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DENGUE AND LAND COVER HETEROGENEITY IN RIO DE JANEIRO

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ABSTRACT

Dengue epidemics in Brazil have become more frequent and more severe and involving larger populations in the last years. In Brazil *Aedes aegypti* is the only known vector. During the 2007–2008 period, Rio de Janeiro state experienced the most severe dengue epidemics ever reported in terms of morbidity and mortality. During this period, 322,371 cases and 240 deaths were registered, with 100 deaths due to dengue haemorragic fever/ dengue shock syndrome and 140 due to other dengue-related complications. Dengue transmission is influenced by closely related factors, many of which directly associated to the environment. Every city has its own specificities that are mainly given by its landscape and human populations. Rio de Janeiro is a city of 6 million individuals who share a heterogeneous space of ~1,200km^2. Human population density ranges from 5,000 inhabitants/km^2 average mainly in the lowlands, with slums (or *favelas*) mainly in the slopes, where densities reach ~40,000 inhabitants/km^2. These 6 million individuals live in highly urbanized, medium-urbanized and peri-urban transition zones with pockets of rural and semi–rural areas surrounded by the expanding city, mostly in the lowlands interspersed by three mountain complexes. To analyze the heterogeneous space of the city of Rio de Janeiro in relation to dengue, neighborhoods land cover maps where juxtaposed to dengue georeferenced cases, during the epidemic period 2007-2008. This analysis resulted in the observation of spatial clusters of high incidence dengue cases (hotspots) in 7 areas, namely, Jacarepaguá, Downtown, Island, Guaratiba, Northern, Western and Pedra. The most important cluster was constituted by the Jacarepaguá lowland urban ecosystem. Do the different urban ecosystems differ epidemiologically in terms of when and how dengue is transmitted? In Rio de Janeiro, is there a dengue of highly urbanized areas, a dengue of medium urbanized areas and a dengue of medium-high vegetated areas? Or in all those different urban ecosystems there is a shared characteristic that favor dengue transmission? Even though further studies should be conducted taking other aspects into account, the present study indicates that the different urban ecosystems observed might influence dengue transmission in Rio de Janeiro.
Keywords: Dengue; Rio de Janeiro; urban ecosystem.

RESUMO

DENGUE E A HETEROGENEIDADE DA COBERTURA DA TERRA NO RIO DE JANEIRO. As epidemias de dengue no Brasil têm sido cada vez mais frequentes, de maior incidência e gravidade. No

Brasil, *Aedes aegypti* é o único vetor comprovado de dengue. Durante o período 2007-2008, o estado de Rio de Janeiro sofreu uma das epidemias de dengue mais graves da sua história em termos de morbidade e mortalidade. Durante este período, 322.371 casos e 240 mortes foram registrados, com 100 mortes devido à febre hemorrágica/ síndrome de choque e 140 mortes devido a outras complicações relacionadas ao dengue. A transmissão do dengue é influenciada por fatores estreitamente relacionados, muitos dos quais diretamente associados ao ambiente. Cada cidade tem suas próprias características que são dadas principalmente por sua paisagem e populações humanas. O Rio de Janeiro é uma cidade de 6 milhões de indivíduos que compartilham um espaço heterogêneo de ~1.200km^2. A densidade da população humana varia entre 5.000 habitantes/km^2 em média, nas planícies, chegando à densidade de ~40.000 habitantes/km^2 vivendo em favelas, principalmente nos morros. Estes 6 milhões de indivíduos vivem em zonas altamente urbanizadas, médio-urbanizadas e peri-urbanas de transição, como os bolsões de áreas rurais e semi-rurais cercados pela cidade em expansão, em sua maior parte nas planícies intercaladas por três complexos de montanhas. Para analisar o espaço heterogêneo da cidade de Rio de Janeiro, mapas de cobertura da terra e de bairros foram justapostos a casos georeferenciados de dengue, durante o período epidêmico 2007-2008. Essa análise resultou na identificação de aglomerados de bairros (*clusters*) com elevada incidência de dengue (*hotspots*) em 7 áreas, denominados Jacarepaguá, Centro, Ilhas, Guaratiba, Norte, Ocidental e Pedra. O aglomerado mais importante foi aquele constituído pelo ecossistema urbano da planície de Jacarepaguá. Estes diferentes ecossistemas urbanos diferem epidemiologicamente no sentido de quando e como o dengue é transmitido? No Rio de Janeiro, há um dengue de áreas altamente urbanizadas, um dengue de áreas médio-urbanizadas e um dengue de áreas cobertas por vegetação? Apesar de serem necessários estudos adicionais que tomem em consideração outros aspectos, o presente estudo indica que os diferentes ecossistemas urbanos observados podem repercutir na transmissão do dengue no Rio de Janeiro.
Palavras-chave: Dengue; Rio de Janeiro; ecossistema urbano.

RESUMEN

DENGUE Y HETEROGENEIDAD DE LA COBERTURA DE LA TIERRA EN RIO DE JANEIRO. Las epidemias de dengue en Brasil se han vuelto cada vez más frecuentes y severas y han involucrado poblaciones cada vez mayores en los últimos años. En Brasil, *Aedes aegypti* es el único vector conocido de dengue. Durante el período 2007-2008, el estado de Río de Janeiro sufrió la epidemia de dengue más grave de su historia en términos de morbilidad y mortalidad. Durante este período, se registraron 322.371 casos y 240 muertes, con 100 muertes por dengue hemorrágico y síndrome de choque y 140 muertes debidas a otras complicaciones relacionadas con el dengue. La transmisión del dengue es influenciada por factores estrechamente relacionados, muchos de los cuales están directamente relacionados con el ambiente. Cada ciudad tiene características específicas, que se dan principalmente por su paisaje y sus poblaciones humanas. Río de Janeiro es una ciudad de 6 millones de habitantes que comparten un espacio heterogéneo de ~ 1,200 km^2. La densidad de población presenta una media de 5.000 habitantes/km^2, principalmente en las tierras bajas, mientras en los barrios marginales (o *favelas),* situados principalmente en las laderas, la densidad puede llegar a ~ 40.000 habitantes/km^2. Estos 6 millones de personas viven en zonas alta y medianamente urbanizadas, y zonas peri-urbanas de transición, con bolsillos de áreas rurales y semi rurales rodeados por la ciudad en expansión, sobre todo en las tierras bajas, intercaladas entre tres complejos montañosos. Para analizar la heterogeneidad espacial de la ciudad de Río de Janeiro en relación con el dengue, mapas de cobertura del suelo de los barrios fueron yuxtapuestos a los casos de dengue georreferenciados durante la epidemia de 2007-2008. Este análisis dio lugar a la observación de agrupamientos espaciales (*clusters*) de alta incidencia de casos de dengue (*hotspots*) en 7 áreas, a saber, Jacarepaguá, Centro, Isla, Guaratiba, Norte, Oeste y Pedra. El grupo más importante está constituido por el ecosistema urbano de tierras bajas en Jacarepaguá. Son los diferentes ecosistemas urbanos epidemiológicamente diferentes, en términos de cuándo y cómo se transmite el dengue? Hay un dengue de las zonas altamente urbanizadas, un dengue de las zonas medianamente urbanizadas y un dengue de áreas cubiertas con vegetación, o en los diferentes ecosistemas urbanos hay una característica común

que favorezca la transmisión del dengue? Aunque nuevos estudios se deben realizar teniendo en cuenta otros aspectos, el presente estudio indica que los diferentes ecosistemas urbanos observados tienen importancia en la transmisión del dengue en Río de Janeiro.
Palabras clave: Dengue; Rio de Janeiro; ecosistemas urbanos.

INTRODUCTION

DENGUE IN BRAZIL AND IN THE CITY OF RIO DE JANEIRO

Dengue epidemics have become more and more frequent and involved larger populations worldwide (Guzman *et al*. 1990, Harris *et al*. 2000, Nogueira *et al.* 2005). This trend is also true in Brazil, where, as in many tropical regions of the world, dengue is considered a major public health problem (Gubler 1998, Schatzmayr 2000). Dengue is an urban disease transmitted by a highly synanthropophilic mosquito, the *Aedes aegypti* (Linnaeus, 1762). *Ae. aegypti* is the most important dengue vector worldwide (Gubler & Kuno 1997, Halstead 2007, Honório *et al.* 2009b) and the only known vector in Brazil (Lourenço-de-Oliveira *et al.* 2004).

In Brazil, there were more than 700,000 clinically cases of dengue reported in 2008 (WHO/PAHO 2008). In the period of 2007-2008, Rio de Janeiro state experienced the most severe dengue epidemics ever in terms of morbidity and mortality (Lourenço-de-Oliveira 2008). During this period, 322,371 cases and 240 deaths were registered, with 100 deaths due to dengue haemorragic fever/ dengue shock syndrome and 140 due to other dengue-related complications (SESDEC-RJ 2008) representing a case-fatality rate of 9.4:10,000. Contrasting with previous epidemics, the 2008 epidemic, essentially caused by DENV-2 virus, was characterized by a higher incidence of severe cases in children. In fact, 36% of deaths reported occurred in individuals <15 years old (Secretaria de Defesa Civil do Rio de Janeiro-SESDEC-RJ 2008, Teixeira *et al.* 2008, Honório *et al.* 2009c). The capital of the Rio de Janeiro state is the city of Rio de Janeiro. Rio de Janeiro city is the second biggest city in the country and has been heavily affected by dengue epidemics of increasing magnitude and severity (Luz *et al.* 2008). In the last four years, the city of Rio de Janeiro has held dengue incidence rates ranging from 138,027 dengue cases (incidence rate of 2,356 per 100,000 inhabitants/ year) in the 2002 epidemics to 14,113 cases (240.9 incidence rate) in the pre-epidemic year of 2006 in a population of ~6 million individuals (Secretaria Municipal de Saúde do Rio de Janeiro-SMS 2010).

DENGUE TRANSMISSION

Dengue transmission is influenced by closely related factors many of which directly associated to the environment. Dengue infection dynamics is complex, involves four serotypes, the peculiarities of the human immune response, the high vector competence of *Ae. aegypti*, and the environmental characteristics of urban areas. Among the major factors influencing dengue transmission are: i) the abundance, survival and behavior of the principal mosquito vector, *Ae. aegypti*; ii) the time required for development of the dengue virus in *Ae. aegypti*; iii) the level of herd immunity to the circulating virus serotype; and iv) the density distribution and movement of humans (Halstead 1990, Getis *et al.* 2003, Honório *et al.* 2003, Teixeira *et al.* 2005, Honório *et al.* 2009c).

