Population mobility, demographic, and environmental characteristics of dengue fever epidemics in a major city in Southeastern Brazil, 2007-2015

Mobilidade populacional e características demográficas e ambientais das epidemias de dengue em uma metrópole no Sudeste do Brasil, 2007-2015

Movilidad de la población y características demográficas y ambientales de la epidemia de dengue en una gran ciudad del sudeste de Brasil, 2007-2015

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Abstract

Around 14% of world dengue virus (DENV) cases occur in the Americas, most of them in Brazil. While socioeconomic, environmental, and behavioral correlates have been analyzed thoroughly, the role played by population mobility on DENV epidemics, especially at the local level, remains scarce. This study assesses whether the daily pattern of population mobility is associated with DENV incidence in Campinas, a Brazilian major city with over 1.2 million inhabitants in São Paulo State. DENV notifications from 2007 to 2015 were geocoded at street level (n = 114,884) and combined with sociodemographic and environmental data from the 2010 population census. Population mobility was extracted from the Origin-Destination Survey (ODS), carried out in 2011, and daily precipitation was obtained from satellite imagery. Multivariate zero-inflated negative binomial regression models were applied. High population mobility presented a relevant positive effect on higher risk for DENV incidence. High income and residence in apartments were found to be protective characteristics against the disease, while unpaved streets, number of strategic points (such as scrapyards and tire repair shops), and precipitation were consistently risk factors.

Dengue; Population Dynamics; Environment

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Introduction

Despite the growing concern about other infectious diseases transmitted by *Aedes aegypti*, such as Zika virus and chikungunya, dengue virus (DENV) remains a global threat [1,2]. The incidence of this disease has grown dramatically in recent decades. About 3.9 billion people in 128 countries are at risk of infection [3]. Regionally, approximately 70% of dengue cases are observed in Asia, followed by Africa (16%) and the Americas, 14% [4]. In 2016, more than 3.1 million DENV cases were reported in the Americas, more than 70% of them in Brazil [5].

Historically, Brazil succeeded in eliminating *Ae. aegypti* during the 1940s, and that campaign inspired the Pan American Health Organization (PAHO) to pursue the elimination in the Americas in the 1950s [6]. Although *Ae. aegypti* was eliminated from the Americas (with the exception of Colombia, Venezuela, British Guyana, Suriname, and the United States), the mosquito was reestablished in the early 1970s [7]. The reintroduction of DENV in Brazil occurred at the beginning of the 1980s, at the Northern state of Amapá [8]. Since then, the disease has grown from an incidence rate close to 0 in 1985 to more than 735 cases per 100,000 inhabitants in 2019 [9,10].

The urbanization process in Brazil produced cities founded on social inequalities, with profound differential access to sanitation services such as water provision as well as sewage system and garbage collection [11]. These gaps in urban infrastructure made Brazilian cities highly suitable for the reproduction of *Ae. aegypti* [12,13,14,15], imposing a major obstacle to the implementation of DENV control policies. In parallel to human behavior [16], incomplete urbanization is a key factor to understand the maintenance and expansion of the vector of this infectious disease in the country [17].

In Brazil's most populous state, São Paulo, DENV transmission began to be reported – with clinical and laboratory diagnosis – in March 1984 [18]. Campinas is the third most populous city in São Paulo, having first reported DENV autochthonous transmission in 1996 [19]. Since then the disease remained endemic, with major epidemics recorded in 2007, 2014, and 2015.

While socioeconomic, environmental, and behavioral correlates of dengue have been analyzed for different contexts in Brazil [20,21,22], more information is necessary to comprehend the role played by population mobility, especially at the local level. This study addresses this issue, and our hypothesis is that population movements are a relevant driving force for dengue diffusion locally. The analysis considered nine consecutive years (from 2007 to 2015), addressing temporal and spatial variations.

We chose Campinas because (i) dengue is an increasing public health threat in the city; (ii) in 2014, Campinas registered the highest number of DENV cases in the Brazil (7% of the total cases, while it shares only 0.6% of population in the country); (iii) in 2015, the city recorded the most prominent DENV incidence rate among the municipalities with over 1 million inhabitants; (iv) it is highly diverse in socioeconomic status of population groups and in access to urban infrastructure (social inequalities), being similar to other Brazilian and Latin American urban contexts; and (v) Campinas has collected unique data on regular daily mobility.

Methods

Study area

The municipality of Campinas (22º53'20"S, 47º04'40"W) is located in Southeastern Brazil, the most economically dynamic region of the country. It has over 1.2 million inhabitants and it is located 100km from the city of São Paulo, the capital of São Paulo State [23]. Campinas is the geographical center and main city of the Campinas Metropolitan Area, composed of 20 municipalities, with 2.8 million inhabitants [24]. With an area of around 800km², the space occupation in Campinas municipality is highly heterogeneous. Although population density is about 1,360 people per km², it considerably varies from highly populated to nearly empty neighborhoods. The weather is tropical, with rains during the summer (December to March), and drought in the winter (June to September). The average minimum temperature is 19ºC (66.2ºF), and the maximum is 29ºC (84.2ºF).

