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Detection and modelling of case clusters for urban leptospirosis

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Summary

OBJECTIVE To analyse the epidemiological profile of 488 cases of leptospirosis in Rio de Janeiro, Brazil between 1997 and 2002, using a variety of methods of spatial epidemiology, to establish alert guidelines in general hospitals, which might be a tool to improve diagnosis and treatment of leptospirosis to reduce lethality rates.

METHODS Scan statistics identified six space–time clusters, which comprised a range of 2 to 28 cases per cluster. Generalized linear mixed models were used to evaluate risk factors for a cluster case which incorporated individual characteristics and spatial information on environmental and climactic factors in a single model frame.

RESULTS Cluster case events were associated with heavy rainfall (OR 3.71; 95% CI 1.83–7.51). The model did not identify socioeconomic or environmental covariates that significantly influence the risk of developing a cluster rather than non-cluster case.

CONCLUSION Clustering of leptospirosis in this urban setting appears to be due to transmission during heavy rainfall.

keywords leptospirosis, urban epidemics, geographic information systems, spatial epidemiology, generalized linear mixed model

Introduction

Leptospirosis is a globally distributed, life-threatening zoonosis (Edwards & Domm 1960; Faine 1999; Levett 2001; Bharti *et al.* 2003; McBride *et al.* 2005). Infection occurs during direct contact with animal reservoirs or indirectly during contact with water and/or soil contaminated with the urine of reservoirs (Farr 1995; Levett 2001). Severe disease develops in 5–10% of symptomatic infections and causes multisystem complications such as acute renal failure and pulmonary haemorrhage. Overall case fatality is high and varies from 5% to 15% (Edwards & Domm 1960; Farr 1995; Faine 1999), depending on the geographic region.

Leptospirosis is now recognized as an emerging infectious disease due to changes in its epidemiology. In developed countries, leptospirosis was traditionally a sporadic disease associated with risk occupations such as farming and animal husbandry, abattoir work and veterinarians (Farr 1995; Faine 1999; Levett 2001). More recently it has been increasingly associated with recreation and water sports (Jansen *et al.* 2005) and travel (Boland *et al.* 2004) and has become the cause of outbreaks during athletic events, in disaster situations and in adventure tourism (Morgan *et al.* 2002; Watson *et al.* 2007). However, the major burden of leptospirosis is borne by developing countries (Faine 1999; Kariv *et al.* 2001; Levett 2001; Bharti *et al.* 2003), where disease incidence ranges between 10 and 100 per 100 000 inhabitants (Everard *et al.* 1995; Merien & Perolat 1996; Yersin *et al.* 1998; Smythe 1999; Tangkanakul *et al.* 2005; Wuthiekanun *et al.* 2007). Leptospirosis is a major public health problem in rural communities in developing countries, where it affects poor subsistence farmers and herders. In addition to endemic transmission of leptospirosis, large outbreaks occur in these settings (Tangkanakul *et al.* 2005; Wuthiekanun *et al.* 2007), as has been reported during post-monsoon seasons.

Moreover, leptospirosis has emerged to become a health threat in urban centres (Ko *et al.* 1999; McBride *et al.* 2005). Rapid and spatially disorganized process of urbanization throughout the developing world has created unhealthy physical and social urban environments (Sclar *et al.* 2005). At present more than 1 billion of the world's population resides in slum settlements (UN-Habitat 2003). The lack of adequate sewage systems, trash deposits and

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poor housing favour high rodent densities which in turn lead to environmental contamination with pathogenic *Leptospira* and high level transmission of leptospirosis in these communities (Yersin *et al.* 1998; Ko *et al.* 1999; Barcellos & Sabroza 2001; Kupek *et al.* 2001; Sarkar *et al.* 2002; Romero *et al.* 2003; Tassinari *et al.* 2004).