Due to the synanthropic behavior of *Ae. aegypti*, dengue is strongly related to urban- and peri-urban ecosystems, since these types of human settlements are ecotopes where the dengue virus and its mosquito vector find suitable conditions for their transmission cycle (Consoli & Lourenço-de-Oliveira 1994). *Ae. aegypti* is generally abundant in the urbanized areas in the city of Rio de Janeiro, rarely invades the urban forest fringes, traverses short distances, has high daily survival rates and breeds almost exclusively in artificial containers (Cunha *et al.* 2002, Braks *et al.* 2003, Lourenço-de-Oliveira *et al.* 2004). Container's productivity, and consequently the infestation levels of an area is usually influenced by a series of factors that vary between seasons, such as temperature, rainfall, water evaporation, and use of water by households. Studies conducted in Rio de Janeiro state on container productivity and *Ae. aegypti* infestation levels in slums and urban areas, showed that container productivity varied according to seasons and urbanization degree and that large and open-mouthed containers, such as water tanks and metal drums, located outdoors were the most productive in both areas (Maciel-de-Freitas *et al.* 2007). In this way, *Ae. aegypti* infestation stability is due to the high production observed in permanent containers generally used to store water in slums and urbanized areas. Even though most of the *Ae. aegypti* bionomics is well known, dengue control seems to be difficult to accomplish in a city with high spatial heterogeneity like Rio de Janeiro (Luz *et al.* 2003, Maciel-de-Freitas *et al.* 2007). The human domicile and peridomicile spaces are the shelter for *Ae. aegypti* where it also breeds and blood feeds. These domicile and peridomicile spaces however, are of many types and are located in heterogeneous neighborhoods.

URBAN ECOSYSTEMS

Cities were created by humans to provide better quality of life from the wild nature. Every city has its own characteristics that are given by its landscape, human populations cultural past and trends for the future. Priorities and values for the environment are determined by resources available but also by cultural beliefs (Piracha & Marcotullio 2003).

Approximately 3 billion individuals or 50% of the world's population live at high densities in urban and peri-urban areas in only 1-2% of the world's land (Piracha & Marcotullio 2003). Disregarding the individual sizes of these urban and peri-urban city areas, more than a million cities house less than a third of the world's urban people: 2/3 live in urban centers of half a million or less individuals. To support city growth, the transformation of some 20% or more of the terrestrial land into anthropic transformed agro-ecosystems is mandatory in a continuous expansion of urban areas that is generally irreversible (Piracha & Marcotullio 2003). Agricultural villages are the most extensive of all densely populated human agglomerations with 1 out of 4 individuals living in them (Ellis & Ramankutty 2008).

Urban expansion is usually a non reversible process. Besides rapid transportation, demographic and societal changes such as population growth and urbanization contribute greatly to the increased incidence and geographic spread of diseases such as dengue (Rosen 1999). Rapid urbanization is generally carried out at the expenses of infrastructure that includes basic civic amenities like water supply, sanitary sewage and garbage collection. This lack of infrastructure is especially important for dengue since it results in the creation of numerous breeding habitats for *Ae. aegypti.*

RIO DE JANEIRO ECOSYSTEMS

Rio de Janeiro is a city of 6 million individuals who share a heterogeneous space of ~1,200km^2. Human population density ranges from an average of 5,000 inhabitants/ km^2 mainly in the lowlands, to densities of ~40,000 inhabitants/km^2 in slums (or *favelas*) mainly located in the slopes (Instituto Brasileiro de Geografia e Estatística 2010). These 6 million individuals live in highly urbanized, medium urbanized and peri-urban transition zones with pockets of rural and semi-rural areas surrounded by the expanding city, mostly in the lowlands interspersed by 3 mountain complexes, the Tijuca Massif (*Maciço da Tijuca*), the Pedra Branca Massif (*Maciço da Pedra Branca*) and the Gericinó-Mendanha Massif (*Maciço do Gericinó-Mendanha*) (Figure 1). These massifs are covered by Atlantic Forest vegetation and valuable remnants of its original ecosystems to form one of the biggest urban forests in the world. The occupation of the lowlands and slopes has been a spontaneous process, resulting more from interests in the real estate market rather than from a city Director Plan (Egler 2007).

The city of Rio de Janeiro presents highly favourable conditions for transmission of dengue (Schatzmayr *et al.* 1986, Nogueira *et al.* 2001, Nogueira *et al*. 2005, Honório *et al*. 2009b). Rio de Janeiro is the second biggest city of Brazil, after São Paulo, presenting high human density distributed in heterogeneous neighborhoods (or bairros). Areas of high human population density of low income are found side by side with wealthy areas in almost all neighborhoods in Rio de Janeiro with slums and luxurious houses sometimes in close proximity. Indeed, 513 slums in 158 neighborhoods were catalogued by the Census 2000 in the city of Rio de Janeiro (IBGE 2000). Apart from the existence of slums side by side with wealthy middle- and high-income human populations, neighborhoods are diverse in what concerns land cover, land use and microclimate conditions. Income distribution and poverty inequalities remain a major cause of difficulties in urban management and in provision of adequate housing and infrastructure, ultimately affecting health. Spatial and temporal health risks are created by inadequate housing in crowded conditions, where infrastructure like water supply and sanitation are usually absent (Piracha & Marcotullio 2003).

The patchy mosaic of urban ecosystems in Rio de Janeiro not only impairs life history parameters analyses of *Ae. aegypti* and dengue but moreover, difficult dengue control. The urban ecosystem mosaic in the city of Rio de Janeiro led to a proposition of an epidemiologically-based neighborhood division by one of us (Magalhães 2008). Controlling *Ae. aegypti* has proven a difficult undertaking in modern urban ecossystems. The influences of various social and environmental factors on spatially heterogeneous neighborhoods (Figure 2) are important challenges faced by control teams.

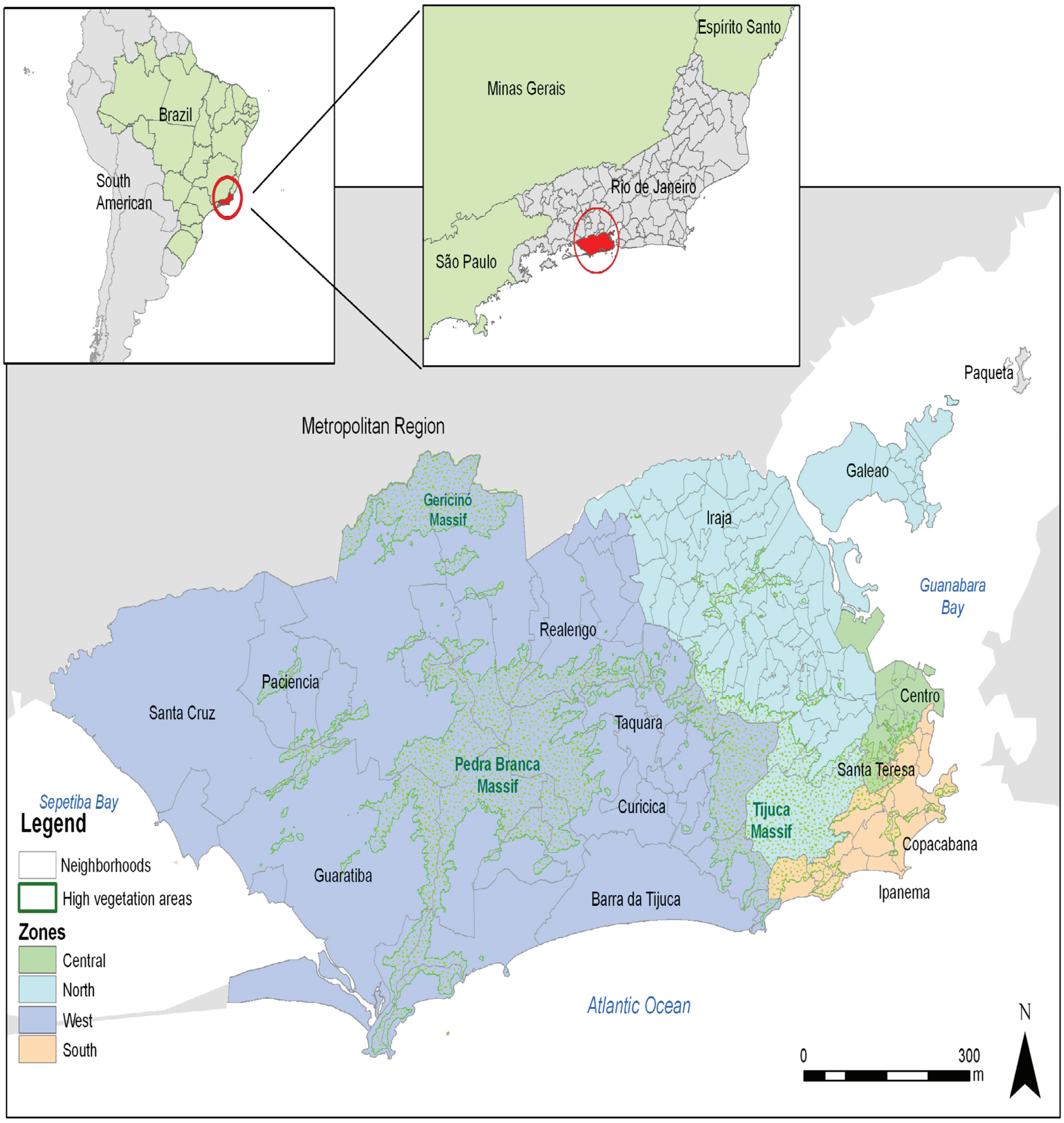

Figure 1. Rio de Janeiro zones, massifs and a few neighborhoods.

