213.9	385.7	635.9	267.5	273.8	741.4	3105.7
Cruces	35.8	134.3	89.5	152.2	161.2	205.9	304.4	1244.5	1020.7	2113.0	2739.7	8201.3
Cumanayagua	76.3	103.3	140.2	71.3	123.0	216.5	241.1	263.2	201.7	334.6	346.9	2118.3
Lajas	48.1	54.1	84.1	60.1	132.2	354.6	276.5	721.2	589.0	769.3	991.6	4080.8
Palmira	83.9	115.8	135.8	211.7	551.1	1234.0	1697.2	1673.3	1441.6	1186.1	790.7	9121.0
Rodas	71.1	71.1	55.0	80.8	109.9	93.8	203.7	236.0	119.6	455.9	837.3	2334.2
Province	91.9	111.3	121.5	148.2	185.0	320.0	451.7	692.3	443.6	526.8	810.0	3902.3

Source: Database of Nonspecific Febrile Syndrome. Deputy Directorate of Epidemiology. CPHEM 2025.

*Incidence per 100,000 inhabitants

The monoserum analysis for Dengue in suspected cases showed a reactivity of 15.3% throughout the period, supporting the high circulation of CHIKV as the predominant etiological agent in this outbreak (Figure 2).



	33	34	35	36	37	38	39	40	41	42	43
SFI	307	372	406	495	618	1069	1509	2273	1441	1718	2663
MSD	193	197	167	238	305	389	445	214	479	590	879
% Reactividad	8.8	9.6	11.4	13.4	16.1	20.8	20.4	25.2	19.2	15.9	10.5

Source: Nonspecific Febrile Syndrome database. Deputy Directorate of Epidemiology. CPHEM 2025.

Figure 2 Report of Nonspecific Febrile Syndrome in Dengue monoserum studies and % reactivity according to epidemiological weeks. EW 33-43/2025

The cumulative incidence of RT-PCR-confirmed cases showed a different pattern, with the municipalities of Rodas (84.06*), Cruces (80.58*), and Palmira (71.88*) being the most affected (Table 2). The appearance of confirmed cases was detected starting in epidemiological week 35 (Aguada de Pasajeros) and gradually spread to other municipalities, with a marked increase from epidemiological week 40 onward.

Table 2 Temporal distribution of the incidence of confirmed CHIKV cases (per 100,000 inhabitants) according to the date of symptom onset by municipality and epidemiological week. Cienfuegos, week 33-43/2025

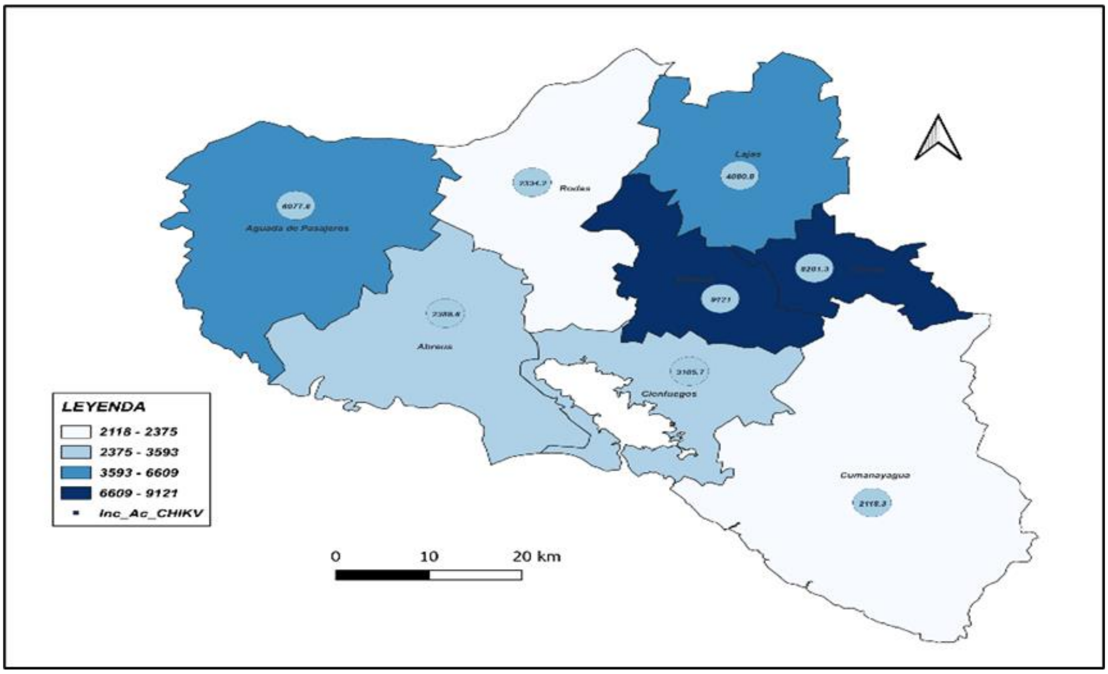
SE/Municipalities	Abreus	Aguada de Pasajeros	Cienfuegos	Cruces	Cumanayagua	Lajas	Palmira	Rodas
35	0.00	4.22	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.58	0.00	0.00	6.01	3.99	3.23
39	0.00	0.00	2.88	0.00	0.00	0.00	19.97	6.47
40	24.58	21.12	3.46	44.77	7.38	12.02	19.97	12.93
41	12.29	21.12	17.87	17.91	4.92	0.00	15.97	35.56
42	0.00	12.67	21.91	17.91	0.00	12.02	11.98	25.86
Cumulative incidence	**36.87**	**59.13**	**46.70**	**80.58**	**12.30**	**30.05**	**71.88**	**84.06**