Despite its location within an economically developed area of the country, the city has patent contrasts in terms of population socioeconomic characteristics and urban infrastructure. There are

still gaps in access to water, sewage, and garbage collection. Although the 2010 population census [23] reports that almost all the population had access to piped water (99%), the regularity of the supply can vary according to the area of the city, a problem intensified during the severe drought the city faced in 2014, with subsequent water shortages [25]. Garbage and sewage collection are also virtually widespread, reaching 99% and 87% of the population, respectively [23], although the remaining gaps are greater especially in the outskirts of the city.

The most affluent groups live in the center and north of the municipality, where urban infrastructure is of better quality. In contrast, the south concentrates the impoverished people, with less access to urban services. The urban configuration of Campinas encourages population mobility, given that the territory is abundantly crossed by major roads and highways (Figure 1).

Figure 1

Origin-Destination (OD) units of Campinas, São Paulo State, Brazil.
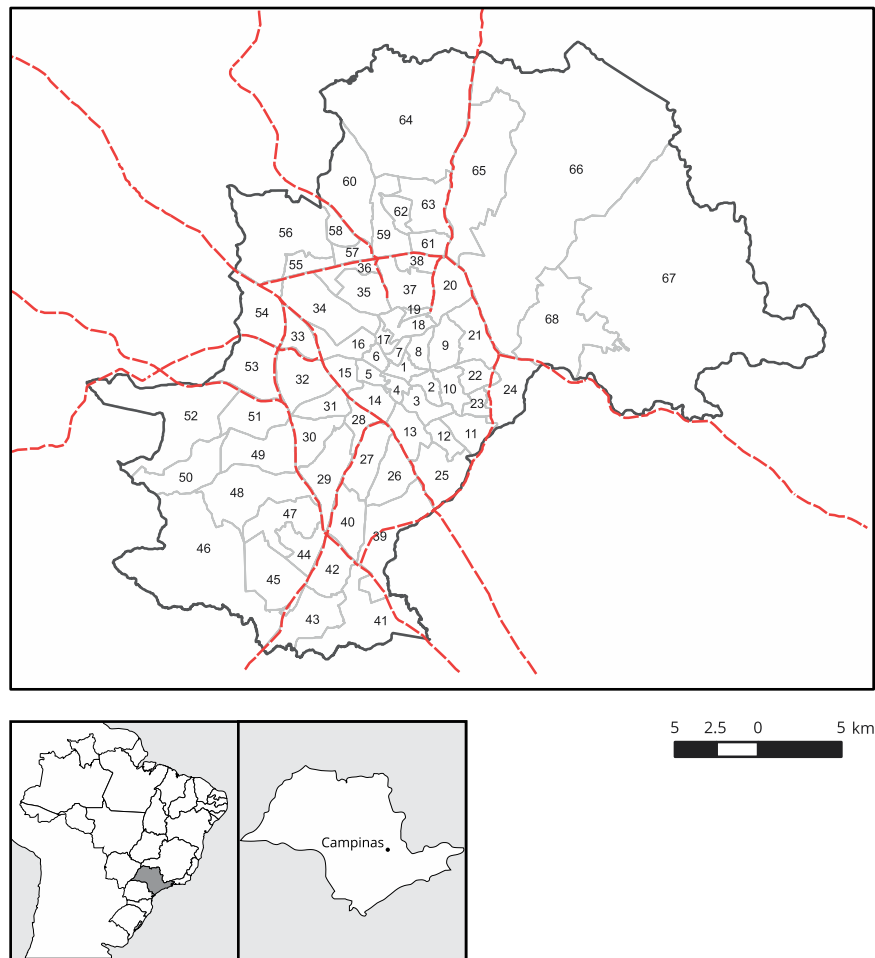
Source: elaborated by the authors based on the shapefiles from the Brazilian Institute of Geography and Statistics (IBGE), 2010, and State Metropolitan Transportation Secretariat, 2011.
Note: red dotted lines refer to the main state roads that cross Campinas; numbers refer to OD units; unit 1 (center of the figure) comprises the city center.

Dengue transmission in Campinas

Campinas had its first large dengue epidemic in 2007, with 1,100 cases per 100,000 inhabitants. Two consecutive epidemics followed in 2014, with 3,647 cases per 100,000 inhabitants, and in 2015, when over 5,600 cases per 100,000 inhabitants were registered. Each epidemic cycle corresponded to the circulation of a new serotype: DEN-3 in 2007 and DEN-1 in 2014 and 2015.

Variables and data sources

We studied 114,884 reported DENV autochthonous cases from January 1st 2007 to December 31st 2015, provided by the Information System on Diseases of Notification (SINAN) [26]. The spatial location of the cases was recorded at the patients' household addresses. The transformation of addresses in coordinates was performed by an enterprise specialized at this task (Geograph Informática e Serviços Ltda., São Paulo, Brazil). Temporal detail was based on the reported date of the beginning of symptoms. Most cases were diagnosed using the clinical-epidemiological criteria, and a small number of cases were analyzed using serologic exams and virus isolation, which occurs especially for more severe cases and deaths.