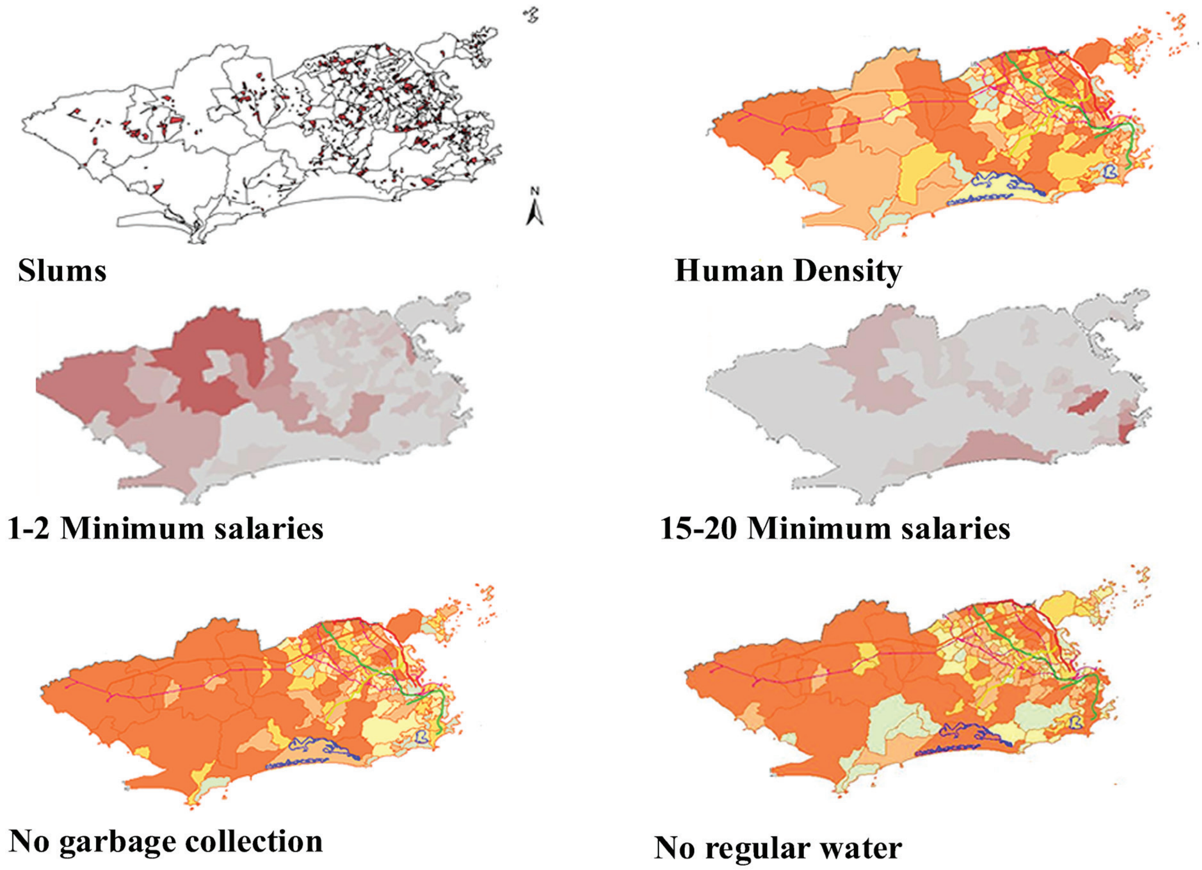

Figure 2. The city of Rio de Janeiro and its spatial heterogeneity in characteristics like slums distribution (areas in red), human density (green-less individuals, red-more individuals), number of domiciles in which income is 1-2 minimum salaries and 15 to 20 minimum salaries (grey-less domiciles, red-more), number of domiciles without garbage collection (green-less domiciles, red-more) and number of domiciles without regular water (green-less domiciles, red-more domiciles).

To analyze the heterogeneous space of the city of Rio de Janeiro in relation to dengue, land use maps of its neighborhoods where juxtaposed to dengue georeferenced cases during the epidemic period 2007-2008.

METHODOLOGY

RIO DE JANEIRO

The city of Rio de Janeiro is the capital of the State of Rio de Janeiro and part of the Southeastern Region of Brazil. The city of Rio de Janeiro is situated at 22°54'23" latitude south and 43°10121" longitude west with 1214.13 km^2 of land area (or 1,255km^2 of total area), including the islands and continental waters. It measures 70km from east to west and 44km from north to south (IBGE 2010) (Figure 1).

The city of Rio de Janeiro (thereafter only Rio de Janeiro) is currently administratively divided in 4 zones (Central, Northern, Western, Southern), 33 Administrative Regions and 160 neighborhoods (Prefeitura do Rio 2010) (Figure 2). The larger metropolitan area of Rio, or the Greater Rio, includes other 17 municipalities and is considered one of the 25 biggest megacities in the world with an area of 5,384km^2 and more than 10 million inhabitants (Decker *et al.* 2000).

The current Rio de Janeiro's 160 neighborhoods division was established in 2004 (Prefeitura do Rio

2010). Because the database in this study used the 158 neighborhoods division, population data from the Census 2000 (IBGE 2010) with the same number of neighborhoods (158) was used.

Rio de Janeiro's Gini index of inequality of wealth is 0.48 (IBGE 2010). The Gini coefficient can range from 0 (corresponding to complete equality) to 1 (complete inequality). The poverty index of Rio de Janeiro is 23.85%, the 7th city in Brazil. Average income is 1 thousand Brazilian reais/month (Census 2000, IBGE 2010). This value corresponds nowadays to 2 minimum salaries (current minimum wage = 510.00 reais or 231 euros, exchange rate of July 2010) (IBGE 2010).

Rio de Janeiro's climate is classified as tropical humid and can be divided into two seasons: the hot-wet season, from approximately December to May, and the cool-dry season, from approximately June to November (Luz *et al.* 2008). In the hot-wet season, temperatures range between 21°C and 30°C with 145mm accumulated rainfall per month averages (10-year averages). In the cool-dry season, temperatures range from 17°C to 26°C with 117 mm accumulated rainfall per month averages (10-year averages) (Luz *et al.* 2008).

Although dengue occurs throughout the year, cases peak from January to May during the hot-wet season (Siqueira *et al.* 2005, Camara *et al.* 2007). Field studies show that *Ae. aegypti* vector populations peak concurrently with dengue cases reports (Honório *et al.* 2001).

DENGUE DATA

Dengue database was provided by the Secretary of Health of the Rio de Janeiro Municipality (Secretaria Municipal de Saúde do Rio de Janeiro, SMS-RJ). Dengue data comprised of the dengue registered cases for the year 2007 and the first 20 weeks for 2008 with full address, sex, age, dengue laboratory diagnostics and dengue outcome among other data. Dengue cases were georeferenced using residential addresses from the SMS database. SMS dengue database and an address database for Rio de Janeiro (Laboratory of Geoprocessing, ICICT, FIOCRUZ, Rio de Janeiro) were used for georeferencing. The address database contained street segments with street name, begin and end for odd and even numbers for each segment and, the postal code address. Residential addresses of individuals reporting dengue were automatically located by proximity in these segments in Terraview 3.2.0 resulting in a subset of the original database.

Time series dengue data from SMS were also used (SMS 2010, http://www.saude.rio.rj.gov.br/cgi/public/cgilua.exe/sys/reader/htm/preindexview.htm?editionsectionid=364&user=reader).

HUMAN POPULATION AND LAND COVER DATA

Percentage of land occupied by slums, human density and corrected human density were determined based on the land cover data. Corrected human density was calculated by subtracting areas where human occupation is unlikely, i.e., highly vegetated areas, water, sand, beaches and mangroves.

Maps were obtained as land use maps from the Laboratory of Geoprocessing (FIOCRUZ). Since land use map themes dealt with mixed land use (urban, peri- and non-urban) and land cover (high and low vegetated areas), the term land cover (that would encompass zero, low, medium and high vegetated areas) was used to refer to this data set.

Land cover maps displayed 10 classes from which 3 were merged to totalize 7 classes: 1) densely populated, corresponding to highly urbanized areas without trees or with very limited number of trees; 2) urban non-consolidated, corresponding to areas of urban growth; 3) anthropic field, equivalent to field areas for pasture or agriculture; 4) medium vegetation or areas <50% vegetation coverage; 5) high vegetation or areas >50% vegetation coverage; 6) water, corresponding to areas covered by water bodies such as lakes, rivers or by the sea; 7) sandbank, beach and mangrove, or an area with any of these characteristics.

DATA ANALYSES

Dengue georeferenced data was analysed in ArcGis 9.1 (ESRI, Redlands, California) and TerraView 3.2.0 (Instituto Nacional de Pesquisas Espacias, São José dos Campos, 2010 available at http://www.dpi.inpe.br/terraview). Annual dengue incidence rates per 100,000 inhabitants were calculated from dengue reported cases (SMS 2010) for the year 2007 and 2008 for 158 neighborhoods. A kernel density estimator map (Gaussian function and smooth kernel of 100m radius) was created in order to show the smoothed spatial density distribution of dengue cases for the 72 epidemiological weeks of the study period. An animation was created with these maps to show the spatial and temporal dynamics of dengue. Neighborhoods and land cover maps were layered. The kernel distribution with the spatial density distribution of dengue cases for the 72 epidemiological weeks, a list of the 20 neighborhoods presenting the highest dengue incidence rates and the observation of time series maps from the Secretary of Health of the Rio de Janeiro Municipality (SMS 2010) were scrutinized and visually adjusted to produce clusters of dengue hotspots. Land cover, dengue distribution and neighborhood division maps were layered in order to examine heterogeneity. An urban ecosystem division for Rio de Janeiro was proposed based on analyzed data.

RESULTS

LAND COVER HETEROGENEITY

Patterns of heterogeneous composition were observed when Rio de Janeiro's neighborhood division and land cover maps were layered (Figure 3).

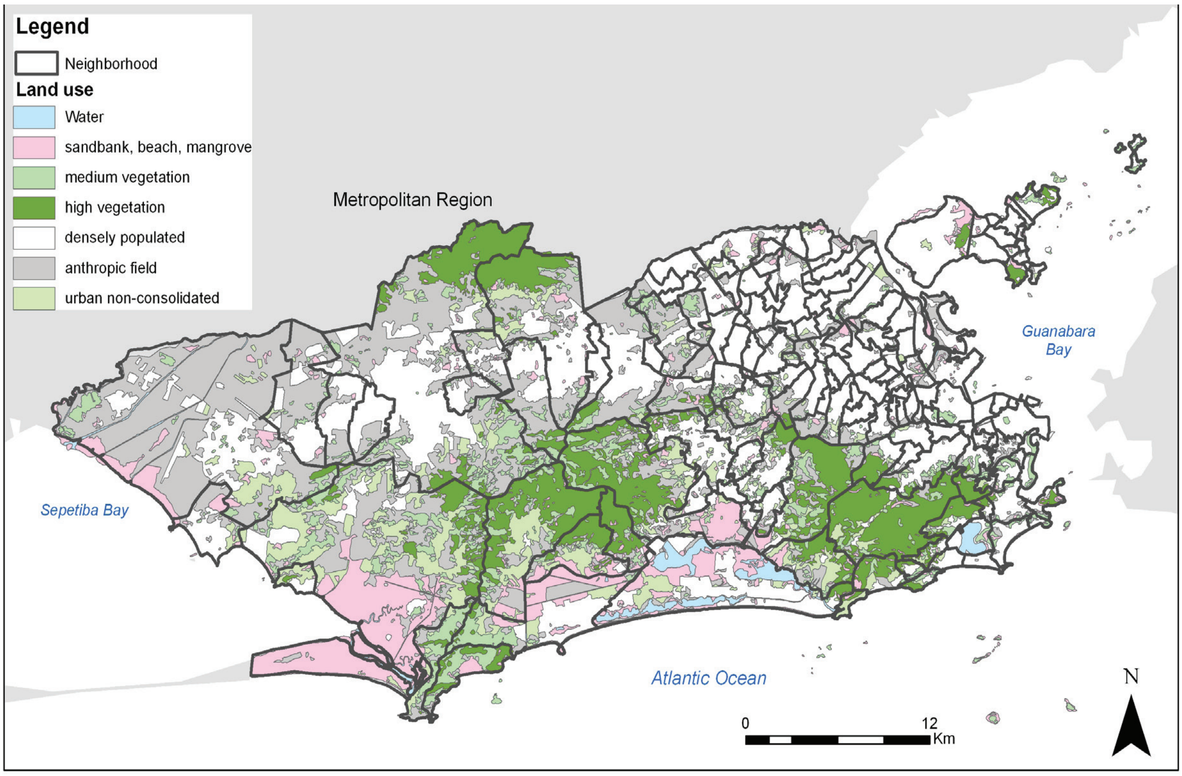

Figure 3. Neighborhood division and types of land use in Rio de Janeiro, Brazil.

