

Using spatial analysis to identify areas vulnerable to infant mortality

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ABSTRACT

Objective. To analyze the spatial distribution of infant mortality and identify clusters with high risk of death in the first year of life.

Methods. The Thiessen (Voronoi) polygon method was used to analyze spatial distribution of the infant mortality rate, calculated by municipality. The triennium 2006–2008 was used as a reference to estimate the average infant mortality rate, and the first analysis of the spatial distribution of the rate was performed to test for first-order spatial stationarity. The spatial pattern was then analyzed using Moran's index and G-statistic ($\alpha = 5\%$).

Results. The surface projections on trends showed that infant mortality is not constant in space. The Moran index (0.34, $P < 0.01$) and G-statistic (0.03, $P < 0.01$) confirmed a spatial autocorrelation between infant mortality and clusters when the Thiessen polygon method was used.

Conclusions. The Voronoi polygons proved accurate for spatial analysis of infant mortality and were predictive of clusters with high risk of death in the first year of life.

Key words

Infant mortality; spatial analysis; geographic information systems; Brazil.

Infant mortality has been declining worldwide (1, 2), but in Brazil this decline has been unevenly distributed (3). In view of these inequalities and the fact that about 70% of the deaths are preventable (4), some studies have pointed to the magnitude of this problem and to the need to reduce infant mortality rates (3).

Deaths occurring in children under one year of age—measured by the infant mortality rate—are nonrandom. This indicator is significantly affected by geo-

graphic space, with wide variations and inequalities among areas (5, 6). In recent years, researchers have focused their investigations on the spatial distribution of infant deaths (7, 8).

Joining health and geographic space data allows for better understanding of infant death distribution in different social groups (9, 10) and for mapping of vulnerable areas and social and health inequalities (11–13). Epidemiologic surveillance data can help support planning and decision making in health (14).

Methods are available that apply the category “geographic space” in health studies (8, 14). However, few studies have used Thiessen (Voronoi) polygons, which are a useful approach for describing areas of influence for health events with significant

accurate results (15, 16). This approach makes it possible to determine comparable minimum areas based on the areas of influence of each municipality (17). While municipal boundaries are legally defined, Voronoi polygons are generated based on natural neighborhoods (17, 18). In this sense, the current study aimed to analyze the spatial distribution of infant mortality, identifying clusters with high risk of death in the first year of life.

MATERIALS AND METHODS

An ecologic study was developed in the 184 municipalities of Pernambuco, a state of northeastern Brazil. Infant mortality rates were calculated by municipality, the units of analysis used in this study.

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To minimize random fluctuations in the number of deaths and births the triennium 2006–2008 was used as a reference to estimate average infant mortality rates. They were calculated by dividing total deaths in children less than one year old during the triennium by total live births during the same period for each municipality.

For the initial exploratory analysis of infant mortality rate, measures of central tendency and dispersion (mean, median, mode, and standard deviation) were calculated, and the Shapiro–Wilk test was performed to check for normal distribution ($\alpha < 5\%$).

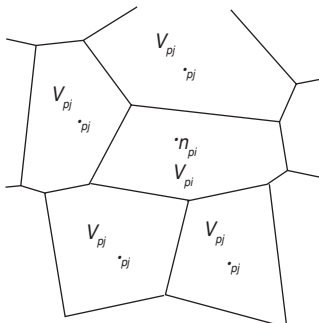
Infant mortality rate was analyzed at two geographic levels: municipal boundaries of 184 municipalities and regions generated by using Voronoi polygons. Given a set of points p_i in a Euclidean plane, the region V_{p_i} for each point that was closer to p_i than any other point p_j determined a space corresponding to a Voronoi polygon (17–19).

In this study, points p_i and p_j were central areas of municipalities with a higher concentration of people, and areas V_{p_i} and V_{p_j} were new municipal divisions generated from the central areas as shown in Figure 1.

The first analysis of the spatial distribution of the infant mortality rate was performed to test for first-order spatial stationarity. A trend surface analysis was carried out, noting that there is a first-order stationary distribution when the average indicator is distributed evenly across the region studied.

The spatial pattern of the infant mortality rate was then analyzed using Moran's index and *G*-statistic and calculated based on first-order spatial contiguity relationships.