Leptospirosis is a major public health problem in Brazil. More than 35 000 confirmed cases were identified between 1985 and 1997, among which case fatality was 12.5% (FUNASA 2005). The majority of these cases were reported from large urban centres (Ko *et al.* 1999). Leptospirosis cases occur throughout the year in this setting (Sarkar *et al.* 2002), indicating that there is endemic transmission. However, large outbreaks have been reported during seasonal periods of heavy rainfall and flooding (Ko *et al.* 1999; Barcellos & Sabroza 2001; Navarro *et al.* 2002; Sarkar *et al.* 2002; Tassinari *et al.* 2004). Leptospirosis is well-known to occur in disaster situations such as hurricanes and monsoons (Watson *et al.* 2007) and is increasingly recognized as an emerging infectious disease with cyclic climatic events (Hunter 2003).

We analysed cases identified during surveillance for leptospirosis in the city of Rio de Janeiro between 1997 and 2002 to detect space–time clusters and identify factors that influence endemic and epidemic transmission in this urban setting. Refined identification of case clusters in urban leptospirosis and elucidation of the environmental, climactic and social factors which influence these cluster events are required to understand the behaviour of the disease. Furthermore, timely detection of outbreaks and identification of their determinants may help in establishing alert guidelines for surveillance and health care professionals and in turn, may improve diagnosis and treatment of leptospirosis which is necessary to reduce the high fatality rates associated with urban epidemics.

Methods

Study area

The city of Rio de Janeiro (population 5.8 million; FIBGE 2001) has a large diversity of geographic, environmental and socioeconomic characteristics. The city boundaries include swamps and mountains as high as 800 m; densely populated areas as well as unpopulated forests and slum communities in close proximity to upper and middle class neighbourhoods. The urban plan of Rio de Janeiro was defined by decades of public investment in urban infrastructure, prioritizing neighbourhoods in the southern areas adjoining the ocean beaches, while neglecting the poorer regions in the north and west sectors of the city (Abreu 1987) (Figure 1). Slum communities (‘*favelas*’) are distributed throughout the city and occupy diverse geographic settings, which include most mountains and swamp regions in the city. Seasonal heavy tropical rain and flooding occur during the summer period between December and March and affects regions with inadequate water drainage.

Data sources and indicators

Between 1997 and 2002, 514 leptospirosis cases were reported to the Municipal Health Secretary of Rio de Janeiro according to clinical, epidemiological and laboratory criteria of the Brazilian Ministry of Health (FUNASA 2005). Cases are reported on the basis of having signs and symptoms compatible of leptospirosis, such as jaundice, acute renal insufficiency and haemorrhage; reported history of contact with potential risk factors such as flooding and reservoirs and laboratory evidence for the diagnosis obtained during microscopic agglutination test, culture isolation evaluations.

Automatic geocoding (Geoprocessing Laboratory 2001) localized only about 64% of the case residence according to census tract. A manual search algorithm (Skaba *et al.* 2004) identified an additional 31% cases. Thus, the total geocodification process located the residence of 488 (95%) cases in 446 census tract polygons (Figure 2). No differences were detected between geocoded and the small number (26) of non-geocoded cases. Digital maps in 1:5000 scale were obtained from the Geoprocessing Laboratory/DIS/CICT/FIOCRUZ (2001) and were used to create databases in the publicly-available geographic information system TerraView version 3.1.2 (Câmara *et al.* 2000). Socioeconomic indicators, such as residents per households, years of education of the head of household, numbers of inhabitants residing in slum areas, per capita household income, access to potable water and closed sewage systems, were obtained from the year 2000 national census (FIBGE 2001). Information was aggregated in 8145 census tracts. The Civil Defense Authority of Rio de Janeiro performs routine surveillance of flooding and provided digital maps of flood regions for the city. High-risk areas for flooding were defined as the area within a buffer of 1 km surrounding the Civil Defense Authority defined flood regions (Figure 1). A network of 32 meteorological stations provided daily rainfall data for the city for the study period (GEORIO 2006). Voronoi tessellation was used to define the area of influence of the dataset generated from each station (Figure 2). This technique divides a plane with n points into n convex polygons (‘Voronoi or Thiessen polygons’). Each point in a given polygons is closer to its central point than to the central point of other polygons (Brasel & Reif 1979). Bartlett’s test