DENGUE DATA

Highest Incidence Neighborhoods

The 20 neighborhoods (out of 158) with the highest annual dengue incidence rates in 2007 and 2008 were selected from the SMS database (SMS 2010) (Tables 1 and 2).

Table 1. The 20 neighborhoods with the highest incidence rates in Rio de Janeiro in 2007. Neighborhoods are ranked according to the incidence rates. Population data are from the Census 2000.

Neighborhood	Dengue Incidence per 100,000 inhabitants	Nb. Dengue cases	Human Population
Camorim	3816.8	30	786
Anil	3085.7	665	21 551
Saúde	2516.0	55	2 186
Curicica	2391.4	594	24 839
Paquetá	2221.6	76	3 421
Grumari	2205.9	3	136
Gardênia Azul	2029.3	391	19 268
Catumbi	1564.2	202	12 914
Pedra de Guaratiba	1330.9	129	9 693
Bonsucesso	1305.8	252	19 298
Barra de Guaratiba	1095.9	48	4 380
Santo Cristo	1070.9	103	9 618
Catete	1067.9	232	21 724
Cidade de Deus	1004.8	382	38 016
Gloria	1000.2	101	10 098
Recreio dos Bandeirantes	934.2	351	37 572
Campo Grande	892.1	2 654	297 494
Paciência	891.6	745	83 561
Centro	833.0	326	39 135
Guaratiba	763.2	665	87 132

Table 2. The 20 neighborhoods with the highest incidence rates in Rio de Janeiro in 2008. Neighborhoods are ranked according to the incidence rates. Population data are from the Census 2000.

Neighborhood	Dengue Incidence per 100,000 inhabitants	Nb. Dengue cases	Human Population
Camorim	22646.3	178	786
Curicica	17987.8	4 468	24 839
Saúde	12854.5	281	2 186
Caju	12681.7	2 242	17 679
Bonsucesso	10213.5	1 971	19 298
Santo Cristo	9440.6	908	9 618
Anil	9285.0	2 001	21 551
Jacaré	8779.8	649	7 392
Costa Barros	6762.6	1 753	25 922
Vargem Grande	6340.0	590	9 306
Jardim América	6282.3	1 630	25 946
Cocotá	5865.6	288	4 910
Pedra de Guaratiba	5808.3	563	9 693
Gardênia Azul	5719.3	1 102	19 268
Barra de Guaratiba	5684.9	249	4 380
Mangueira	5347.9	727	13 594
Vargem Pequena	5079.8	586	11 536
Cidade de Deus	5042.6	1 917	38 016
Zumbi	4458.6	91	2 041
Ramos	4238.5	1 591	37 537

SPATIO-TEMPORAL DENGUE

Time series maps from the Secretary of Health of the Rio de Janeiro Municipality (SMS 2010) were visually analyzed (data available at http://www.saude.rio.rj.gov.br). Kernel density estimator maps and animation resulted in maps containing hotspots of dengue cases for 72 epidemiological weeks showing the spatial and temporal dynamics of dengue during January 2007 to March 2008 in Rio de Janeiro (Figure 4 and Annex video*). For 2007, automatic georeferencing could not locate 9,985 registered dengue cases, or 45,8% from the 21,783 registered cases from the SMS database from January 2007 to March 2008. For 2008, a total of 8,727 registered dengue cases or 22.8% from the 38,253 registered cases in 2008 could not be assigned to an address.

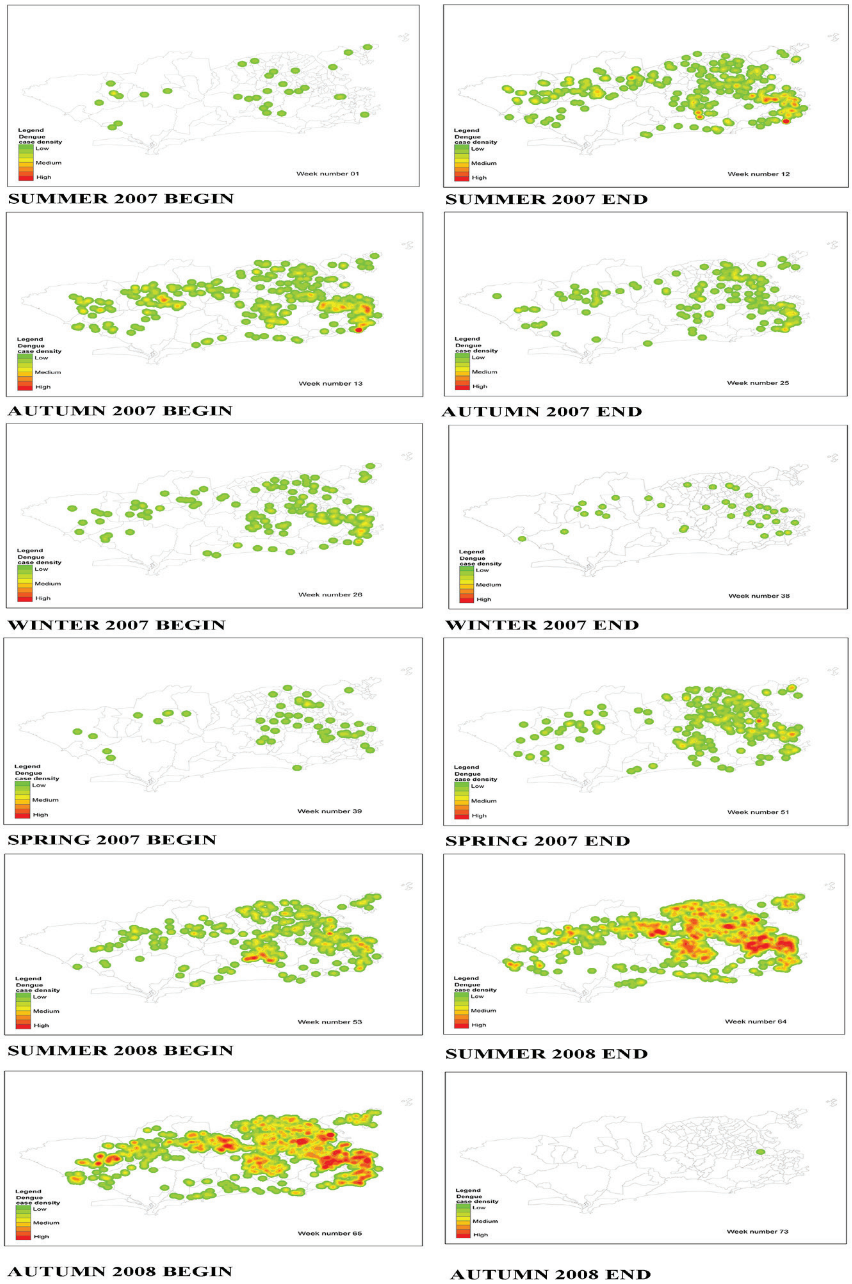

Figure 4. Most representative kernel maps of dengue incidence in Rio de Janeiro city, among the 72 weekly maps created for 2007-2008. Weeks 1-12 and 52 represent summer, 13-25 autumn, 26-38 winter and 39-51 spring.

* windows media video in www.oecologiaaustralis.org

Based on the dengue incidence rates, time series maps and hotspots distribution maps, 7 main clusters of high dengue incidence in Rio during the 2007-2008 epidemics were identified (Tables 3 and 4) (Figures 5 and 6). The term hotspot was used in this text to refer to an area in a neighborhood with high number of dengue cases. The term cluster was used in the sense of an aggregate of neighborhoods presenting dengue hotspots. The 7 observed clusters were ordered by importance based on dengue incidence, number of neighborhoods affected and persistence. The 7 clusters were named Jacarepaguá, Downtown, Island, Northern, Guaratiba, Western (this only in 2007) and Pedra (this only in 2008) (Tables 3 and 4).

Table 3. Clusters of neighborhoods presenting highest dengue incidence rates in 2007 in Rio de Janeiro; number and name for dengue clusters, neighborhood names, dengue incidence (per 100,000 inhabitants), human population, area occupied, human density, percentage of slum area and actual slum area.

Cluster Number	Cluster Name	Neighborhood	Dengue Incidence per 100,000	Human Population	Area (km^2)	Human Density/ km^2	% of Slum	Slum Area (km^2)
1	Jacarepaguá	Anil	30857	21 551	3.79	5686.41	2.52	0.10
		Camorim	38168	786	2.16	92.00	0	0.00
		Cidade de Deus	10048	38 016	1.54	24756.02	3.63	0.06
		Curicica	23914	24 839	3.37	7381.02	5.1	0.17
		Gardênia Azul	20293	19 268	1.58	12204.90	27.46	0.43
2	Downtown	Catete	10679	21 724	0.66	33006.84	9.76	0.06
		Catumbi	15642	12 914	0.50	25972.26	35.76	0.18
		Centro	8330	39 135	5.68	6886.45	0	0.00
		Gloria	10002	10 098	1.09	9295.29	0	0.00
		Santo Cristo	10709	9 618	1.79	5384.93	0.81	0.01
		Saúde	25160	2 186	0.34	6388.37	0	0.00
3	Island 1[1]	Paquetá	22216	3 421	1.36	2521.90	0	0.00
4	Northern	Bonsucesso	13058	19 298	8.54	8939.33	1.8	0.04
5	Guaratiba	Barra de Guaratiba	10959	4 380	9.49	461.96	0	0.00
		Grumari	22059	136	9.61	14.16	0	0.00
		Guaratiba	7632	87 132	135.14	644.70	0.65	0.88
		Pedra de Guaratiba	13309	9 693	3.53	2745.76	0	0.00
		Recreio dos Bandeirantes	9342	37 572	31.23	1203.09	1.87	0.58
6	Western	Campo Grande	8921	297 494	119.30	2493.62	0.74	0.88
		Paciência	8916	83 561	23.45	3563.91	8.62	2.02

[1] Island 1= Paquetá Island

Table 4. Clusters of neighborhoods presenting highest dengue incidence rates in 2008 in Rio de Janeiro; number and name for dengue clusters, neighborhood names, dengue incidence (per 100,000 inhabitants), human population, area occupied, human density, percentage of slum area and actual slum area.