Source: Database of Nonspecific Febrile Syndrome. Deputy Directorate of Epidemiology. CPHEM 2025.

*Incidence per 100,000 inhabitants.

3.2. Distribution of cases and spatial patterns

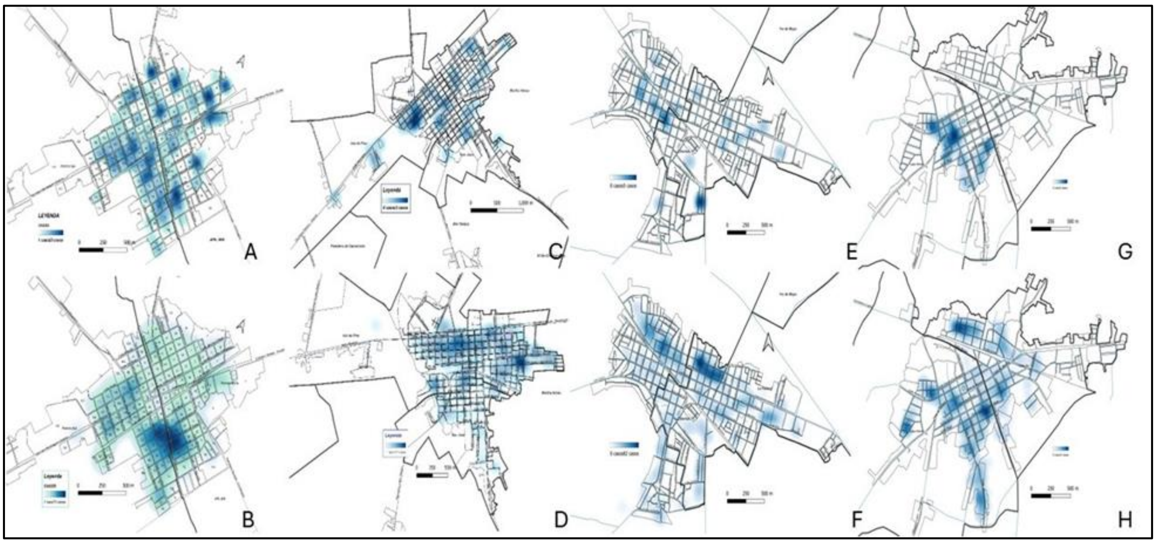
The spatial distribution of incidence revealed marked heterogeneity among municipalities (Figure 3). For suspected and probable cases, the highest cumulative values were concentrated in Palmira (9,121.0) and Cruces (8,201.3). This geographic pattern persisted when analyzing only confirmed cases, with the municipalities of Rodas (84.06) and Cruces (80.58) having the highest incidences, thus spatially consolidating these municipalities, and Cruces in particular, as the most significant epicenters of the outbreak.

