Spatio-temporal analysis of adverse birth outcomes using space-time cube

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Summary

This study explores spatio-temporal trends in adverse birth outcomes in Black mothers in eastern Massachusetts in 2000-2014. To address variance instability in the data, the adverse birth outcomes rates are adjusted using Bayesian statistics. A space-time cube is created and temporal trends in rates are assessed using Kendall-Mann statistics. The results show statistically significant increases in rates in 19 census tracts and decreases in 47 census tracts. To explore associations with neighborhood-level factors, a racial and ethnic diversity index is employed. Results show that racial and ethnic diversity in tracts with increasing rates is significantly lower than in tracts with decreasing rates.

KEYWORDS: space-time cube; GIS; birth outcomes; Mann-Kendall statistics

1. Introduction

Adverse birth outcomes (ABO), such as preterm delivery and low birth weight, are associated with increased infant mortality and higher risks of delayed motor and social skills, as well as learning disabilities (Fan et al., 2013; Hutchinson et al., 2013). In the Unites States, there are significant racial disparities in birth outcomes: rates of preterm births and low birth weight are two times higher for Black than White infants (Lu et al., 2010). Multiple studies conducted in the southern United States concluded that the degree of racial segregation or isolation is strongly associated with adverse birth outcomes in Blacks (Anthopolos et al., 2011; Mason et al., 2009). This study employs data visualization and spatial analysis to explore ABO rates in Black mothers in eastern Massachusetts (United States) over the period 2000-2014. Specifically, this research addresses the following questions: Are there areas in eastern Massachusetts where ABO rates have been steadily increasing or decreasing over 15 years of study? Are the areas experiencing opposite ABO trends any different from each other in terms of ethnic and racial diversity?

2. Data and Methods

The study area includes Boston, the largest city in New England, and its surrounding towns in eastern Massachusetts, covering 1865 sq.km. Birth data for 2000-2014 were obtained from the Massachusetts Department of Public Health. All data were geocoded by the Department of Public Health to the census block level (the smallest enumeration unit in the U.S. Census). Only singleton live births to Black mothers were selected for the analysis. The data were aggregated to census tracts in order to facilitate the analysis of associations with demographic data. Each birth was assigned to a category of low birth weight (weight < 2500 g) or normal birth weight (weight >= 2500 g), and a full term birth (gestational age > 37 weeks) or preterm birth (gestational age <= 37 weeks). A birth that was either preterm or low

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birth was considered an adverse birth outcome (ABO). The total number of births and the number of ABOs was calculated for each census tract for each year.

Census tract boundaries were obtained from the Office of Geographic Information, Commonwealth of Massachusetts (www.mass.gov/mgis/massgis.htm). There are 613 census tracts in the study area. The tracts that did not have any singleton live births to Black mothers during the 15 years of study were excluded from the analysis, leaving 487 census tracts for the analysis.

The diversity index was obtained from ESRI's 2010 Census data. This index measures racial and ethnic diversity. It "shows the likelihood that two persons, chosen at random from the same area, belong to different race or ethnic groups." (ESRI, 2015). The higher the index, the higher the diversity.

2.1 Calculating ABO rates

Two types of ABO rates were calculated – raw and adjusted. Raw rates were calculated by dividing the number of ABOs in census tract by the total number of births in census tract. This approach produces unreliable rates for areas with small number of births. For example, if there were only two births in an area, and one of them was low weight, then ABO rate is 50%. This is often referred to as a "small numbers problem". One common approach to addressing this problem is to calculate adjusted, smoothed rates using Bayesian statistics. Using this approach, an estimate is obtained by combining the data with "prior" information, such as the overall mean for the entire study area (Anselin et al., 2006). Adjusted ABO rates were calculated using Empirical Bayes smoother algorithm in GeoDa software separately for each year and then spatially joined to census track centroids. These adjusted rates are used in subsequent analyses in this paper.

2.2 Creating space-time cube

Space-time cube of ABO rates was created in ArcGIS software (ESRI, 2017), with a time step of one year and 200m x 200m spatial bins. These spatial dimensions are based on minimal distance between centroids of census tracts and ensure that not more than one census tract centroid falls inside any spatial bin. The vertical dimension of the space-time cube is 15 time periods (2000-2014).

2.3 Analyzing trends in ABO rates

To analyze spatio-temporal patterns, Emerging Hot Spot analysis and Mann-Kendall trend test were used. Emerging Hot Spot analysis compares values in each bin with values in its spatial and temporal neighbors, using Getis-Ord Gi* statistic. The output from this analysis indicates percent of times a location was a statistically significant hot or cold spot. The Mann-Kendall trend test identifies statistically significant temporal trends in ABO rates for each location, regardless of its neighbors. This test compares values within each spatial bin over time. "The Mann-Kendall statistic is a rank correlation analysis for the bin count or value and their time sequence." (ESRI, 2017) The output from the Mann-Kendall test is a spatial layer showing each spatial bin belonging to one of the seven categories: Up trend – 99% confidence; Up trend – 95% confidence; Up trend –90% confidence; Down trend – 99% confidence; Down trend – 95% confidence; Down trend –90% confidence; No significant trend.