Cluster Nb	Cluster Name	Neighborhood	Dengue Incidence per 100,000	Human Population	Area (km^2)	Population Density/ km^2	Slum %	Slum Area (km^2)
1	Jacarepaguá	Anil	9285	21551	3.8	5686.3	2.5	0.1
		Camorim	22646	786	8.5	92.0	0.0	0.0
		Cidade de Deus	5043	38 016	1.5	24685.7	3.6	0.1
		Curicica	17988	24 839	3.4	7370.6	5.1	0.2
		Gardênia Azul	5719	19 268	1.6	12194.9	27.5	0.4
2	Downtown	Caju	12682	17 679	5.3	3316.9	8.9	0.5
		Santo Cristo	9441	9 618	1.8	5373.2	0.8	0.0
		Saúde	12855	2 186	0.3	6429.4	0.0	0.0
3	Island 2[1]	Cocotá	5866	4 910	0.5	10673.9	0.0	0.0
		Zumbi	4459	2 041	0.2	10742.1	0.0	0.0
4	Northern	Bonsucesso	10214	19 298	2.2	8934.3	1.8	0.0
		Jacaré	8779	7 392	0.8	8800.0	5.2	0.0
		Mangueira	5348	13 594	1.0	13327.5	42.5	0.4
		Ramos	4238	37 537	2.7	13699.6	3.3	0.1
		Costa Barros	6763	25 922	1.8	14812.6	41.4	0.7
		Jardim América	6282	25 946	2.0	13305.6	7.5	0.1
5	Guaratiba	Barra de Guaratiba	5685	4 380	9.5	461.5	0.0	0.0
		Pedra de Guaratiba	5808	9 693	3.5	2745.9	0.0	0.0
7	Pedra	Vargem Grande	6340	9 306	39.1	238.3	0.6	0.2
		Vargem Pequena	5079	11 536	13.8	835.3	1.4	0.2

1= Island; 2= Ilha do Governador Island

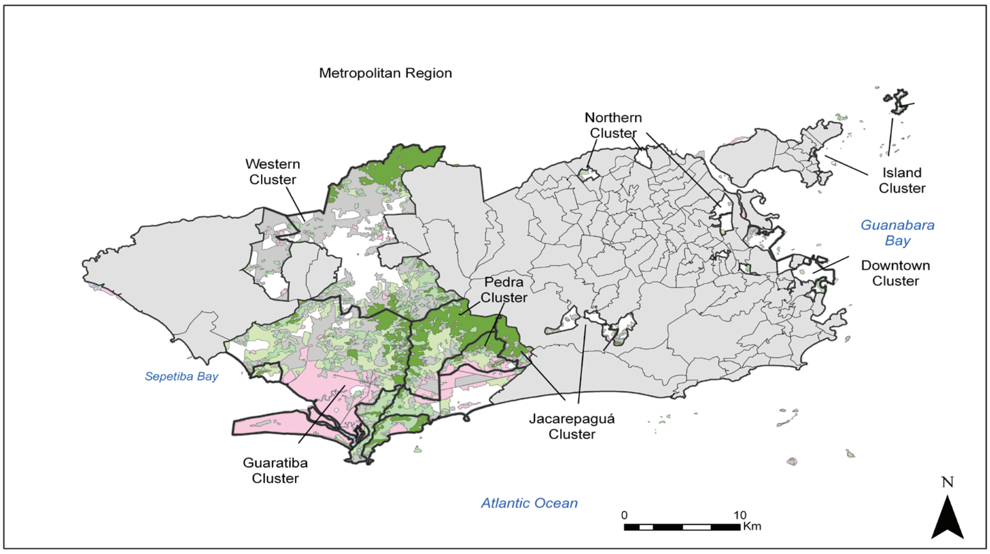

Figura 5. Rio de Janeiro dengue clusters for 2007 and 2008. See legend in Figure 3 for land cover types depicted.

Dengue incidence rates in the identified clusters were high according to the SMS classification.

SMS classifies dengue incidence rates into 8 classes: class 1 = 0 to 0.1 incidence rates, class 2 = 0.01 to 27, class 3 = 27 to 150, class 4 = 150 to 250, class 5 = 250 to 470, class 6 = 470 to 2000, class 7 = 2000 to 5000, class 8 = 5,000 to 20,000 (SMS 2010).

During 2007 most clusters ranked in SMS' class 6, except for Anil, Camorim, Curicica, Gardênia Azul (cluster 1), Paquetá (cluster 3) and Grumari (cluster 5) that were within SMS' class 7.

During 2008 the situation worsened, with most clusters fitting into SMS' class 8, except for Zumbi (cluster 3) and Ramos (cluster 4) which ranked in class 7.

Neighborhoods, land cover and dengue georeferenced cases for the 7 clusters were layered (Figures 5 and 6).

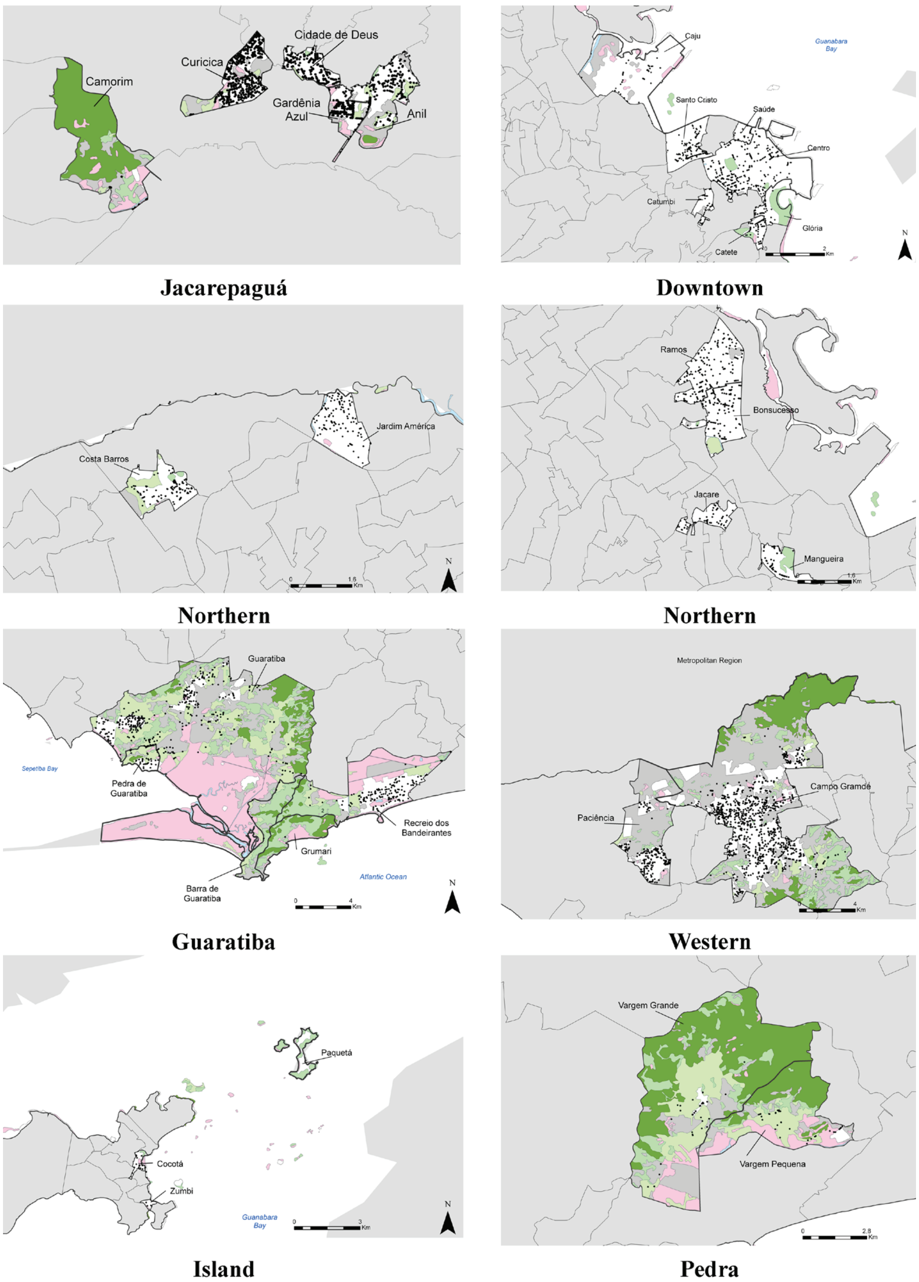

Figura 6. Rio de Janeiro dengue clusters, land cover characteristics and total georeferenced dengue cases in 2007 and 2008 (black dots). See legend in Figure 3 for the land cover types depicted.

Observation of the temporal dynamics of georeferenced cases (windows media video in www.oecologiaaustralis.org) shows that the Downtown cluster could also expand its range to neighborhoods of the Southern zone (Copacabana, Ipanema and Laranjeiras). This cluster is more persistent, with dengue cases decreasing only after the week 27 of 2007. During the epidemiological weeks 50 to 52, at the end of 2007 and beginning of 2008, dengue was widespread with hotspots all over Rio. However, it could be seen that high incidence indices persisted in the neighborhoods belonging to the Jacarepaguá cluster.

Four neighborhoods reported no dengue case in 2007. These neighborhoods were Campos dos Afonsos, Parque Columbia, Praia da Bandeira and Cidade Universitária. All these neighborhoods are of low density (≤500 inhabitants/km^2), except for Praia da Bandeira (with 20,000 inhab./km^2) and Parque Columbia where no habitant is registered. In 2008, only Parque Columbia reported no dengue case.