To assess if high mobility was associated with high dengue incidence – while controlling for other correlates – we used information about population mobility in Campinas obtained from the *Origin-Destination Survey* (ODS), carried out in 2011 [27]. ODS included all population travels between or within ODS units (from now on called only OD units) during one regular business day (Monday to Friday); interviews were carried out from September to November 2011. The assumption in using these data was that patients infected with DENV are mobile.

ODS divided Campinas into 68 units, based on the transportation zoning system, urban equipment infrastructure, and physical barriers. In this study, we used 66 of these units (two of the 68 units were inhabited) as our main unit of analysis. The reasons for this choice were two-fold: (i) each OD unit comprised two or more census tracts, making it straightforward to merge mobility with census data; and (ii) households were sampled within each OD unit, impeding the reorganization of this information on other spatial units under the risk of biasing the survey results.

For each of the 66 OD units, we estimated dengue incidence rates (cases per 100,000 inhabitants) over the 469 epidemiological weeks of the study period. The epidemiological week is the main temporal unit that the Brazilian Ministry of Health uses to organize, to process, and to plan health policies in the country, including those concerning infectious diseases.

Furthermore, we calculated covariates that could influence DENV transmission. These covariates can broadly be categorized as demographic variables reflecting peoples' attributes (household per capita income, sex ratio, and population density), and environmental variables (residence in apartments, unpaved streets, and raw sewage). These variables were extracted from the 2010 population census [23] and aggregated to the OD unit level.

We also gathered data on strategic points (SP), comprising locations such as junkyards, tire repair shops, deposits of recyclable materials, etc. They are essential for understanding dengue occurrence, as these areas present huge potential to accumulate *Aedes* breeding sites [15,28,29]. The addresses of SP in Campinas were obtained from the Superintendence for Control of Endemic Diseases (SUCEN) [30], which allowed georeferencing and then obtaining the total number of SP per OD unit. Although the information on SP locations was available only for 2017, our assumption was that SP can change from one specific location to another, but their relative spatial distribution within Campinas tends to be similar over time.

Concerning environmental factors, we compiled data about rainfall, since water is essential for the vector reproduction. Weekly information on precipitation was extracted from the Climate Hazards Group InfraRed Precipitation with Station data [31]. This dataset provides the estimated precipitation per day based on near real-time meteorological stations associated to satellite imagery, at a 5km resolution. The accumulated precipitation was calculated per epidemiological week for each OD unit. After an assessment of previous works, we tested different lags: two weeks, four weeks (one month), eight weeks (two months), and 12 weeks (three months). This lag aimed to cover the expected time

necessary for the precipitating water to pool, and for the entire cycle of transmission (from oviposition to a confirmed dengue case) to take place [10,21,32].

Three categorical variables were considered to better capture the intensity of transmission and mobility. The first, "high week", comprised weeks containing a proportion of dengue cases higher than 1.92% of total annual cases, which would be expected if cases were equally distributed along the weeks of the year (0 = no; 1 = yes). The second, "high area", distinguished the ODs with more than 300 cases per 100,000 inhabitants, per week (0 = no; 1 = yes). This threshold was chosen inspired by the Brazilian standard criteria to assess dengue incidence rates that are estimated annually [28]; our study used the same criteria, but considering the week, in order to highlight the most prominent areas with high DENV figures. Finally, the variable "high mobility" identified areas with population mobility higher than the median observed in the city: 1,800 travels per 1,000 inhabitants (0 = no; 1 = yes); this variable was calculated considering the differences in mobility levels between different ODs.

Analytical approach

A zero-inflated negative binomial regression (ZINB) model was used. The ZINB model accounts for extra-variation (overdispersion) in data [33]. The outcome variable was dengue incidence rate: DENV cases per 100,000 inhabitants per OD unit and epidemiological week. Covariates included demographic (household income per capita, sex ratio, population density) and environmental factors (dwelling in apartments, unpaved streets, raw sewage, number of strategic points, and accumulated precipitation). Moreover, dummy variables were used for high mobility, high epidemiological weeks, and high incidence areas. The selection of independent variables to include in the final models was based on the stepwise backward process. The final model was chosen based on Akaike information criterion (AIC) for alternative distributions, such as negative binomial, Poisson, and zero-inflated.

Considering the variation of DENV distribution through space and time, five models were ran. Model 1 included all observations (n = 30,954 OD-weeks). Models 2 and 3 were stratified by high (n = 8,778 OD-weeks) and low epidemiological weeks (n = 22,176 OD-weeks). Models 4 and 5 stratified the analysis by intensity of transmission, the former considering only high areas (n = 637 OD-weeks) and the latter the low areas (n = 30,317 OD-weeks). Models were controlled by year, taking 2015 as reference, accounting for differences between yearly variation in incidence rates. In all models, the variable population mobility was exactly the same, and statistical significance was evaluated at a p-value < 0.01.