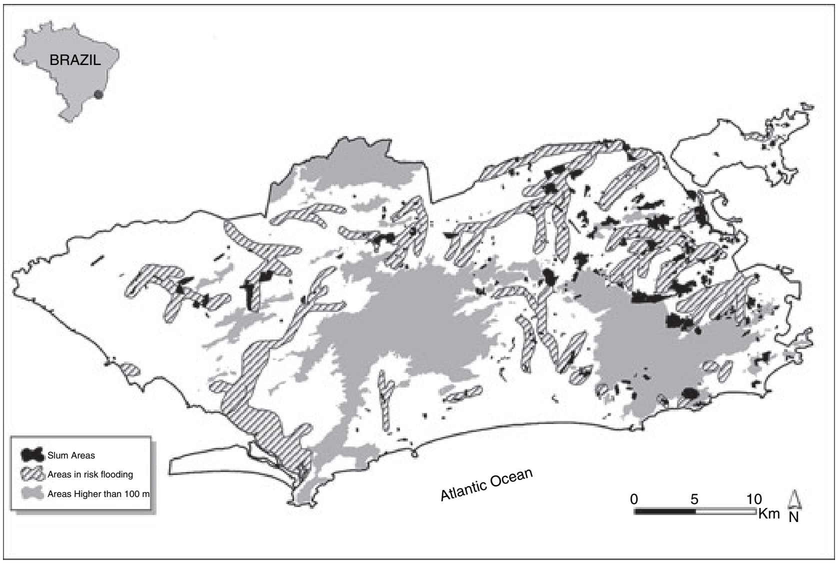

Figure 1 Distribution of areas with altitude greater than 100 m, slums areas and regions of flood risk in Rio de Janeiro, Brazil.

was used to evaluate the rainfall variability among the study years and Voronoi polygons that corresponded to the areas of influence surrounding meteorological stations (Snedecor & Cochran 1982).

Statistical methods

SatScan software system was used to perform spatial scan statistics and identify space and time clusters among leptospirosis cases (Kulldorf & Nagarwalla 1995). The algorithm is based on building a series of moving cylindrical windows in which the circular base and height correspond to a geographic area and time span, respectively. An infinite number of overlapping cylinders of different size and shape are generated which together encompass the entire study area and time span. The number of cases observed in each defined window is compared with the expected number, calculated based on the at-risk population in the study area. The maximum likelihood ratio is used to detect windows where the number of observed cases is significantly greater than expected (Kulldorf & Nagarwalla 1995). The size of the moving windows was restricted to <10% of the population (585 790 inhabitants). The incubation period of leptospirosis varies from 2 to 30 days, yet the usual range is 5–14 days (Faine 1999). We, therefore, evaluated windows with a maximum time span of 30 days in the models that incorporated the presumed incubation period and the possibility that exposures associated with an outbreak event occurred over a 2- to 3-week period. The SatScan software system was used to identify clusters.

A cluster case was defined as a leptospirosis case, which belonged to a cluster. A generalized linear mixed model was used to evaluate risk factors for a cluster case in comparison with non-cluster case. A multilevel analysis was performed with two spatial levels: individual level and the 32 Voronoi polygon surrounding the meteorological stations. The census tract socioeconomic indicators were used to define the socioeconomic level of each case residence. It was not included as a level in the multilevel analysis because almost no census tract presented more than one case. Each case was related to the mean daily rainfall (measured at the closest meteorological station) that occurred during the preceding 3–20 days before the date of initiation of the symptoms. To identify the threshold of mean daily rainfall associated with the risk for developing cluster cases, several models were fitted, which evaluated different cut-points for mean daily rainfall.

Since information on covariates was obtained for spatial areas, not to the individual, a random effect term (intercept) was included in the logistic multilevel model, assuming a multivariate normal distribution with mean of zero. The variance partition coefficient (VPC) measures the proportion of variance explained by the higher level Voronoi polygon. Values for the VPC, which approach zero, provides an indication that the variability among areas does not affect the estimated parameter (Snijders & Bosker 1999). Akaike's corrected information criterion was used to select the best fit model (Mcculloch & Searle 2000). Models were fitted in the statistical package R version 2.2.1 (R Development Core Team 2005).