Dengue cases were concentrated between the weeks 1 to 5 (summer) of 2008 in most of the 20 cluster-forming neighborhoods with the exception of Camorim where dengue incidence peaked in a period when all other neighborhoods were receding. In the period from week 7 until 11 (spring) of 2008 there was another peak of dengue cases in the majority of the neighborhoods (data not shown).

Caju, Guaratiba, Camorim, Curicica and other neighborhoods did not report decrease in the incidence rates, presenting significant peaks at weeks 12 and 13 (end of summer, beginning of autumn) of 2008. Jacaré, Saúde and Camorim were the latest neighborhoods still presenting cases at weeks 15 and 16 (autumn), when all other neighborhoods reported a decrease in dengue cases (data not shown).

RIO DE JANEIRO'S NEIGHBORHOODS HETEROGENEITY

Types of cover land varied in percentage in each of the 158 neighborhoods (Table 5) and percentage of land occupied by slums showed great variation among neighborhoods (Table 6). Human density also varied among neighborhoods (Table 7).

Table 5. Percentage of land cover types for neighborhoods that form clusters of high dengue incidence rates of Rio de Janeiro. Highly urbanized neighborhoods first. Neighborhoods ordered from 1 to 158, only dengue cluster-forming neighborhoods are shown.

Neighbor-hood Order	Neighborhood	Highest Dengue Year	Densely Populated %*	Urban Non-Consoli-dated %	Anthropic Field %	Medium Vegeta-ted %	Highly Vegeta-ted %	Water %	Sandbank, Beach, Mangrove %
10	Saúde	2007/2008	100.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Santo Cristo	2007/2008	99.14	0.00	0.00	0.00	0.00	0.86	0.00
20	Jacaré	2008	99.02	0.00	0.00	0.00	0.00	0.98	0.00
27	Ramos	2008	96.80	0.00	3.20	0.00	0.00	0.00	0.00
28	Centro	2007	96.79	0.00	0.33	2.80	0.00	0.08	0.00
31	Jardim América	2008	95.74	0.00	1.64	0.02	0.00	1.14	1.45
35	Cidade de Deus	2007/2008	93.24	2.92	0.00	2.01	0.00	0.00	1.83
37	Zumbi	2008	92.20	0.00	0.00	0.00	0.00	0.00	7.80
38	Catumbi	2007	91.06	0.00	8.94	0.00	0.00	0.00	0.00
43	Bonsucesso	2007/2008	89.03	7.87	1.82	0.61	0.00	0.67	0.00
54	Cocotá	2008	84.36	0.00	0.00	8.47	0.00	0.00	7.17
67	Mangueira	2008	78.31	0.00	0.01	21.68	0.00	0.00	0.00
71	Caju	2008	76.34	0.00	16.16	0.00	0.00	2.03	5.47
85	Catete	2007	68.84	0.00	8.51	18.39	0.00	0.00	4.26
89	Costa Barros	2008	66.40	20.99	9.47	2.81	0.00	0.00	0.34
95	Curicica	2007/2008	63.17	10.60	21.14	0.00	0.00	0.00	5.09
98	Glória	2007	59.97	0.00	0.10	38.27	0.00	0.00	1.66

Continuação Tabela 5

Neighbor-hood Order	Neighborhood	Highest Dengue Year	Densely Populated %*	Urban Non-Consoli-dated %	Anthropic Field %	Medium Vegeta-ted %	Highly Vegeta-ted %	Water %	Sandbank, Beach, Mangrove %
100	Gardênia Azul	2007/2008	58.49	6.14	16.58	1.21	0.00	0.00	17.58
106	Anil	2007/2008	55.42	11.64	23.30	1.57	2.83	0.00	5.24
123	Paqueta	2007	36.87	0.65	0.00	57.40	0.00	0.00	5.08
131	Paciencia	2007	33.60	1.67	58.34	3.68	0.00	0.00	2.70
134	Pedra de Guaratiba	2007/2008	31.35	50.01	6.65	1.66	6.07	0.00	4.25
137	Campo Grande	2007	29.03	4.37	39.72	9.25	16.65	0.00	0.98
139	Recreio dos Bandeirantes	2007	27.49	10.99	12.81	14.85	2.50	1.63	29.74
149	Guaratiba	2007	6.59	19.05	23.43	9.76	7.11	0.97	33.08
153	Vargem Pequena	2008	2.37	22.42	13.52	6.36	31.91	1.05	22.37
154	Camorim	2007/2008	1.36	0.88	13.70	7.01	65.65	0.63	10.77
155	Vargem Grande	2008	0.81	18.54	13.82	11.90	48.63	0.12	6.19
157	Grumari	2007	0.00	0.00	8.00	43.88	32.21	0.00	15.92
158	Barra de Guaratiba	2008	0.00	17.74	22.68	47.89	8.55	0.22	2.91

*Densely populated = highly urbanized areas without trees or with very limited number of trees; urban non-consolidated = areas of urban growth; 3) anthropic field, equivalent to field areas for pasture or agriculture; medium vegetation = areas <50% vegetation coverage; high vegetation = areas >50% vegetation coverage; water = areas covered by water bodies such as lakes, rivers or by the sea; sandbank, beach and mangrove = an area with any of these characteristics.

Table 6. Neighborhoods of Rio de Janeiro that form clusters of high dengue incidence ordered by the percentage occupied by slums in its land area (2007/2008 normal font and 2008 in italics). Neighborhoods ordered from 1 to 158, only dengue cluster-forming neighborhoods are shown.

Neighborhood Order	Neighborhood	Slum area%	Population 2000	Area km2	Human density
4	*Mangueira*	*42.52*	*13594*	*1.02*	*13327.45*
5	*Costa Barros*	*41.35*	*25922*	*1.75*	*14812.57*
8	Catumbi	35.76	12914	0.50	25828.00
16	Gardênia Azul	27.46	19268	1.58	12194.94
50	Catete	9.76	21724	0.66	32915.15
56	*Caju*	*8.86*	*17679*	*5.33*	*3316.89*
57	Paciencia	8.62	83561	23.45	3563.37
62	*Jardim América*	*7.45*	*25946*	*1.95*	*13305.64*
74	*Jacaré*	*5.15*	*7392*	*0.84*	*8800.00*
76	Curicica	5.10	24839	3.37	7370.62
87	Cidade de Deus	3.63	38016	1.54	24685.71
90	*Ramos*	*3.26*	*37537*	*2.74*	*13699.64*
98	Anil	2.52	21551	3.79	5686.28
105	Recreio dos Bandeirantes	1.87	37572	31.23	1203.07
106	Bonsucesso	1.80	19298	2.16	8934.26
113	*Vargem Pequena*	*1.37*	*11536*	*13.81*	*835.34*
119	Santo Cristo	0.81	9618	1.79	5373.18
120	Campo Grande	0.74	297494	119.30	2493.66
122	Guaratiba	0.65	87132	135.14	644.75

Continuação Tabela 6

Neighborhood Order	Neighborhood	Slum area%	Population 2000	Area km2	Human density
123	*Vargem Grande*	*0.62*	*9306*	*39.05*	*238.31*
131	Barra de Guaratiba	0.00	4380	9.49	461.54
132	Camorim	0.00	786	8.54	92.04
135	Centro	0.00	39135	5.68	6889.96
138	*Cocotá*	*0.00*	*4910*	*0.46*	*10673.91*
140	Gloria	0.00	10098	1.09	9264.22
141	Grumari	0.00	136	9.61	14.15
148	Paquetá	0.00	3421	1.36	2515.44
149	Pedra de Guaratiba	0.00	9693	3.53	2745.89
153	Saúde	0.00	2186	0.34	6429.41
158	*Zumbi*	*0.00*	*2041*	*0.19*	*10742.11*

Values were calculated based on land cover data (Table 5).

Table 7. Neighborhoods of Rio de Janeiro ordered by human density. Neighborhoods ordered from 1 to 158, only dengue cluster-forming neighborhoods shown (2007/2008 normal font and 2008 in italics).

Neighborhood Order	Neighborhood	Human density	% Slum area	Population 2000	Area km²
4	Catete	32915.15	9.76	21724	0.66
7	Catumbi	25828.00	35.76	12914	0.50
10	Cidade de Deus	24685.71	3.63	38016	1.54
41	*Costa Barros*	*14812.57*	*41.35*	*25922*	*1.75*
45	*Ramos*	*13699.64*	*3.26*	*37537*	*2.74*
48	*Mangueira*	*13327.45*	*42.52*	*13594*	*1.02*
49	*Jardim América*	*13305.64*	*7.45*	*25946*	*1.95*
70	Gardênia Azul	12194.94	27.46	19268	1.58
82	*Zumbi*	*10742.11*	*0.00*	*2041*	*0.19*
83	*Cocotá*	*10673.91*	*0.00*	*4910*	*0.46*
93	Gloria	9264.22	0.00	10098	1.09
94	Bonsucesso	8934.26	1.80	19298	2.16
95	*Jacaré*	*8800.00*	*5.15*	*7392*	*0.84*
108	Curicica	7370.62	5.10	24839	3.37
110	Centro	6889.96	0.00	39135	5.68
115	Saúde	6429.41	0.00	2186	0.34
117	Anil	5686.28	2.52	21551	3.79
121	Santo Cristo	5373.18	0.81	9618	1.79
130	Paciencia	3563.37	8.62	83561	23.45
131	*Caju*	*3316.89*	*8.86*	*17679*	*5.33*
135	Pedra de Guaratiba	2745.89	0.00	9693	3.53

Continuação Tabela 7

Neighborhood Order	Neighborhood	Human density	% Slum area	Population 2000	Area km^2
137	Paquetá	2515.44	0.00	3421	1.36
138	Campo Grande	2493.66	0.74	297494	119.30
147	Recreio dos Bandeirantes	1203.07	1.87	37572	31.23
148	*Vargem Pequena*	*835.34*	*1.37*	*11536*	*13.81*
149	Guaratiba	644.75	0.65	87132	135.14
152	Barra de Guaratiba	461.54	0.00	4380	9.49
155	*Vargem Grande*	*238.31*	*0.62*	*9306*	*39.05*
156	Camorim	92.04	0.00	786	8.54
157	Grumari	14.15	0.00	136	9.61

Values were calculated based on land cover data (Table 5).