Geographical information system (GIS) tools for merging different datasets were carried out in QGIS software version 3.10 (https://qgis.org/en/site/). Data cleaning, descriptive and statistical analyses were performed in Stata 14.0 (https://www.stata.com).

Ethics statement

This research does not require an Institutional Review Board approval because it comprises an analysis of secondary and anonymized data.

Results

From 2007 to 2015, 123,042 dengue cases were reported in Campinas, ranging from 159 in 2009 to 58,720 in 2015. In total, 114,884 (93.4%) cases did not present sufficient information to be geocoded at household level and included in the analysis. Geocoding success was high, and it varied from 90% in 2014 to 99.4% in 2009. To validate the geocoding results, we investigated a randomly selected sample, comparing with their locations. We found an average error of 200m, what was acceptable considering that these points were afterwards aggregated into our analysis units.

Table 1 presents descriptive statistics of the continuous OD-level variables. DENV incidence rate per 100,000 inhabitants by OD-weeks, ranged from the mean 0.21 in 2009 to 96.92 in 2015. The smallest standard deviation was observed in 2009, 1.93, whereas the highest was 256.30, in 2015. After investigating different time lags: two, four, eight, and 12 weeks, we found that the eight-weeks

Table 1

Descriptive statistics of the continuous Origin-Destination (OD)-level variables.

Variables	Mean	SD	Range
Reported dengue cases by OD-week (outcome)			
Count (number of cases)			
2007	2.97	8.88	0-97
2008	0.77	0.33	0-6
2009	0.46	0.28	0-5
2010	0.61	2.16	0-43
2011	0.80	2.65	0-35
2012	0.15	0.60	0-11
2013	1.68	6.20	0-106
2014	10.74	33.91	0-481
2015	16.19	47.09	0-527
Rate (cases per 100,000)			
2007	17.99	66.88	0.0-1,498.1
2008	0.60	7.80	0.0-3,74.5
2009	0.21	1.93	0.0-87.1
2010	3.79	16.58	0.0-374.5
2011	6.03	34.92	0.0-1,084.0
2012	0.91	8.20	0.0-374.5
2013	10.22	40.66	0.0-749.1
2014	63.22	164.66	0.0-2,264.8
2015	96.92	256.30	0.0-4,494.4
Climate (exposure)			
Precipitation lagged eight weeks (sum in mm)			
2007	27.31	33.53	0.0-188.1
2008	28.86	26.32	0.0-137.5
2009	26.09	26.31	0.0-109.4
2010	30.19	37.78	0.0-163.8
2011	28.91	36.62	0.0-208.9
2012	32.32	33.68	0.0-172.5
2013	32.09	31.58	0.0-120.5
2014	24.90	25.87	0.0-124.1
2015	28.09	26.25	0.0-108.7
Demographic (exposure)			
Household income per capita (BRL)	1,347.13	850.18	397.4-4,031.8
Total population sex ratio (male/female per 100)	95.46	8.15	78.7-118.7
Population density (persons/km²)	3,260.38	2,878.71	15.1-13,180.3
Environmental (exposure)			
Number of SP	9.8	13.6	0-65
Residence in apartments (%)	18.94	22.46	0.0-95.0
Households in unpaved streets (%)	7.21	11.34	0.0-59.8
Households with open sewage (%)	3.82	8.1	0.0-38.4

SD: standard deviation; SP: strategic points.

Source: dengue – Information System on Diseases of Notification (SINAN); climate – Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS); demographic (Household income per capita, Total population sex ratio, Population density) and environmental data (Residence in apartments, Households in unpaved streets, Households with open sewage) – population census, Brazilian Institute of Geography and Statistics (IBGE), 2010; Number of SP – Superintendence for Control of Endemic Diseases (SUCEN).

lag (two months) presented the highest coefficient associated with the dependent variable (dengue incidence rate). The sum of dengue cases and the accumulated precipitation lagged eight weeks is presented in Figure 2.

The accumulated precipitation (lagged by eight weeks) ranged from an average of 24.9mm in 2014 to 32.3mm in 2012. Mean household income per capita by OD was BRL 1,347.13, and the total population mean sex ratio among OD units was 95.46. Population density was, on average, 3,260 people per km^2, although it considerably varied from the minimum 15 to the maximum 13,180. OD areas presented an average of 9.8 SP, ranging from 0 to 65. Also, around 19% of all households were classified as apartment, these types of residence were most common in the downtown (up to 95%). On average, 7.21% of households in the municipality were located in unpaved streets, varying substantially from one location to the other: from 0% in well-provided OD units to nearly 60% of unpaved streets in others. Also, an average of 3.82% households presented raw sewage, ranging from 0% to more than 38% across the different units of analysis.

Regarding the intensity of transmission and mobility (Table 2), there were 8,778 OD-weeks (28.4% of the total) with higher proportion of dengue cases than expected, while 637 OD-weeks were classified as High Areas (2.1% of the total), i.e., with elevated incidence rates. Additionally, considering that the variable High Mobility uses the median to divide the OD areas in terms of population mobility, areas with high and low mobility are numerically identical, with 15,477 OD-weeks in each (50%).