FIGURE 1. New municipal divisions generated from areas with higher concentrations of people, Pernambuco, northeastern Brazil, 2006–2008



Global Moran's index (*I*) is given by the following formula

$$I = \frac{n}{\sum_{i=1}^n \sum_{j=1}^n w_{ij}} \times \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} z_i z_j}{\sum_{i=1}^n z_i^2}$$

where z_i is the deviation of the infant mortality rate in municipality i from the mean rate in the state, w_{ij} is the weight of neighboring municipalities i and j , and n is the total number of municipalities.

G-statistic is given by the formula

$$G = \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} x_i x_j}{\sum_{i=1}^n \sum_{j=1}^n x_i x_j}, \forall j \neq i$$

where x_i and x_j are infant mortality rates in the neighboring municipalities i and j , w_{ij} is the weight of neighboring municipalities i and j , and n is the total number of municipalities.

The Moran index and the *G*-statistic are interpreted under the null hypothesis (H_0) that infant mortality rates are distributed randomly. This hypothesis assumes that infant mortality rate is first-order stationary—that is, its average is spatially constant. Acceptance or rejection of H_0 is based on a *P* value and a *z* score associated with Moran's index (*I*) and *G*-statistic. Table 1 summarizes the interpretation of these indicators at $P \leq 0.05$.

Another major factor in the calculation of indicators is the choice of weights w_{ij} . These weights take into account the proximity of municipalities—the closer they are the greater the weight, or the farther apart they are the lower the weight. Closeness can be defined by distance or contiguity; however, both definitions have some drawbacks.

Closeness defined by distance is obtained from centroids of municipalities, but whether the population is concentrated exactly in these centroids is not revealed. Closeness is defined by contiguity when there is a common bound-

ary between municipalities. Considering that populations concentrate mostly in central areas, these areas can be farther apart in two neighboring than in two non-neighboring municipalities, affecting the weighting. Another complicating factor is the fact that municipal boundaries are legally defined and generally form irregular polygons, which may refute the assumption of homogeneity of infant mortality rates in the entire municipality.

To minimize proximity issues between municipalities it was decided to use Thiessen (Voronoi) polygons.

This study was approved by the Research Ethics Committee of Aggeu Magalhães Research Center (protocol number CAAE 0079.0.095.000-10).

RESULTS

During the triennium studied, 7 895 deaths were reported in children under one year old, with an overall infant mortality rate of 18.15‰ of live births and wide variations between municipalities (standard deviation = 6.26, median = 19.41, average = 20.21). The null hypothesis of normal infant mortality rate was accepted (Shapiro–Wilk test = 0.9872, $P = 0.093$).

Figure 2 shows the spatial distribution of infant mortality rates, stratified by the natural breaks method, in 184 municipalities and 184 Voronoi polygons generated from central areas.

Trend surface analysis projections of infant mortality rates in the east and north show that the rates are not spatially constant. The distribution of infant mortality rates is skewed in the municipalities, with declining rates in the north and east. This trend is quite similar using legally defined boundaries and Voronoi polygons, as shown in Figure 3.

When legally defined boundaries were used, the global Moran index was

TABLE 1. Interpretation of *I* and *G* indicators

Results	Moran's index (<i>I</i>)	<i>G</i> -statistic (<i>G</i>)
$P \leq 0.05$ Positive <i>z</i> score	Rejects H_0 . High or low infant mortality rates with clustering into nonrandom patterns.	Rejects H_0 . High infant mortality rates with clustering into nonrandom patterns.
$P \leq 0.05$ Negative <i>z</i> score	Rejects H_0 . High and low infant mortality rates with nonrandom dispersion patterns.	Rejects H_0 . Low infant mortality rates with nonrandom dispersion patterns.
$P > 0.05$	Accepts H_0 . Infant mortality rates have random distribution.	Accepts H_0 . Infant mortality rates have random distribution.