Some neighborhoods are characterized by a diversity of land cover types and human density estimation was corrected to account for the probable inhabited land only. This correction was performed subtracting high vegetation areas plus water, beaches, sandbanks and mangroves from the total area, to obtain a more accurate view of the human occupation (Table 8). When human density correction was applied, low human density areas like Guaratiba, Vargem Grande, Vargem Pequena, Grumari, Recreio dos Bandeirantes and a few others neighborhoods not belonging to clusters (Jardim Botânico, São Conrado, Urca, Table 8) had a 2-fold increase in their densities. For Camorim (where 65% of its area is covered by high vegetation) a 4-fold increase in human density was observed (from 90 inhab./km^2 to 400 inhab./km^2) (Table 8). This correction also showed for example that Rocinha (a 100% slum neighborhood) is more densely populated with 55,000 inhab./km^2 than reported (40,000 inhabitants/km^2) (Table 8). As an example, Copacabana had an increase of 36,000 inhab./km^2 to 40,000 inhab./km^2 when sand and beaches were subtracted from its total area. Most of the remaining neighborhoods kept human density values relatively the same.

Table 8. Neighborhoods of Rio de Janeiro ordered by corrected values of human density based on land cover area (Table 5). Neighborhoods ordered from 1 to 158, only dengue cluster-forming neighborhoods (2007/2008 in bold), 2008 in italics) and other neighborhoods cited in the text (normal font) are shown.

Neighborhood Order	Neighborhood	Corrected Human density	Human density
1	Rocinha	55680.1	36114.1
2	Copacabana	40011.6	35946.5
4	**Catete**	**34379.7**	**32915.2**
9	**Catumbi**	**25828.0**	**25828.0**
11	**Cidade de Deus**	**25145.9**	**24685.7**
39	**Gloria**	**15809.2**	**9264.2**
45	***Costa Barros***	***14861.6***	***14812.6***
46	**Gardênia Azul**	**14796.1**	**12194.9**

Continuação Tabela 8

Neighborhood Order	Neighborhood	Corrected Human density	Human density
51	***Ramos***	***13699.6***	***13699.6***
52	***Jardim América***	***13660.8***	***13305.6***
58	***Mangueira***	***13327.5***	***13327.5***
81	***Zumbi***	***11650.9***	***10742.1***
82	***Cocotá***	***11498.3***	***10673.9***
100	Jardim Botânico	9254.5	3805.4
101	**Bonsucesso**	**8994.5**	**8934.3**
102	***Jacaré***	***8887.1***	***8800.0***
109	**Curicica**	**7765.9**	**7370.6**
118	**Centro**	**6895.5**	**6890.0**
121	**Saude**	**6429.4**	**6429.4**
122	**Anil**	**6185.4**	**5686.3**
126	**Santo Cristo**	**5419.8**	**5373.2**
129	São Conrado	4472.5	1856.1
130	Urca	4356.5	2766.4
133	**Paciência**	**3662.6**	**3563.4**
134	***Caju***	***3585.8***	***3316.9***
137	**Pedra de Guaratiba**	**3062.2**	**2745.9**
138	**Campo Grande**	**3027.4**	**2493.7**
141	**Paquetá**	**2650.1**	**2515.4**
143	***Vargem Pequena***	***1870.0***	***835.3***
144	**Recreio dos Bandeirantes**	**1819.0**	**1203.1**
150	**Guaratiba**	**1096**	**644.8**
152	***Vargem Grande***	***528.8***	***238.3***
153	**Barra de Guaratiba**	**522.6**	**461.5**
155	**Camorim**	**401.0**	**92.0**
157	**Grumari**	**27.3**	**14.2**
158	Parque Columbia	0.0	0.0

URBAN ECOSYSTEMS IN RIO DE JANEIRO

Characteristics of the dengue clustered neighborhoods revealed differences regarding human density, slum area, urban area, highly vegetated area, anthropic field area, medium vegetated, sand-beaches-mangrove area and incidence rates. Based on these differences an urban ecosystem classification of dengue clusters was proposed (Table 9).

Table 9. Urban ecosystems related to dengue in Rio de Janeiro.

	Cluster Name	Neighbor hood	Human Density	Slum %	Urban %	High Veg* %	Anth %	Med Veg %	SBM	Dengue 2007	Dengue2008	Urban Ecosystem
1	Jacarepaguá	Anil	6185	3	55	3	23	2	5	30857	9285	Medium-High Populated
		Camorim	401	0	1	67	14	7	10	38168	22646	Low Slums
		C. Deus	25146	4	93	0	0	2	2	10048	5043	Medium Urban
		Curicica	7766	5	63	0	21	0	5	23914	17988	Medium Vegetated
		Gardênia	14796	27	58	0	17	1	17	20293	5719	Medium Anthropic
			10859 (±8490)	**8 (±10)**	**54 (±30)**	**14 (±27)**	**15 (±8)**	**2 (±2)**	**8 (±5)**	**24656 (±9529)**	**12136 (±6990)**	Medium Diversity
2	Downtown	Caju	3586	9	76	0	16	0	5	12682		Medium-High Populated
		Catete	34379	10	69	0	9	18	4	10679		Medium Slums
		Catumbi	25828	36	91	0	9	0	0	15642		High Urban
		Centro	6896	0	97	0	0	3	0	8330		Low Vegetated
		Glória	15809	0	60	0	0	38	2	10002		Low Anthropic
		S.Cristo	5420	1	99	0	0	0	0	10709	9441	Low Diversity
		Saúde	6429	0	100	0	0	0	0	25160	12855	
			12931 (±11619)	**8 (±13)**	**85 (±16)**	**0**	**5 (±6)**	**8 (±15)**	**2 (±2)**	**13315 (±5711)**	**11148 (±2414)**	
3	Island 1[1]	Cocotá	11498	0	84	0	0	9	7		5866	Medium Populated
		Paquetá	2650	0	37	0	0	57	5	22216		Low Slums
		Zumbi	11651	0	92	0	0	0	8		4459	Medium-High Urban
			8600 (±5153)	**0**	**71 (±30)**	**0**	**0**	**22 (±31)**	**7**	**22216**	**5163 (±995)**	Low-Medium Vegetated
												Low Anthropic
												Medium Diversity
4	Northern	Bonsucesso	8944	2	90	0	2	0	1	13058	10214	Medium-High Populated
		C.Barros	14862	41	66	0	9	3	0		6763	Medium-High Slums
		Jacaré	8887	5	99	0	0	0	0		8779	High Urban
		J. América	13661	7	96	0	2	0	1		6282	Low Vegetated
		Mangueira	13327	43	78	0	0	22	0		5348	Low Anthropic
		Ramos	13699	3	97	0	3	0	0		4238	Low Diversity

Continuação Tabela 8

	Cluster Name	Neighbor hood	Human Density	Slum %	Urban %	High Veg* %	Anth %	Med Veg %	SBM	Dengue 2007	Dengue2008	Urban Ecosystem
			12230 (±2620)	**17 (±18)**	**88 (±13)**	**0**	**3 (±3)**	**4 (±9)**	**0**	**13058**	**6937 (±1541)**	
5	Guaratiba	B.Guaratiba	523	0	0	9	23	48	3	10959	5685	Low Populated
		Grumari	27	0	0	32	8	44	16	22059		Low Slums
		Guaratiba	1096	1	7	7	23	10	33	7632		Low Urban
		P.Guaratiba	3062	0	31	6	7	2	4	13309	13309	Medium-High Vegetated
		Recreio	1819	2	27	3	13	15	30	9342		Medium Anthropic
			1305 (±1187)	**1 (±1)**	**13 (±15)**	**11 (±12)**	**15 (±8)**	**24 (±21)**	**17 (±14)**	**12660 (±5656)**	**9497 (±5391)**	Medium-High Diversity
6	Western	C.Grande	3027	1	29	17	40	9	1	8921		Low-Medium Populated
		Paciência	3663	9	34	0	60	4	3	8916		Low Slums
			3345 (±450)	**5 (±6)**	**32 (±4)**	**9 (±12)**	**50 (±14)**	**7 (±4)**	**2 (±1)**	**8919 (±4)**		Low-Medium Urban
												Low-Medium Vegetated
												High Anthropic
												Medium-High Diversity
7	Pedra	V. Grande	529	1	1	48	14	12	6		6340	Low Populated
		V. Pequena	1870	1	2	32	13	6	22		5079	Low Slums
			1200 (±948)	**1**	**2 (±1)**	**40 (±11)**	**14 (±1)**	**9 (±4)**	**14 (±11)**		**5710 (±892)**	Low Urban
												High Vegetated
												Medium Anthropic
												Medium Diversity

*High Veg-Highly Vegetated, Anth-Athropic, Med Veg-Medium Vegetated, SBM-sand, beaches and mangroves.

DISCUSSION

Among other factors, human density and organization, microclimate and land cover create areas with particular environmental heterogeneous conditions in Rio de Janeiro.

For the analysis conducted in this paper, it has been assumed that dengue transmission occurs in the human domicile or in its immediate peridomicile rather than at work, during leisure or commuting, due to the ubiquity of *Ae. aegypti* in Rio de Janeiro.

Human density and organization

Highly urbanized and densely populated neighborhoods in the tropics are among the major risk factors for *Ae. aegypti* infestation and dengue (Gubler 1998, WHO 2010). *Ae. aegypti* is more prevalent in highly urbanized and densely populated neighborhoods of Rio de Janeiro (Braks *et al.* 2003, Carbajo *et al.* 2006, Honório *et al.* 2009c). High infestation levels of *Ae. aegypti* are associated with high risk of dengue transmission both as an endemic as well as an epidemic disease (Tauil 2001, Luz *et al.* 2003, Honório *et al.* 2009a, 2009b, 2009c).

Slums are a disorganization of the urban fabric, and the usual prevailing conditions like absence of garbage collection and overcrowded human conditions are related to high risk of dengue transmission. Data on slums used in this study date back to 2003. In some neighborhoods it is likely that slum areas increased and that new slums have appeared. However, the overall growth of the neighborhoods where the slums are situated should compensate for slum growth in area and number. In most slums, lack of infrastructure includes the absence of formal addresses. The lack of georeferenced dengue case reports in slums could have led to an underestimation of the role of slums in dengue transmission.

High dengue incidence in neighborhoods like Pedra de Guaratiba, Saúde, Zumbi, Glória, Centro, where there are no slums, indicate that in some ecosystems slums *per se* cannot be implicated as a risk factor for dengue transmission. In some other neighborhoods, a small percentage of their area is occupied by slums, as for example, Jacaré (5% of its area as slum), Curicica (5%), Cidade de Deus (4%), Anil (3%), Santo Cristo (1%) and Vargem Grande (1%) (Table 3).

On the other hand, slums occupy a great portion of cluster-forming neighborhoods like Mangueira (43% of its area as slum), Costa Barros (41%), Catumbi (36%) and Gardênia Azul (28%).