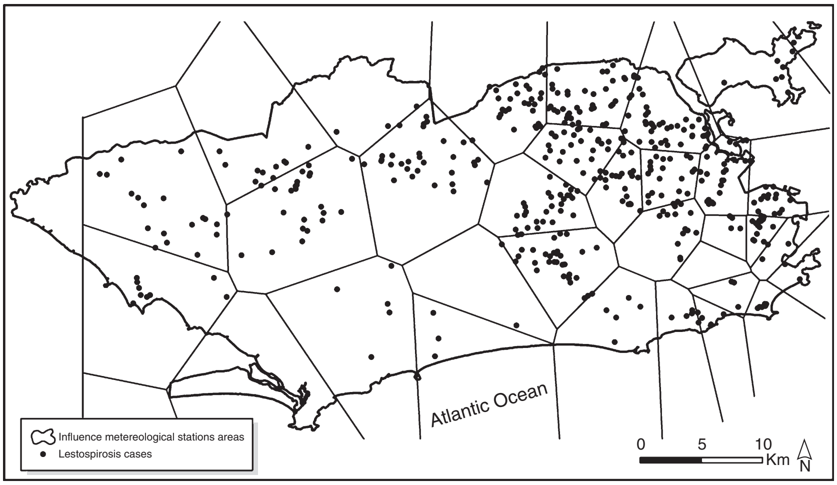

Figure 2 Distribution of leptospiosis cases and Voronoi polygons associated with each of the 32 meteorological stations in Rio de Janeiro, Brazil.

Results

The incidence of leptospirosis in Rio de Janeiro ranged from 1.06 to 2.05 cases per 100 000 population between 1997 and 2002 (Table 1). The highest incidence was observed in 1997 and 1998 and then decreased by 50% to the end of the period. Cases were distributed throughout the populated areas of the city but were concentrated in the poorer northern region of lowlands and spared the wealthier southeastern sectors of the city (Figure 1).

Scan statistic analysis identified six space–time clusters, with one cluster occurring in each of the six surveillance years (Table 2). Significant clusters of 13 and 19 cases were detected in 1997 and 1998, respectively. Attack rates associated with the 1997 and 1998 clusters were 5.10 and 5.62 per 10 000 person-years, respectively. The four clusters identified between 1999 and 2002, albeit not significant due to the small number of associated cases (2–5), were responsible for high attack rates (144.80 and 1.52 per 100 000 person-years) in the cluster population. The six clusters had time spans between 14 and 25 days. Among clusters, four out of six occurred during the summer season associated with heavy rainfall and flooding. The large 1997 and 1998 clusters occurred in the same regions, but the 1998 cluster encompassed a geographical area twice the size of that for the 1997 cluster (Figure 3). The four clusters identified between 1999 and 2001 were small, both in area and case counts. The 2002 cluster was localized over a swamp region occupied by *favelas*, as defined by the Brazilian census bureau (FIBGE 2001) (Figures 1 and 3). More than 20% of the population in the six cluster areas lived in *favelas*, whereas 4% of the population in non-cluster areas of the city resided in such conditions.

The temporal association with the summer season suggested the influence of rainfall on leptospirosis case clustering. A large variability was observed with respect to the spatial and temporal distribution of rainfall. The coefficient of variation was more than 200% in each of the surveillance years (Table 1), indicating significant variation in daily rainfall throughout the year. Furthermore rainfall, as measured by the 32 meteorological stations, was significantly heterogeneous across the city (P-value < 0.001, Bartlett's test).

Table 1 Leptospirosis cases and rainfall in Rio de Janeiro, Brazil from 1997 to 2002

Year	1997	1998	1999	2000	2001	2002
Total cases	114	111	64	65	71	63
Incidence*	2.05	1.99	1.14	1.16	1.20	1.06
Total rainfall (mm)	28 202	50 698	31 010	33 105	33 134	32 913
Days with <4 mm of rain	180	191	177	148	142	151
Variation coefficient for annual rainfall (%)†	211	259	218	260	286	251

*Cases per 100 000 population.
†Variation coefficient is estimate by SD/mean ratio.