The spatial distribution of the total number of epidemiological weeks with high incidence rates shows a concentration of High Areas in the North of Campinas, encompassing neighborhoods such as Cidade Universitária, Real Parque, Jardim Santa Izabel, Parque das Universidades, Jardim São Marcos, and Jardim Santa Mônica. It also highlights the significance of DENV cases in the Southwest region, where we find Ouro Verde, Satélite Íris, Florence, Cosmos, Sirius, Jardim Paulicéia, and Jardim Campos Elísios neighborhoods. These areas are the ones with the highest historical concentration of dengue cases in the city during the study period, and it is also where epidemics recurrently occur.

As for the intensity of mobility, while the "most mobile" populations were apparently widespread in Campinas, they mostly overlapped with High Areas distribution, which beforehand suggested a link between population mobility and dengue occurrence. The exception to this pattern is the downtown, in which we notice high mobility but no expressive records of dengue occurrence.

Figure 2

Sum of dengue cases and accumulated precipitation (lagged eight weeks), by epidemiological weeks. Campinas, São Paulo State, Brazil, 2007-2015.
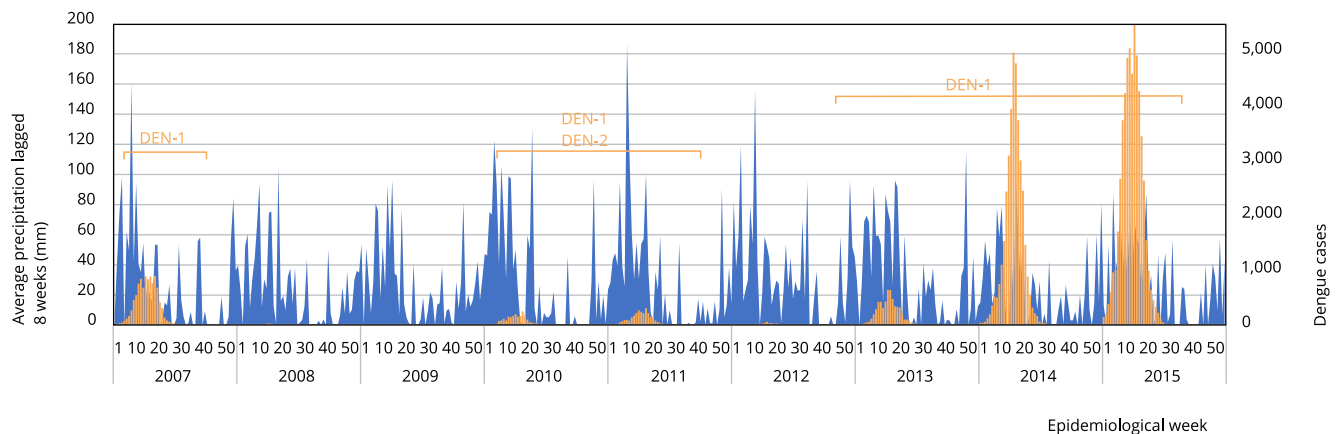
Source: dengue – Information System on Diseases of Notification (SINAN); climate – Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS).
Note: dengue cases represented in orange bars and precipitation in blue area; predominant dengue serotype(s) indicated in orange.

Table 2

Dummy variable definitions and descriptive statistics.

Variables and description	Value	Observations (%)	Total
Scale (exposure)			
High week *	0 = No	22,176 (71.6)	30,954
	1 = Yes	8,778 (28.4)	
High area **	0 = No	30,317 (97.9)	30,954
	1 = Yes	637 (2.1)	
Mobility (exposure)			
High mobility ***	0 = No	15,477 (50.0)	30,954
	1 = Yes	15,477 (50.0)	

Source: elaborated by the authors.

* Proportion of cases > 1.92% of the annual cases;

** > 300 cases per 100,000 inhabitants, by epidemiological week;

*** Population mobility > 1,800 median travels per 1,000 inhabitants.

In assessing the role of population mobility, the complete model (Model 1, Table 3), showed that, on average, living in a highly mobile area was associated with an increase of 40% in dengue incidence rates. Over the entire study period, the increase of one SP in a study unit was followed by an increment, on average, of 3% in dengue incidence rates. Similarly, the increase of 1% in unpaved roads and raw sewage system was associated with an increase of 1% in dengue incidence rates. On the other hand, dwelling in apartments was protective against the disease, although barely significant. Indicator variables High Week and High Area were statistically significant and presented coefficients with high magnitude, supporting stratified analyses.