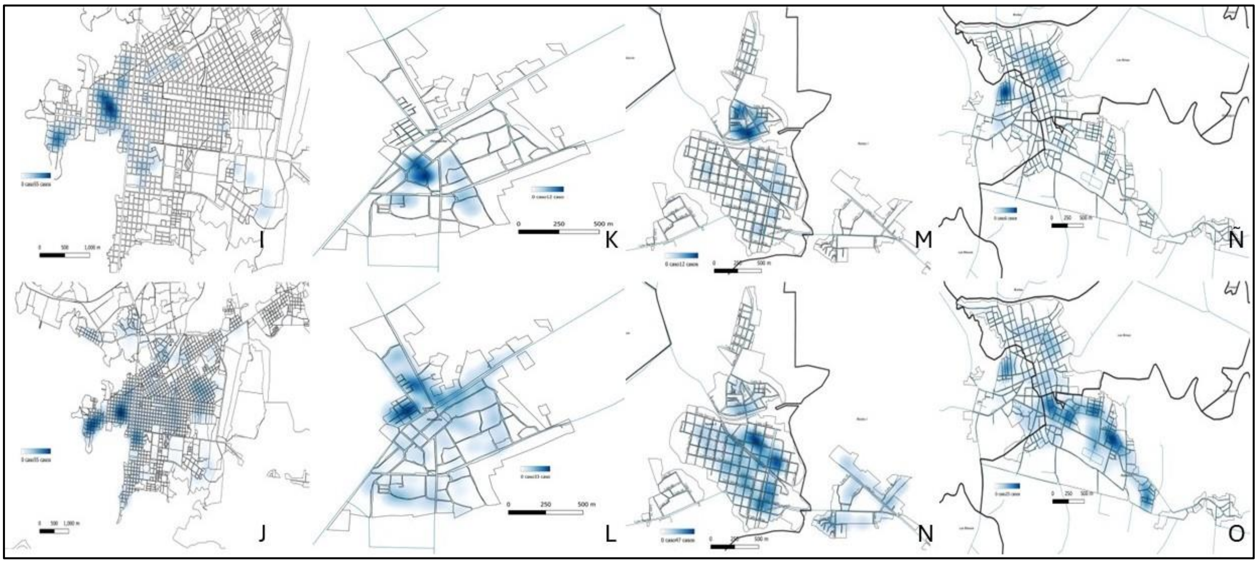


Source: Database of Nonspecific Febrile Syndrome. Deputy Directorate of Epidemiology. CPHEM 2025. *Incidence per 100,000 inhabitants.

Figure 3 Spatial distribution of the incidence of suspected and confirmed CHIKV cases by municipality of origin. Cienfuegos epidemiological week 33-43/2025

Spatial analysis confirmed a non-random distribution of cases (Figure 4), with a statistically significant positive spatial autocorrelation (Global Moran's Index = 0.45, $p < 0.001$). Kernel density analysis identified statistically significant primary clusters, located predominantly in the urban districts of each municipality. These clusters accounted for 79% of all cases reported at the end of epidemiological week 43. The spatial correlation between areas with a high incidence of suspected/probable cases and areas with the highest density of confirmed cases is graphically illustrated.





A: Concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 33, Palmira municipality. **B:** Dispersion and concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 43, Palmira municipality. **C:** Concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 33, Cruces municipality. **D:** Dispersion and concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 43, Cruces municipality. **E:** Concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 33, Aguada municipality. **F:** Dispersion and concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 43, Aguada municipality. **G:** Concentration of suspected, probable and confirmed cases of CHIKV in epidemiological week 33, Lajas municipality. **H:** Dispersion and concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 43, Lajas municipality. **I:** Concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 33, Cienfuegos municipality. **J**: Dispersion and concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 43, Cienfuegos municipality. **K:** Concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 33, Abreus municipality. **L:** Dispersion and concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 43, Abreus municipality. **M:** Concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 33, Rodas municipality. **N:** Dispersion and concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 43, Rodas municipality. **Ñ**: Concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 33, Cumanayagua municipality. **O**: Dispersion and concentration of suspected, probable, and confirmed CHIKV cases in epidemiological week 43, Cumanayagua municipality.

Source: Database of Nonspecific Febrile Syndrome. Deputy Directorate of Epidemiology. CPHEM 2025.

Figure 4 Dispersion and concentration of suspected, probable and confirmed cases of CHIKV by municipalities, popular councils and blocks

4. Discussion

This study provides a detailed spatiotemporal analysis of the initial phase of the CHIKV outbreak in Cienfuegos Province, Cuba, an area previously considered non-endemic. Our findings not only delineate the rapid progression and geographic heterogeneity of the outbreak, but also offer crucial insights into the factors underlying arbovirus transmission in island settings with active vector control programs (Fimia *et al*., 2022a; Diéguez *et al*., 2025a, b).