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Multilevel models were used to evaluate the spatial and temporal influence of rainfall and spatial influence of socioeconomic and environmental characteristics on the risk of a leptospirosis case belonging to a cluster *vs*. non-cluster (Table 3). Initial analyses did not identify a significant association between cluster cases and mean values for daily rainfall which occurred during the 3–20 day period preceding onset of the case's illness. However, a threshold of heavy rainfall may be required to precipitate flooding cluster event. Subsequent analyses found that a threshold of mean daily rainfall >4 mm was significantly associated (OR 3.71; 95% CI 1.83–7.51) with leptospirosis cluster events. Higher threshold values for mean daily rainfall (i.e. >5, >6 mm) were significantly associated with leptospirosis cluster events while such associations were not found when threshold values lower than 4 mm were used in the analyses. Significant associations were not observed for demographic, socioeconomic and environmental available covariates such as flooding risk areas and slum settlements, indicating that leptospirosis cases, either cluster or non-cluster, have a similar environmental and socioeconomic risk profile (Table 3). The best fit model included a single covariate, mean daily rainfall >4 mm, along with random effects. The high VPC (51%) indicates that incorporation of random effects in the model adequately accounted for the variability associated with the spatial level of Voronoi polygons.

Discussion

This study addressed two questions: the identification of space–time clusters of leptospirosis cases and the effects of the climactic, socioeconomic and environmental variables on outbreaks. The ability to distinguish outbreaks from background endemic events is critical for mounting rapid and focused public health responses. Health education campaigns may be used in a targeted manner to identify cases early in the illness and therefore reduce the high case fatality (5–40%) associated with leptospirosis (Edwards & Domm 1960; Farr 1995; Faine 1999; Levett 2001; Bharti *et al.* 2003; McBride *et al.* 2005). Furthermore, an understanding of environmental risk factors for cluster events provides the basis to identify and implement interventions aimed at preventing future outbreaks.

We identified six distinct cluster events of leptospirosis during a 6-year surveillance period in Rio de Janeiro. Cluster events occurred in regions that comprised *favela* communities during a 14- to 25-day period and were associated with high attack rates (1.52–287.92 per 100 000 person-years). Most of the cluster events occurred during the summer, which is the season of heavy rainfall and flooding in the city. Detection of disease clusters has

Table 2 Characteristics of leptospirosis case clusters identified between 1997 and 2002

Cluster	1	2	3	4	5	6
Time span (days)	21	24	15	14	18	25
Time frame	04/01/97–28/01/97	07/01/98–30/01/98	04/03/99–20/03/99	23/09/00–06/10/00	28/04/01–25/05/01	03/01/02–27/01/02
Cluster area (km^2)	24.96	50.26	0.20	0.05	0.14	17.69
No. of cases	13	19	2	2	2	5
Population in cluster area	402 325	566 208	3361	1811	5906	478 952
Cluster attack rate (cases per 10 000 person-years)	5.10	5.62	144.80	287.92	68.67	1.52
Relative risk*	24.50	29.45	867.05	1393.24	446.42	12.68
P-value	0.001	0.001	0.291	0.161	0.590	0.973

*Relative risk was calculated as observed/expected ratio.