Table 1 also presents models stratified by high and low epidemiological weeks (Models 2 and 3), and by high and low incidence areas (Models 4 and 5). Results indicate that precipitation was positively associated with dengue incidence rates in periods of low transmission weeks and low incidence areas (Models 3 and 5). The variable households in unpaved streets was significantly correlated with dengue incidence rates in high transmission weeks and areas (Models 2 and 4). Living in high mobility areas was consistently a risk a factor for dengue incidence rates across all models. On average, living in a highly mobile area increased dengue incidence rate in 46% and 69% during high transmission weeks and in high transmission areas, respectively (Models 2 and 4). During low transmission weeks and in low transmission areas, highly mobile population increased by 26% and 35% dengue incidence rates, respectively (Models 3 and 5). Similarly to the complete model (Model 1), the mobility variable had the largest association with dengue incidence across all stratified models.

In Model 3, income per capita was protective against dengue fever, although not significant. Sex ratio was a protection factor against the disease in all stratified models, suggesting that more male residents are associated with a lower dengue incidence rate – in Models 2 and 4, the increase of one male per 100 female residents was followed by a decrease of 7% and 9% in the incidence rates, respectively.

Regarding SP, Models 1 to 5 showed that the addition of one SP contributed to an average increase of 3% in dengue incidence rates, with low variation across the different models. Similarly, the increase in 1% of population dwelling in apartments reduced approximately 1% to 2% of dengue incidence rates on average across the distinct models' stratification.

Population density did not differentiate residents across periods and areas with distinct levels of transmission (Models 1 to 5). Likewise, the increase in the proportion of households in each area with raw sewage system did not present substantial and consistent effects on dengue incidence rates.

Living in a high incidence area increased dengue rates by three times in high transmission weeks (Model 2), whereas in low transmission weeks it increased rates by eight times (Model 3). Conversely, during high transmission weeks living in high incidence areas duplicated dengue rates (Model 4), whereas living in low incidence areas increased dengue incidence by more than 15 times (Model 5).

Table 3

Zero-inflated negative binomial regression (ZINB) models considering all Origin-Destination (OD)-weeks (Model 1), and stratified by High weeks (Model 2), Low weeks (Model 3), High areas (Model 4) and Low areas (Model 5).

Parameter	Model 1 (n = 30,954)		Model 2 (n = 8,778)		Model 3 (n = 22,176)		Model 4 (n = 637)		Model 5 (n = 30,317)	
	IRR	95%CI	IRR	95%CI	IRR	95%CI	IRR	95%CI	IRR	95%CI
Climate										
Precipitation	1.01 *	1.00-1.01	0.99	0.99-1.00	1.01 *	1.01-1.02	1.00	0.99-1.00	1.01 *	1.00-1.01
Demographic										
Income	0.99 *	0.99-0.99	0.99 *	0.99-0.99	0.99	0.99-1.00	0.99 *	0.99-0.99	0.99 *	0.99-0.99
Sex ratio	0.94 *	0.94-0.95	0.93 *	0.92-0.93	0.98 **	0.96-0.99	0.91 *	0.91-0.92	0.96 *	0.95-0.97
Population density	1.00 *	1.00-1.00	1.00 *	1.00-1.00	1.00 *	1.00-1.00	1.00 *	1.00-1.00	1.00 *	1.00-1.00
High mobility	1.41 *	1.32-1.49	1.46 *	1.38-1.55	1.26 *	1.12-1.42	1.69 *	1.52-1.88	1.35 *	1.26-1.44
Environmental										
SP	1.03 *	1.02-1.03	1.03 *	1.02-1.03	1.03 *	1.02-1.03	1.02 *	1.02-1.02	1.03 *	1.03-1.03
Apartment	0.98 *	0.98-0.99	0.98 *	0.98-0.98	0.99 *	0.98-0.99	0.99 *	0.99-0.99	0.98 *	0.98-0.99
Unpaved	1.01 *	1.01-1.01	1.02 *	1.01-1.02	0.99	0.99-1.01	1.03 *	1.03-1.04	1.00	0.99-1.01
Open sewage	1.01 *	1.01-1.02	1.01 *	1.00-1.01	1.02 *	1.00-1.03	0.98 *	0.97-0.99	1.02 *	1.01-1.02
Scale										
High week	15.19 *	14.32-16.11					2.22 *	1.72-2.88	15.57 *	14.62-16.58
High area	3.01 *	2.67-3.41	3.10 *	2.85-3.38	8.14 *	3.57-18.56				
Year (reference: 2015)										
2007	0.21 *	0.19-0.23	0.29 *	0.27-0.33	0.16 *	0.13-0.19	0.29 *	0.21-0.41	0.20 *	0.18-0.22
2008	0.01 *	0.01-0.01	0.01 *	0.00-0.01	0.01 *	0.01-0.02	0.12	0.01-1.07	0.01 *	0.00-0.01
2009	0.00 *	0.00-0.00	0.00 *	0.00-0.00	0.00 *	0.00-0.01	1.00	-	0.00 *	0.00-0.00
2010	0.05 *	0.04-0.05	0.07 *	0.06-0.07	0.03 *	0.02-0.04	0.19 *	0.06-0.61	0.05 *	0.04-0.05
2011	0.05 *	0.05-0.06	0.07 *	0.06-0.08	0.04 *	0.03-0.05	0.26 *	0.16-0.45	0.05 *	0.04-0.05
2012	0.01 *	0.01-0.01	0.01 *	0.01-0.01	0.02 *	0.01-0.02	0.12	0.01-1.13	0.01 *	0.01-0.01
2013	0.11 *	0.10-0.12	0.15 *	0.14-0.17	0.09 *	0.08-0.18	0.24 *	0.17-0.35	0.11 *	0.09-0.19
2014	0.64 *	0.59-0.69	0.84 *	0.77-0.91	0.55 *	0.48-0.63	0.91	0.83-1.00	0.62 *	0.57-0.68

95%CI: 95% confidence interval; IRR: incidence rate ratio; SP: strategic points.