The epidemic trajectory observed in Cienfuegos, characterized by an exponential increase in incidence in a period of just ten weeks, is a hallmark of the introduction of an arbovirus into a population with a high degree of immunological susceptibility (Gregianini *et al*., 2023; PAHO, 2023), this "J-curve" pattern being consistent with initial outbreaks of CHIKV documented in other regions of the Americas (Fischer and Staples, 2014; Leparc *et al*., 2014; Pichardo *et al*., 2023). A study by William *et al*. (2024) on the CHIKV outbreak described an extremely rapid exponential growth phase, similar to ours, attributing it to the introduction of a new strain of the virus (Asian lineage) into a population without pre-existing immunity, very similar to what happened with SARS-CoV-2 (Osés *et al*., 2020; Vogt *et al*., 2023; Sánchez *et al*., 2024). The rate of spread in Cienfuegos, with an average of 1.185 cases per week, suggests an intense infectious force and high vector competence of the local *Ae. aegypti* (Campos *et al*., 2022; Fimia *et al*., 2022a, b; Diéguez *et al*., 2025b).

The timeline of confirmed cases, initially detected sporadically before exploding at the provincial level starting in epidemiological week 40, suggests a period of silent virus circulation. This finding is consistent with a study by Cauchemez *et al*. (2014) on CHIKV transmission dynamics, which postulates that transmission chains can remain subthreshold and undetected by conventional surveillance systems for several weeks until a tipping point is reached that triggers an explosive epidemic. Our data support this hypothesis, indicating that the virus was likely introduced and circulated cryptically before the increase in cases of nonspecific febrile syndrome triggered alarms in epidemiological week 33. This window of undetected transmission represents a critical challenge for early control and underscores the limitation of surveillance systems that are activated predominantly by clinical manifestation rather than proactive virological detection (Fimia *et al*., 2021; Fimia *et al*., 2022a, b; Fimia *et al*., 2023).

One of the most significant findings of our analysis was the marked heterogeneity in cumulative incidence among municipalities, which points to the existence of local factors that enhanced transmission (Campos *et al*., 2022; Manrique, 2023; Diéguez *et al*., 2025a, b). The comparison with a CHIKV outbreak analyzed in the coastal region of Colombia, described by Freitas *et al*. (2022), is particularly interesting. In his study, spatial clusters of cases were significantly associated with areas of higher human population density, less access to public services (such as water and sanitation), and a higher density of *Ae. aegypti* breeding sites. Similarly, the epicenter municipalities of Cienfuegos share characteristics of dense urbanization and could present similar socio-environmental vulnerabilities, although this aspect requires further investigation, there are studies on this subject in other provinces of Cuba, which corroborate this (Campos *et al*., 2022; Fimia *et al*., 2022a; Diéguez *et al*., 2025a).

However, our analysis reveals an additional layer of complexity. The distribution of RT-PCR-confirmed cases showed a spatial pattern that did not completely overlap with that of nonspecific febrile syndrome. While Palmira was an epicenter for both, municipalities like Rodas emerged with a cumulative incidence of confirmed cases (84.06 per 100,000 inhabitants) even higher than that of Cruces. This discrepancy can be explained by several factors. First, it may reflect variations in diagnostic capacity and the timeliness of sample collection across territories, a well-documented bias in arbovirus surveillance (Rendón *et al*., 2020). Secondly, and more importantly from an epidemiological perspective, it could indicate differences in the temporal dynamics of viral introduction. It is plausible that Rodas, showing a later peak in confirmed cases (concentrated in epidemiological week 43), represents a second wave of spread from the initial epicenter municipalities, driven by human mobility. A study on dengue transmission in Iquitos, Peru (Stoddard *et al*., 2014) demonstrated how people's daily mobility patterns are critical determinants in the spatial redistribution of the virus within a city, creating secondary transmission foci far removed from the primary foci. A similar mechanism is likely operating in our outbreak, where connectivity between municipalities facilitated successive viral seeding in new susceptible populations.

Formal spatial analysis provided strong evidence to reject the hypothesis of a random distribution of cases. The Global Moran's Index of 0.45 ($p < 0.001$) indicates a strong positive spatial autocorrelation, meaning that areas with high incidence tend to be close to one another. This finding is universal in arbovirus transmission studies and highlights the focal nature of the disease. Kernel density analysis allowed for the precise identification of these foci or "hotspots," locating them predominantly in the urban districts of each municipality, which accounted for 79% of all cases. These results are consistent with those obtained by other authors in Cuba (Campos *et al*., 2022; Diéguez *et al*., 2025a, b).