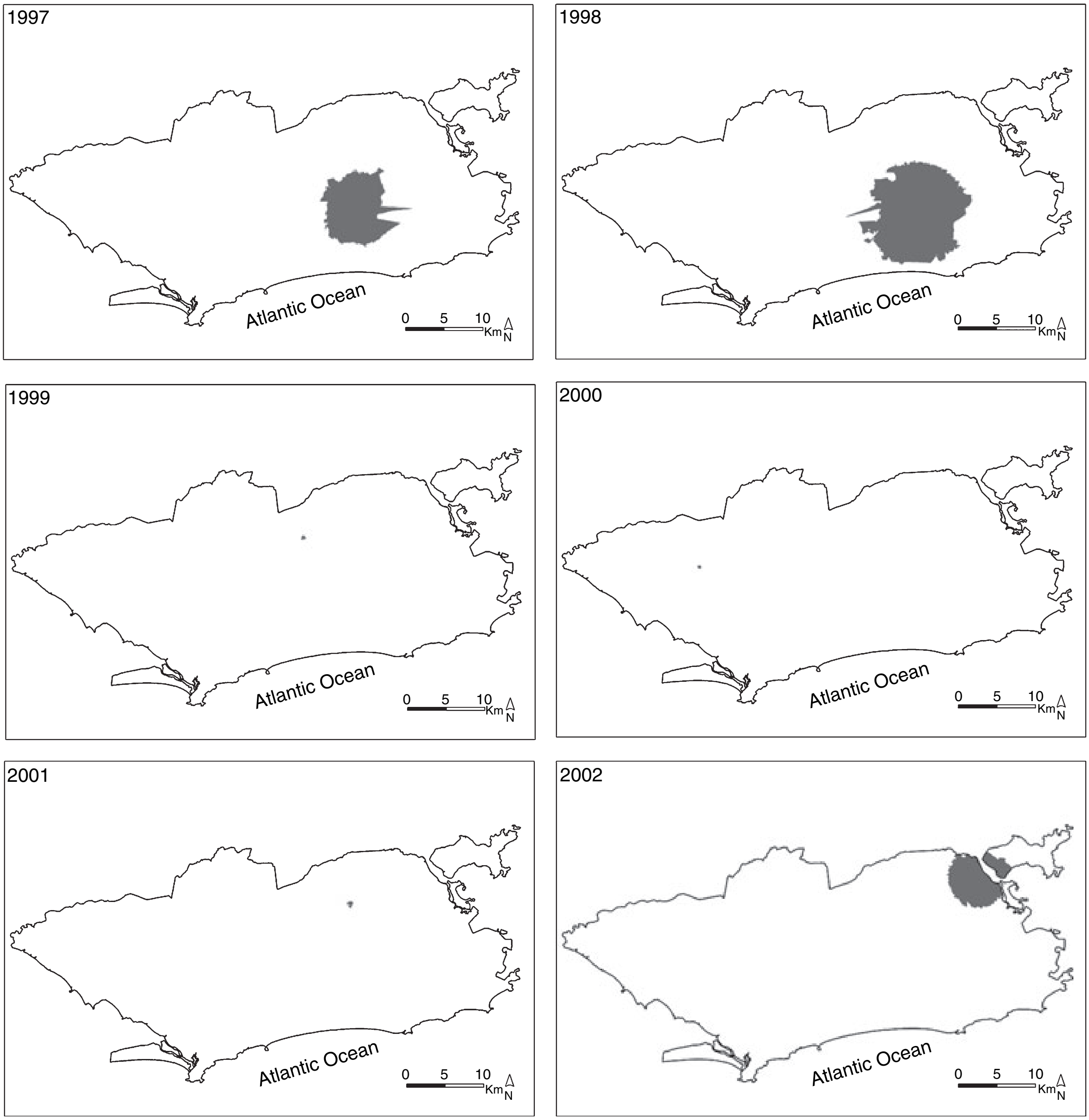

Figure 3 Distribution of six leptospirosis case clusters in Rio de Janeiro from 1997 to 2002, which were identified in spatial scan statistics. The spatial distribution of cluster events is shown according to the census tract in which cluster cases resided. Cluster events in 1999, 2000 and 2001 involved few census tracts while cluster events in 1997, 1998 and 2002 involved more widespread areas of the city. All cluster events occurred in census tracts that were situated in the city's periphery.

been a focus within the field of spatial epidemiology (Elliott *et al.* 2000). An advantage of the scan statistic approach used in this study (Kulldorf & Nagarwalla 1995), in comparison with other methods for identifying space–time clusters (Mantel 1967), is that the scan statistic approach takes into account the differences in the population at risk, while correcting for problems associated with multiple comparisons, and therefore avoids potential selection bias. Furthermore, the scan statistic allows an estimation of the relative risk attributed with the cluster

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Table 3 Generalized linear mixed model estimates of risk factors for leptospirosis cluster cases