Source: elaborated by the authors.

* p ≤ 0.01;

** p ≤ 0.05.

Consequently, living in high transmission areas was associated with a higher increase in dengue incidence rates during low transmission weeks. On the other hand, high transmission weeks were most positively associated with increases in dengue incidence rates in low incidence areas.

Discussion

This study investigates whether the daily pattern of population mobility associates with DENV transmission in Campinas. Our results showed that population mobility stood as a relevant correlate of dengue incidence, regardless of model specification.

While other studies have attempted to assess the role of population mobility, the geographical scale was often coarser [34,35,36,37,38]. Our study advanced current knowledge by showing that, at the local level, it was in the high incidence rate areas and during high transmission weeks that population mobility exerted the most expressive influence on DENV transmission. These results were consistent across different model specification, and after controlling for sociodemographic and environmental

variables. While population mobility was a pertinent factor for the occurrence of DENV epidemics, we found that high mobility and high dengue incidence rates did not perfectly overlap. For example, residents in the downtown are highly mobile, but the area was not associated with high DENV transmission. Based on our results, the type of household could be a possible explanation, as most downtown inhabitants live in apartments, often considered a protective factor against the DENV vector [39,40,41]. Dwelling in apartments was also a variable correlated with income in Campinas, as verticalization occurs more expressively in the downtown, which is also the region with the highest concentration of more affluent people. This result corroborates previous findings of the role of income in DENV epidemics [15,22,42].

The high concentration of population mobility in downtown is mainly due to: (1) concentration of jobs and (2) the way public transportation is organized. However, the data used in our study go beyond this general pattern. This occurs because all trips, for all reasons (study, work, leisure, etc.) and using every type of transportation (bus, car, motorcycle, etc.) was addressed. Furthermore, a new trip is registered each time a person stops in a study unit area, so the entire trajectory in the city is considered in our analysis. Therefore, this investigation handled detailed mobility of the population, being able to accurately capture all places where individuals passed by and, consequently, where they could be infected or facilitated the virus dissemination.

Although dengue seems to spread throughout the city, it is more prevalent in areas with precarious socio-environmental conditions, corroborating previous studies [13,19,43]. We found that DENV cases were more concentrated in – although not limited to – the Southern, Southwestern, and Northwestern portions of Campinas. These are notable areas that concentrate less affluent populations and where environmental conditions favor the occurrence of *Aedes* breeding sites, highlighting the role of local inequalities in transmission. Unpaved streets and raw sewage system, proxies of local environmental quality, were significant risk factors for DENV in the high weeks and high areas transmission models (Models 2 and 4), corroborating previous findings [12,17,20,43,44,45,46,47]. Regarding population density – although previous analysis has found a positive association with dengue incidence [48,49] – our results found no association, as high population density occurs also in downtown, where apartment buildings, a protective factor, predominate.

Precipitation (using an 8-week time lag) was a risk factor for DENV particularly during low weeks (May to January approximately) and low areas transmission models (Models 3 and 5, respectively). It is noteworthy that the most common types of breeding habitats in Campinas are recipients such as plant vases, animal drinkers, demountable swimming pools, cans, bottles and buckets, etc. [30]. Abundance of these containers are directly a result of human behavior and do not necessarily depend on rainwater to be filled up. Moreover, the effect of precipitation can happen in an indirect way. For example, the 2014 epidemics occurred during a severe drought in Campinas [25], which resulted in a behavior of storing water in barrels at home, not always properly covered, then favoring the proliferation of breeding habitats.

There is still an open debate about the role played by sex ratio on dengue epidemics [50]. We found that, on average, men have fewer infections, particularly in high transmission weeks and areas (Models 2 and 4). Nevertheless, these results should be analyzed with caution. There is evidence that women usually seek health care assistance more frequently, not necessarily meaning that they are more affected by diseases, but, instead, that they tend to be more careful with their own wellness [51,52]. In Brazil, a previous study found higher dengue notification among women [53,54], while other showed no significant sex difference [55,56]. In our data, from 2007 to 2015, 55% of patients that notified DENV cases were women while 45% were men, while the 2010 population census indicates that 52% of the residents in Campinas were women, and 48% were men [23]. This sex difference is significant because there is a distinct mobility pattern between males and females. The ODS showed that women tended to have higher mobility within their area of residence, and therefore travel smaller distances than men. The extent to which this pattern implies lower exposure to an infection depends on the characteristics of the areas where they live and where they usually go.