The formation of these urban clusters is not a random phenomenon. It is closely linked to the spatial distribution of the vector and the factors that favor its proliferation. Our finding that these clusters were associated with the highest *Ae. aegypti* infestation rates (≥0.8%) in the month prior to the outbreak is crucial and consistent with recent research. A seminal study by Manrique *et al*. (2023) in Mexico demonstrated that, *Ae. aegypti* infestation is not homogeneous, but rather persistently clusters in "hot spots" that represent only a fraction of the territory (around 20–30%) but contribute disproportionately (more than 50–60%) to adult mosquito production. These "hotspots" act as constant sources of vectors, maintaining transmission even when control measures are applied homogeneously and less intensively in the rest of the area (Diéguez *et al*., 2025a, b).

The implications of this parallel with our results are profound. It suggests that vector control programs in Cienfuegos, although existing, may not have been sufficiently intensive and targeted to suppress mosquito density in these "hot spots" below the critical threshold necessary to prevent an outbreak. An intervention study in Vietnam, published by Kay and Nam (2005), found that vector control focused on "hot spots" identified through spatial analysis was significantly more effective and cost-efficient in reducing dengue incidence than uniform citywide spraying campaigns. Our findings strongly advocate for the adoption of a similar strategy for the control of CHIKV and other arboviruses in Cuba.

The context of arbovirus cocirculation adds another layer of complexity to the interpretation of the outbreak (Paixão *et al*., 2017; Chieh *et al*., 2023). The low reactivity rate for dengue (15.3%) in a scenario of high incidence of nonspecific febrile syndrome is a telling finding. It indicates that, during this period, CHIKV was the dominant circulating pathogen, responsible for the overwhelming majority of fever cases. This phenomenon of one arbovirus "dominance" over another in a specific outbreak has been previously observed in the literature.

A plausible explanation lies in population immunity. Cuba has experienced significant dengue outbreaks in past decades, which could have generated a level of partial immunity in the population that modulated dengue transmission, while the population remained fully susceptible to CHIKV. However, a stronger hypothesis, supported by recent evidence, points to an intrinsic advantage of CHIKV under certain conditions. Research by Bustos *et al*. (2025), which used comparative mathematical models between dengue and CHIKV, suggested that CHIKV may exhibit greater vector transmission efficiency (higher basic reproduction number, R0) in populations without prior immunity, allowing it to outcompete dengue for susceptible hosts. Furthermore, the higher and earlier-onset viremia in CHIKV patients, compared to dengue, could facilitate greater infectivity to mosquito vectors.

This cocirculation scenario has critical diagnostic and clinical implications (Paixão *et al*., 2017; Chieh *et al*., 2023). The similarity in the initial clinical presentations between both diseases can lead to misdiagnoses, with potentially serious consequences for patient management (e.g., the risk of hemorrhage in dengue with the inappropriate use of nonsteroidal anti-inflammatory drugs for CHIKV arthralgia). Therefore, our finding reinforces the urgent need for rapid and accessible differential diagnostic tests at the primary care level during outbreaks of febrile syndromes.

It is important to acknowledge the limitations of this study. First, as a passive surveillance study, it is subject to the inherent underreporting of cases, especially mild or asymptomatic ones, which could lead to an underestimation of the true magnitude of the outbreak. Second, RT-PCR confirmation was not applied to all suspected cases, introducing verification bias. The spatial patterns of confirmed cases may reflect not only viral transmission but also the geographic distribution of access to healthcare services and sample collection. Finally, our analysis focused on basic spatiotemporal and entomological factors; the inclusion of more detailed socioeconomic and environmental variables in future analyses would significantly enrich our understanding of risk factors.

5. Conclusion

Taken together, the characterization of the CHIKV outbreak in Cienfuegos paints a picture of a perfect storm: the introduction of a highly transmissible virus into a susceptible and previously undetected population found an ideal epidemiological landscape characterized by urban "hot spots" with high vector density. The rapid spread and marked spatial heterogeneity observed are consistent with findings from recent studies in other regions, validating the global applicability of these concepts. The results obtained go beyond mere description and offer crucial operational lessons. They point to the need to evolve from reactive and homogeneous vector control to a proactive, risk-based, and deeply focused and stratified approach. Identifying and intensively treating entomological "hot spots," even during inter-epidemic periods, could be key to raising the containment barrier and preventing future outbreaks of this magnitude. Likewise, strengthening syndromic surveillance with real-time laboratory and spatial components is essential to detect silent virus circulation and activate early and targeted responses. The experience in Cienfuegos serves as both a warning and a guide for other non-endemic provinces in Cuba and the Caribbean, underscoring that the threat of arboviruses is constant and that their control demands ever-increasing epidemiological and operational precision.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest exists among the Authors.

Authors' Contributions

All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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