	Full model		Final model	
Variables	OR	95% CI	OR	95% CI
Individual level				
Age group				
<14 years (ref.)	1.00		–	–
15–24 years	0.84	0.05–15.12	–	–
25–34 years	0.85	0.05–14.61	–	–
35–44 years	0.83	0.05–13.69	–	–
>44 years	0.61	0.04–9.96	–	–
Sex				
Male	0.64	0.23–1.80	–	–
Female	1.00		–	–
Level of Voronoi polygon				
Mean daily rainfall >4 mm*	4.67	1.87–11.70	3.71	1.83–7.51
Level of census sector				
>3 inhabitants per household	4.48	0.88–22.84	–	–
>53% family heads with >8 years of schooling	0.57	0.22–1.49	–	–
Slum region (*favela*)	0.64	0.13–3.07	–	–
Residing <1 km from a flood region	1.77	0.48–6.46	–	–
Random effects variance	2.83		4.01	
Akaike's information criterion	209	–	224	–

OR, odds ratio; CI, confidence interval.
*Mean daily rainfall was calculated for the 2- to 30-day period prior on onset of symptoms for the case.

event, and therefore serves as a powerful epidemiological tool.

The spatial scan statistic approach identified clustering of leptospirosis cases despite limitations inherent with passive surveillance information. At present the performance of passive surveillance systems has not been evaluated in Rio de Janeiro or other cities in Brazil, where epidemics of leptospirosis occur. Cases reported to health authorities significantly underestimate the disease burden, since case ascertainment relies on identification of classic severe manifestations (Ko *et al.* 1999; Sarkar *et al.* 2002; McBride *et al.* 2005). A minority (5–15%) of symptomatic infections develop such manifestations (Farr 1995; Faine 1999). Furthermore, case confirmation is achieved in a small proportion of suspected cases because of the low sensitivity of current serologic methods (Levett 2001; McBride *et al.* 2005). It is likely that additional cases were associated with these clusters which were not identified by passive surveillance. In total, 43 (8.8%) of the 488 leptospirosis cases identified during surveillance occurred during a cluster event. Additional clusters may have occurred during the study period but were not detected because they were associated with small numbers of reported cases.

A major challenge in using the scan statistic approach is the difficulty in geocoding cases with information obtained from passive surveillance. Although the task of localizing case residence according to large areas such as administrative regions or neighbourhoods is relatively easier, it does not provide a sufficient degree of precision, especially when slum settlements are interspersed with wealthier communities in small regions. The use of postal code regions is limited by the lack of information on socioeconomic and environmental attributes for these polygons (Barcellos & Sabroza 2000). Census tracts, as used in this study, are an attractive alternative since they are relatively small (mean area of 0.063 km^2 in Rio de Janeiro) and the national census bureau has standardized databases of population counts and socioeconomic indicators for them. However, 31% of the cases required manual ascertainment of the location of their residence, since many had irregular addresses in slum communities which were not represented in official databases. Progress has been made in Brazil to register addresses in marginalized communities (Santos & Barcellos 2006), which in turn may facilitate application of more precise geocodification procedures in the future.

Space–time clustering of leptospirosis cases was based on the geographical location of case residence. This finding suggests that epidemic transmission occurs in the communities where high-risk populations reside. Identification of the place of exposure is critical to formulating effective control interventions for slum communities. Leptospirosis is traditionally considered a sporadic rural-based disease associated with risk occupations. Ecological and case–control studies found that household determinants such as poor sanitation infrastructure, exposure to environmental sources of contamination and high rodent populations, were risk factors for acquiring leptospirosis (Ko *et al.* 1999; Sarkar *et al.* 2002). In this study, information was not available to ascertain the proportion of cases that worked in the same geographical location of their residence or to evaluate potential clustering based on the location of the workplace. In fact, a case–control investigation found that exposure to environmental sources of contamination in the workplace was also a risk factor for acquiring severe leptospirosis (Sarkar *et al.* 2002). More refined epidemiological investigations will therefore be needed to determine the contribution of household and workplace transmission for urban leptospirosis.