FIGURE 2. Spatial distribution of (a) infant mortality rates (IMR) in 184 municipalities and (b) 184 Voronoi polygons, Pernambuco, northeastern Brazil, 2006–2008

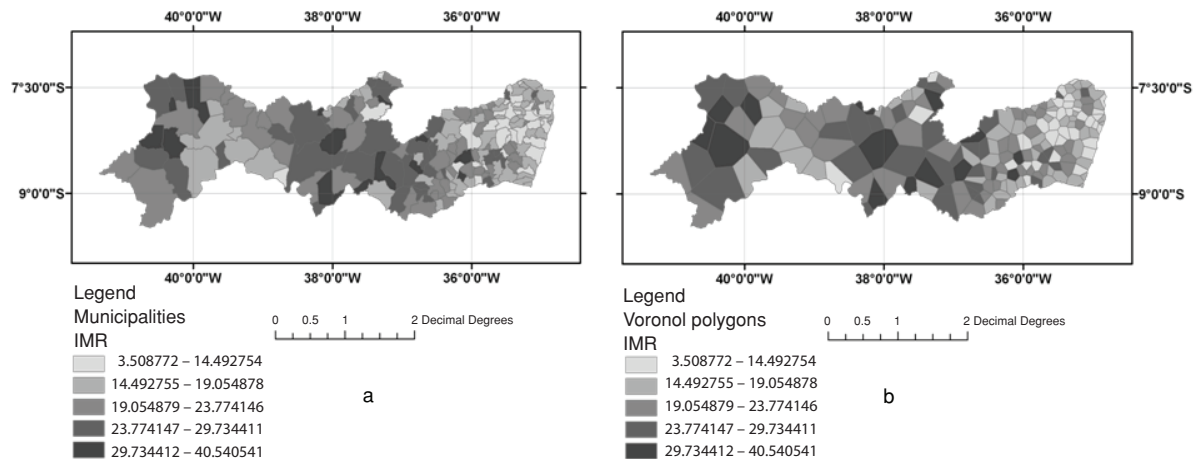
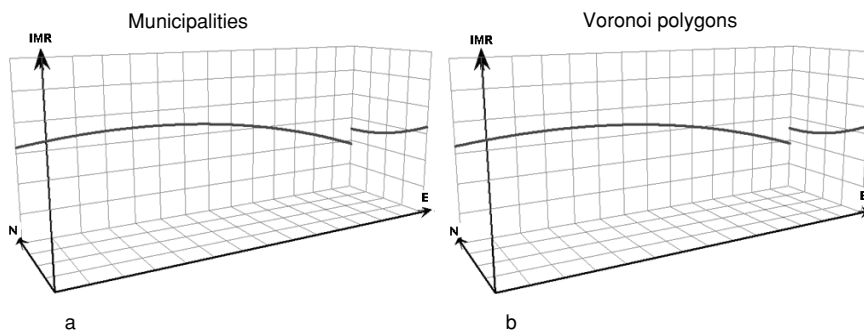


FIGURE 3. Surface trend analysis projections of (a) infant mortality rates (IMR) in municipalities and (b) Voronoi polygons, Pernambuco, northeastern Brazil, 2006–2008



0.29 ($P < 0.01$, z score = 6.41), indicating high or low infant mortality rates with clustering into nonrandom patterns. In contrast, the G -statistic did not confirm a spatial dependence ($P > 0.05$).

When Voronoi polygons were used, the Moran index was 0.33 ($P < 0.01$, z score = 7.28), indicating high or low infant mortality rates with clustering into nonrandom patterns. The G -statistic was 0.03 ($P < 0.01$, z score = 3.15), indicating high infant mortality rates with clustering into nonrandom patterns.

DISCUSSION

Infant mortality showed a spatial pattern that reflects health inequalities. In view of the fact that legally defined boundaries between municipalities are politically determined, the Voronoi polygons proved a useful method for analyzing spatial patterns of infant mortality. This was confirmed by comparing

trend surface analysis, the global Moran index, and the G -statistic before and after the use of Voronoi polygons. The trend surface projections continued to decline in the east–west and north–south after the Voronoi polygons were used, providing evidence that the different rates are markedly associated with social inequalities.

The contrasting results found between the global Moran index and the G -statistic before the use of Voronoi polygons can be explained by the fact that they were calculated using legally defined boundaries. After the use of Voronoi polygons—that is, when first-order spatial contiguity was considered—both I and G results consistently showed spatial dependence of infant mortality.