Regarding SPs, we found that the addition of one SP in an area tended to increase dengue incidence rate by 3%, a result consistent with previous findings [15,29]. Although there are clear guidelines on how to monitor SP, including mandatory inspection visits every 15 days [28], limited financial resources, skilled professionals, or even violence in an area can affect the regularity of these visits [13,15].

This study has some limitations. Firstly, the spatial unit of analysis used was not the finest possible. However, considering that the ODS was conducted based on a sample of the population of each area, the spatial units could not be downsampled. Secondly, the flow of people traveling by air and by bus to other municipalities outside the Metropolitan Area was not addressed in this analysis. Yet, these travels represent a minor part in total daily travel, and thus are unlikely to change our results. Thirdly, as it is the case for any administrative record on DENV infections, they capture only symptomatic cases (those that are registered by the health facility); that is a limitation for any DENV study that relies on administrative records. Fourthly, although reporting of DENV is mandatory, some private facilities do not fully report the occurrence of cases. Nevertheless, the private sector represents a minority of cases, unlikely to bias the results. Fifthly, this study did not contemplate directions of population mobility in a more detailed time frame, restricting the concomitant analysis with the variation of DENV in space and time. Finally, considering data restrictions, we could not precisely assess the mobility pattern of DENV infected patients. Our results indirectly assess how this variable correlate with DENV occurrence, implying association instead of causality.

In this study, we analyzed a large and unique data that combined DENV cases geocoded to patient's residence addresses, socioeconomic characteristics, and mobility information, in a detailed timeframe, for nine consecutive years. Our results provided insights about DENV determinants in a large urban center, suggesting patterns that could be similar in other large cities in Brazil, and also in Latin America.

Contributors

I. C. Johansen contributed to the study conception and design, data curation, formal analysis, methodology, and writing. M. C. Castro contributed to the formal analysis, methodology, and writing. L. C. Alves and R. L. Carmo contributed to the study conception and design and methodology. All authors approved the final version of the article.

Additional informations

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Resumo

Cerca de 14% de todos os casos de dengue (DENV) ocorrem nas Américas, a maioria dos quais no Brasil. Os correlatos socioeconômicos, ambientais e comportamentais já foram analisados em profundidade, mas há pouco conhecimento, principalmente em nível local, sobre o papel da mobilidade populacional nas epidemias de DENV. O estudo pretende verificar se o padrão diário de mobilidade populacional está associado à incidência do DENV em Campinas, cidade brasileira com mais de 1,2 milhão de habitantes no Estado de São Paulo. As notificações de DENV entre 2007 e 2015 foram georreferenciadas em nível de logradouro (n = 114.884) e combinadas com dados sociodemográficos e ambientais do censo populacional de 2010. A mobilidade populacional foi extraída da Pesquisa de Origem/Destino *(POD) realizada em 2011, e a pluviometria diária foi obtida através de imagens de satélite. Foram aplicados modelos de regressão multivariada com resposta binomial negativa inflacionados de zeros. A mobilidade populacional alta apresentou efeito positivo relevante sobre a incidência mais elevada de DENV. Renda alta e residência em apartamento mostrou efeito protetor contra a doença, enquanto ruas não pavimentadas, número de pontos críticos (p.ex.: ferros-velhos e borracharias) e pluviosidade alta apareceram enquanto fatores de risco.*

Dengue; Dinâmica Populacional; Meio Ambiente

Resumen

Alrededor del 14% de los casos mundiales de virus dengue (DENV por sus siglas en inglés) se produce en las Américas, la mayoría de ellos en Brasil. Mientras que las correlaciones socioeconómicas, ambientales y de comportamiento se han analizado a fondo, el papel jugado por la movilidad de la población con epidemia de DENV, especialmente en un nivel local, continúa siendo escasa. Este estudio evalúa si el patrón diario de movilidad de población está asociado con la incidencia de DENV en Campinas, una gran ciudad brasileña con más de 1,2 millones de habitantes en el estado de São Paulo. Las notificaciones de DENV desde 2007 a 2015 fueron geocodificadas en un nivel de calle (n = 114,884), y combinadas con datos sociodemográficos, además de ambientales mediante el censo de población de 2010. La movilidad de la población se extrajo de la Encuesta Origen-Destino *(ODS por sus siglas en inglés), llevada a cabo en 2011, la precipitación diaria se obtuvo mediante imágenes por satélite. Se aplicaron modelos de regresión binomial negativa multivariados con ceros inflados. La alta movilidad de la población presentó un efecto positivo relevante, respecto a un mayor riesgo en la incidencia por DENV. Contar con ingresos altos y residir en apartamentos resultaron ser factores protectores contra la enfermedad, mientras que las calles sin pavimentar, así como algunos puntos estratégicos como los desguaces y tiendas de reparación de ruedas, al igual que las precipitaciones fueron consistentemente factores de riesgo.*

Dengue; Dinámica Poblacional; Ambiente