Multilevel modelling identified rainfall to be a significant risk determinant for a leptospirosis case belonging to a cluster *vs*. non-cluster event. We evaluated rainfall that occurred 3–20 days prior to the onset of illness since this period is the generally accepted range for the incubation period (Faine 1999; Levett 2001). The risk of developing a cluster case was three times greater (OR 3.71; 95% CI 1.83–7.51) than the risk of developing a non-cluster case for a given period when mean daily rainfall in the preceding 3–20 days was >4 mm. The association was not observed with lower cut-off values, thus indicating that a threshold level of rainfall is required to precipitate outbreaks in this urban setting.

Rainfall is a well-recognized risk factor for leptospirosis outbreaks (Faine 1999; Levett 2001; Hunter 2003), especially in disaster situations (Watson *et al.* 2007). It also influences epidemics in urban settings (Ko *et al.* 1999; Barcellos & Sabroza 2000; Kupek *et al.* 2001; Bharadwaj *et al.* 2002). Heavy rainfall may influence the risk for acquiring leptospirosis in different ways. It may affect the normal demographic cycle of rodent reservoirs by altering the reproductive periods and peak population densities (Mills & Childs 1998). In addition, flooding may increase transmission to humans by either driving reservoirs into human dwellings or by facilitating the dissemination of pathogenic *Leptospira* excreted from rodent urine (Roberts *et al.* 2001). In Rio de Janeiro, rainfall above 4 mm measured in any meteorological station should be used as a threshold for alerting health professionals working in public hospitals, especially in the influence area of the station. Rainfall threshold values associated with outbreaks need to be determined in urban settings where leptospirosis is an endemic disease and has the potential to cause outbreaks.

Generalized linear mixed models were used to evaluate risk determinants for leptospirosis cluster events to incorporate demographic, socioeconomic, environmental and climactic covariates encoded at individual and spatial unit levels. Voronoi polygons are often used in environmental studies to evaluate the effect of spatially distributed rainfall measurements (Okabe *et al.* 2000). Census tracts were used since standardized datasets on socioeconomic indicators for populations residing within tracts were available from the national census bureau and information on these factors was incomplete or not reliably collected from cases during routine surveillance. Our approach did not address the hierarchical structure of the spatial data and therefore may have underestimated standard errors for regression coefficients. We assumed that the random effects for geographical areas were independent. The use of a spatially correlated random effect would have been more appropriate, as geographical proximity usually infers a degree of similarity. However, as we were dealing with two different kinds of geographical units, the model would need to use two different neighbourhood matrixes, and such an algorithm is not integrated in available statistical software packages.

We did not identify significant determinants, other than rainfall, which influence the risk of developing a cluster rather than non-cluster case. This may reflect the finding that leptospirosis cases, irrespective of whether they occur in cluster or non-cluster events, are predominantly urban slum dwellers. In Rio de Janeiro, census tracts have a population of approximately 800 inhabitants and are relatively homogeneous, thus limiting the potential for zoning effects related to use of area data. Our study may have not had sufficient precision or power to detect differences in socioeconomic level or environmental exposures that influence the risk of leptospirosis clustering within this poor population. Furthermore, Rio de Janeiro is a city with a complex topology where widely disparate socioeconomic communities are often geographically juxtaposed. Urban slums (*favelas*) are distributed in a mosaic pattern throughout the city.

In summary, we found that urban outbreaks of leptospirosis occur as rainfall surpasses a specific threshold value. Monitoring of rainfall may thus be used to alert health services and communities of outbreak threats and in turn promote rapid responses aimed at early case identification and prevention of mortality due to severe leptospirosis. This study was performed in one city in Brazil, which has specific characteristics of urban poverty, climate and geography. Our findings need to be confirmed in other urban centres where endemic transmission of leptospirosis occurs. Urban epidemics of leptospirosis are likely to become an increasingly important public health problem due to global climate changes that are predicted for the future (IPCC 2007). Urban leptospirosis is a consequence

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of disorganized urbanization and lack of investment in adequate housing, sewage systems and refuses collection services. The most effective interventions will therefore be those that directly address the underlying conditions of poverty, such as lack of access to proper sanitation, which are responsible for the emergence of this urban health problem (Ko *et al.* 1999; McBride *et al.* 2005).

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