The Voronoi polygons are a recognized approach for accurately describing areas of influence for health events (15, 16) based on spatial clustering; municipal polygons are generated

based on the areas of influence of each municipality (17). While this approach has been validated, it is rarely used in health research—probably because it is less complicated to use legally defined municipal boundaries than population clustering for determining neighborhoods. Also, few computer programs have been developed to analyze Voronoi polygons.

Other studies have also found nonrandom spatial distribution of infant mortality (7, 8, 20–22). They pointed to the formation of spatial areas of higher risk of death in children less than one year old (11), particularly in localities with high social deprivation (5) and in rural areas (21). Loyola et al. (12) analyzed infant mortality in the Americas and concluded that the risk of death before the age of one is 20 times higher in less developed than in more developed countries.

Moran's index and G -statistic-positive z scores indicated that neighboring spatial units have very similar infant mortality rates. The Moran index showed the formation of spatial clustering with high or low infant mortality rates, while the G -statistic showed clustering with high infant mortality rates.

Given that health events may have a low occurrence from a statistical standpoint, some strategies are applied to prevent random fluctuations or to make adjustments while constructing indicators. Some studies have used aggregation by population size (23) while others have used the magnitude of the denominator (22) or normalized transformations of

data (24). The current study opted for the use of temporal aggregated data, measuring infant mortality rates during the triennium 2006–2008. Other authors have validated this research strategy (5, 11, 12, 25, 26).

Although good quality birth and death data were available in the state of Pernambuco (27, 28), underreporting of deaths in children under the age of one may be a methodologic limitation of this study.

Studies have applied a wide variety of spatial analysis techniques to study health data (7, 8, 29, 30), which have opened up possibilities for investigating the epidemiologic relationship between space and population and identifying population groups at greatest risk of illness and death (31–39).

The analysis of data involving the influence of geographic space requires taking into consideration territorial division, geographic proximity, and base year sample to avoid distortion (17). When these factors are considered, the Voronoi distance is quite reliable to approximate population heterogeneity, even for some unusual population distribution patterns (15). The method of Voronoi polygons has shown good explanatory power on population change for the quality of fit of the model and coefficients of explanatory variables (15–17). It generates statistics consistent with theoretical assumptions, providing evidence of the reliability of results (17), especially in the analysis of complex irregular shapes that cannot be well described by classic Euclidean geometry (16).

Conclusion

The current study evidenced the accuracy of Voronoi polygons in the spatial analysis of infant mortality. Trend curves remained unchanged and non-random spatial distribution of infant mortality was verified. In conclusion, the use of Voronoi polygons was a predictive approach for identifying population clusters that are at high risk of death in the first year of life and it proved very useful for epidemiologic surveillance systems. Its use is recommended in health studies as it can provide more accurate spatial patterns of infant mortality and thus allow public health authorities to more truthfully monitor this indicator.

Conflict of interests. None.

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RESUMEN

Uso del análisis espacial para determinar las zonas vulnerables a la mortalidad en lactantes

Objetivo. Analizar la distribución espacial de la mortalidad en lactantes y determinar los agrupamientos con alto riesgo de muerte en el primer año de vida.

Métodos. Se usó el método de los polígonos de Thiessen (Voronoi) para analizar la distribución espacial de la tasa de mortalidad en lactantes, calculada por municipios. Se adoptó como referencia el trienio del 2006 al 2008 para calcular la tasa promedio de mortalidad en lactantes, y se llevó a cabo el primer análisis de la distribución espacial de la tasa con objeto de someterla a prueba en cuanto a estacionariedad espacial de primer orden. A continuación se analizó el modelo espacial usando el índice de Moran y la estadística G ($\alpha = 5\%$).

Resultados. Las proyecciones de superficie de tendencias indicaron que la mortalidad en lactantes no es constante en el espacio. El índice de Moran (0,34, $P < 0,01$) y la estadística G (0,03, $P < 0,01$) confirmaron una autocorrelación espacial entre la mortalidad en lactantes y los agrupamientos cuando se utilizó el método de los polígonos de Thiessen.

Conclusiones. Los polígonos de Voronoi mostraron precisión en el análisis espacial de la mortalidad en lactantes y fueron predictivos de los agrupamientos con alto riesgo de muerte en el primer año de vida.

Palabras clave

Mortalidad infantil; análisis espacial; sistemas de información geográfica; Brasil.