Microclimate

The climate of Rio is tropical, warm and humid, local (microclimatic) variations are expected mainly due to differences in altitude, land cover, proximity to the ocean and urbanization. Spatial and temporal variations in microclimatic variables, like temperature evapotranspiration, winds and soil moisture, are likely to play a role in the proximate environment of the human domicile.

The human domicile is affected by the surrounding environment where it is inserted in. Outdoor precipitation, temperature, and other climatic variables may affect indoor temperature and humidity and thus indoor mosquito survival and behavior. A high proportion of outdoor peridomestic containers will also be partially impacted by the ambient climate (Rosa-Freitas *et al.* 2006). High human population density and the availability of disposable containers that can accumulate water, together with vapor pressure (a combined variable of humidity and temperature) are the main variables associated with elevated local *Ae. aegypti* infestation rate and dengue (WHO 2010). Vapor pressure is considered to be the single best natural predictor of potential for dengue occurrence at any given place (Roriz-Cruz *et al.* 2010). For dengue, higher ambient temperature shortens the dengue virus extrinsic incubation period (Watts *et al.* 1987), increases *Ae. aegypti* biting rate (Macdonald 1956), mosquito survival (Rueda *et al.* 1990, Focks *et al.* 1993, Tun-Lin *et al.* 2000) and therefore, increases vectorial capacity and dengue transmission (Reiter 2001).

Cities create heat islands (Landsberg 1981) which are built up areas that are hotter than nearby rural areas. Large concrete and asphalt areas where trees are virtually inexistent are in average 2 to 5ºC warmer than the surrounding vegetated areas, because these substrates absorb heat during the day and radiate heat back at night (Landsberg 1981, Reisen 2010). In the evening, the difference can be as high as 12°C (Environmental Protection Agency-EPA, USA 2010). Wind flows, important to mosquito spread, are also altered due to urbanization. Wind flows are different not only due to temperature differentials but also due to the existence of buildings that can stagnate air movement (Reisen 2010). Monthly rainfall is also greater downwind of cities, partially due to the heat island effect. Rainfall runoff increase due to the high proportion of asphalt coverage and impervious surfaces areas (Reisen 2010), can influence water balance and breeding habitat availability.

Land cover

The difference between high, medium and low urbanized areas is an approximate function of the number of existent trees. In highly urbanized areas, the cooling effect on the air temperature is limited for a single tree or a small group of street trees (Oke 1989). Larger number of trees, present for example in parks, can have a significant cooling effect (Yu and Hien 2006). Evapotranspiration that contributes to air temperature modulation, is highly dependent on soil humidity and therefore likely to be different in vegetated areas and in highly urbanized areas. In urban areas due to sealing of the ground, evapotranspiration cooling is limited (Oke 1989, Spangenberg *et al.* 2008). Wind speeds also are affected by the existence of trees. Trees are important in wind speed, humidity, air and surface temperatures (Williamson & Erell 2001, Spangenberg *et al.* 2008). Proximity of urban settlements to water bodies and forests are likely to buffer or lower temperatures in some areas (Ramos & Santos 2006).

The type of human domicile, together with the degree of urbanization and microclimate are factors that can alter the vectorial capacity equation ultimately altering transmission and epidemic strength (Favier *et al.* 2006, Hemme *et al.* 2010). The presence of dengue in different urban ecosystems in Rio de Janeiro challenges the belief that the more urban and more densely populated an area is, the higher the likelihood of increased dengue incidence rates (as per WHO 2010). In the case of the 2007-2008 dengue epidemics in Rio de Janeiro though, medium to high vegetated areas were as strongly affected as highly urbanized areas. High dengue incidence rates were equally observed in low urbanized, low populated (Jacarepaguá, Guaratiba and Pedra clusters), medium urbanized, low-medium populated (Island and Western clusters) and highly urbanized, highly populated (Downtown and Northern clusters) neighborhoods of Rio de Janeiro (Table 9).

Indeed, the first and most important cluster, in terms of dengue incidence and number of neighborhoods involved, was constituted by a medium-high populated, medium urbanized urban ecosystem in the Jacarepaguá lowland (Table 9). This cluster is located in a rapid expanding urban region in a medium-to-high vegetated area. Jacarepaguá presented the highest dengue incidence rates ~25,000 and ~12,000 average, in 2007 and 2008, respectively (Table 9). The Jacarepaguá lowland urban ecosystem is characterized by being an area between 2 mountain forests, the Pedra Branca Forest and the Tijuca Forest. The 2 forests are constituted by the Atlantic Forest (Mata Atlântica) and its remaining species. The Tijuca Forest is the largest urban forest in the world. Its occupation has experienced marked growth lately, mainly because of building expansion. It is worth noting that Camorim was the neighborhood that held the highest dengue incidence rate, 30,000, in Rio de Janeiro during the 2007-2008 epidemics. Camorim's land cover is characterized as low urbanized (1% urban), of low human density (400 inhab./km^2), highly vegetated (70%) and without slums (Table 9).

Another medium-to-high vegetated area highly affected by dengue included the clusters formed by the neighborhoods of Guaratiba and Pedra. The neighborhoods forming the Guaratiba and Pedra clusters, have in common the fact that their areas are sparsely populated, of low urbanization and highly diverse regarding land coverage. Both Guaratiba and Pedra clusters have medium to high vegetation coverage as well as sand, water and mangrove. In fact, Pedra de Guaratiba and Recreio have ~30% of urban area while Vargem Grande, Vargem Pequena and Grumari have ≤2% urban area (as from 2003 data, Table 9). Pedra de Guaratiba, Guaratiba, Barra de Guaratiba, Vargem Grande and Vargem Pequena have large portions of their urban areas as non-consolidated areas (>17%, Table 5). The Guaratiba and Pedra clusters could be considered as a frontier urban ecosystem, with human occupation expanding towards areas previously covered only by vegetation (Table 9).

Medium-high urbanized, low to medium populated neighborhoods in medium vegetated areas were represented by the Island and Western clusters. Paquetá Island experienced a severe epidemic in 2007 with dengue incidence rate reaching ~20,000 (average). Paquetá holds 37% of its area as urban and 60% as medium vegetated area with 2,500 inhabitants/km^2 (Table 9). The neighborhoods of Cocotá and Zumbi in Ilha do Governador Island formed an important cluster in 2008 with dengue incidence rate of ~5,000 (average). Both Cocotá and Zumbi are highly urbanized have no slums and ~10,000 inhabitants/km^2 (Table 9). The Western cluster formed by the neighborhoods of Campo Grande and Paciência are characterized by 50% anthropic fields, 30% urban area, human density of ~3,000 inhabitants/km^2, a low slum area of 0.7% and 9%, respectively. Low-medium vegetation, medium diversity land coverage would describe the Western cluster.

As expected, highly urbanized, highly populated neighborhoods were also struck by dengue in the 2007-2008 epidemics. This was the case for the Downtown and Northern neighborhoods. These neighborhoods differently from the neighborhoods in the Jacarepaguá cluster are formed by densely populated urbanized areas with virtually no trees. In the Downtown cluster, neighborhoods hold ≥90% urban coverage, except for Caju, Catete and Glória (≥60% urban). An average of 8% of their areas are occupied by slums. All neighborhoods belonging to the Northern cluster possess >90% urban area with the exception of the neighborhood Mangueira and Costa Barros, which although having >66% of their area as urban, are ~40% occupied by slums. Jardim América, Jacaré, Ramos and Bonsucesso have ~5% slum area.

Neighborhoods that are part of clusters generally have low indices of human development (high child mortality, low longevity, low income and education). Guaratiba, Western and Pedra clusters for example, belong to the Campo Grande administrative region, considered to be the lowest in development indices in Rio de Janeiro. Camorim, Vargem Pequena and Recreio dos Bandeirantes had impressive human populational growth in the 1990's (82%, 71% and 62%, respectively) while only 5% of Vargem Grande's adult population hold an university degree (Prefeitura da Cidade do Rio de Janeiro 2003).

Temporal patterns from previous epidemics

Visual observation of neighborhood incidence maps from previous years (SMS 2010) shows that the same clusters appeared as repeated patterns in previous epidemics. Camorim, a small neighbourhood in the Jacarepaguá lowland had the highest incidence rates during December 2003. During the 2005-2006 epidemics (December 2005, January to May 2006) for example, the neighborhoods that constitute the Jacarepaguá lowland had again high incidence rates (SMS 2010). Analyses of neighborhood incidence maps from previous years (2003-2007, SMS 2010), show that when dengue is endemic, dengue cases are spread all over the city, but when dengue is epidemic dengue cases are clustered in preferred repeated areas of the city. These main preferred areas are more or less the same as the main clusters for the 2007-2008 period, mainly represented by the Jacarepaguá lowland, Downtown and Northern clusters of neighborhoods. The Downtown cluster occasionally extended towards Southern neighborhoods.

CONCLUSIONS

As indicated herein, besides aspects of mosquito biology, attention should also be given to specific characteristics of the urban ecosystem for the different neighborhoods. As for many other metropolitan areas, governments may need to adopt specific control activities regarding aspects of mosquito biology in each neighborhood, instead of an uniform control approach for the whole city (Lourenço-de-Oliveira 2008). The 20 dengue cluster-forming neighborhoods should be considered priority areas for control.

In Rio de Janeiro, is there a dengue of highly urbanized areas, a dengue of medium urbanized areas and a dengue of medium-high vegetated areas? Do these different urban ecosystems differ epidemiologically in the sense of when and how dengue is transmitted? Or in all those apparent different urban ecosystems there is a shared characteristic that favor dengue transmission? In Camorim, a highly vegetated and low human populated area where dengue is persistent and high, is there an involvement of *Ae. albopictus*?

The above questions need to be answered by further studies that would also take into account other environmental aspects. Other characteristics like land use, surrounding flora and fauna, income, economic activities, water and waste management, human health management, information, energy and transport and, even local culture may influence the way dengue is transmitted in Rio de Janeiro (Machlis *et al.* 1997, Ishii 2004, Ellis & Ramankutty 2008).

In this study, dengue cases were georeferenced, allowing dengue to be attributed to a particular portion of a neighborhood. Taking into account that transmission occurred indoors, this procedure pinpointed that in Rio de Janeiro, low human density, medium to high vegetated neighborhoods are also prone to display high incidence for dengue.

Further characterization based on data for density population, human behavior and mobility, housing, temperature, altitude, family income, among others, can improve the understanding of dengue and the urban ecosystems in Rio de Janeiro. Notwithstanding, this study contributes to a better understanding of the dynamics of dengue in Rio de Janeiro by assessing the relationship between dengue cases and types of land coverage.

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