2.4 Analyzing ethnic and racial diversity

Areas of significant up and down trends are mapped, and their ethnic and racial diversity index is compared using statistical T-test. This test shows if the mean values for the two groups are significantly different.

3. Results and Discussion

On average, 4174 babies were born to Black mothers each year in the study area between 2000 and 2014. Of those, an average of 533 per year were classified as an adverse birth outcome. The average

annual adjusted ABO rates range from 9.4% to 12%. The minimum rate is 0%, and maximum rate is 75%. ABO rates space-time cube can be displayed in 3D using ArcGlobe (Figure 1).

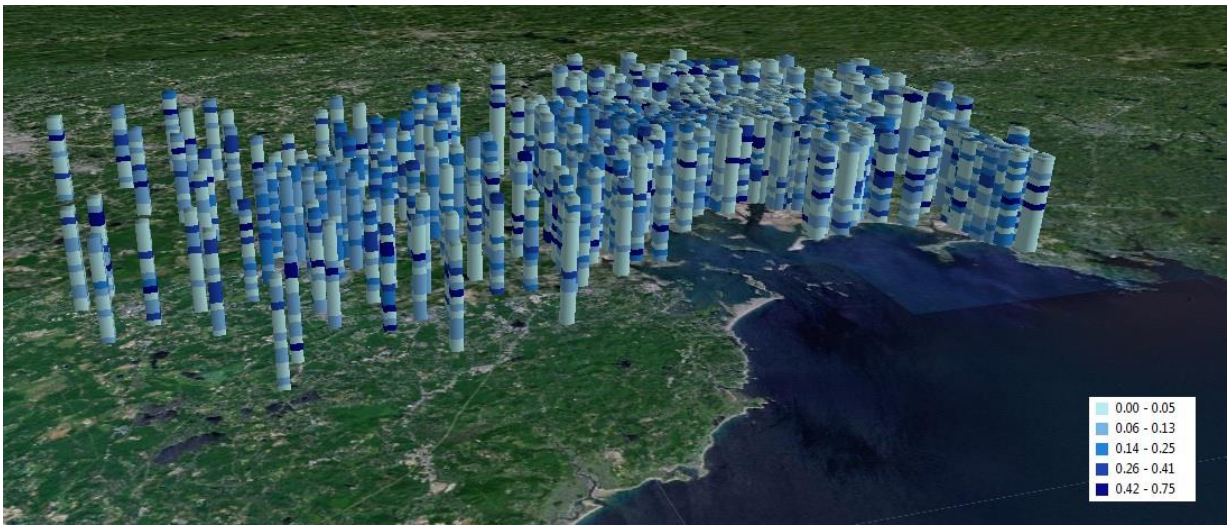

Figure 1 Space-time cube showing Empirical Bayes smoothed annual rates of adverse birth outcomes in Eastern Massachusetts, 2000-2014. Visualization done in ArcGlobe (ESRI®).

Each stack in the visualization represents a discrete spatial bin corresponding to the centroid of each census tract. The bottom part of each stack corresponds to the beginning of the study period (2000) and the top corresponds to the most recent year in the study (2014). Trends in ABO rates are easily observed in 3D visualization, with light colors displaying low ABO rates and dark colors displaying high ABO rates.

The Emerging Hot Spot Analysis identified an area in Boston where census tracts were in a statistically significant hot spot for 60% of the time, or 9 out of 15 years (Figure 2).

The Mann-Kendall test shows statistically significant Up trends in 19 census tracts (increase in ABO rates over time, with 90-99% confidence) and Down trends (decrease in ABO rates over time, with 90-99% confidence) in 47 census tracts. These tracts are distributed randomly throughout the study area and do not form apparent spatial clusters (Figure 3).

The average racial and ethnic diversity index for the entire study area is 50.54. For the census tracts with Up trends, the average diversity index value is 37.52, and for the tracts with Down trends, it is considerably higher (52.17). T-test confirms that the difference between mean diversity index values for the two groups is significant (p-value = 0.013). These results confirm findings from previous research about the relationship between racial segregation and adverse birth outcomes.

Using space-time cube analyses is helpful in studying health outcomes in two ways. First, its 3D visualization in GIS software enables researches to interact with the data – zoom, pan, rotate the cube, look at bins from any vantage point and at any scale - to observe and draw conclusions about spatial and temporal patterns. The ability to overlay the cube on top of satellite imagery provided with the software gives even greater context for the data. Second, Emerging Hot Spot Analysis and Mann-Kendall test allow applying data mining techniques to large volume of data and extracting meaningful information from it. Areas that were persistent spatio-temporal hot spots and areas that showed statistically significant Up and Down trends deserve further exploration and analysis. The GIS analysis and data visualization play an important role in helping public health professionals focus on areas with alarming trends thus leading to more focused interventions.

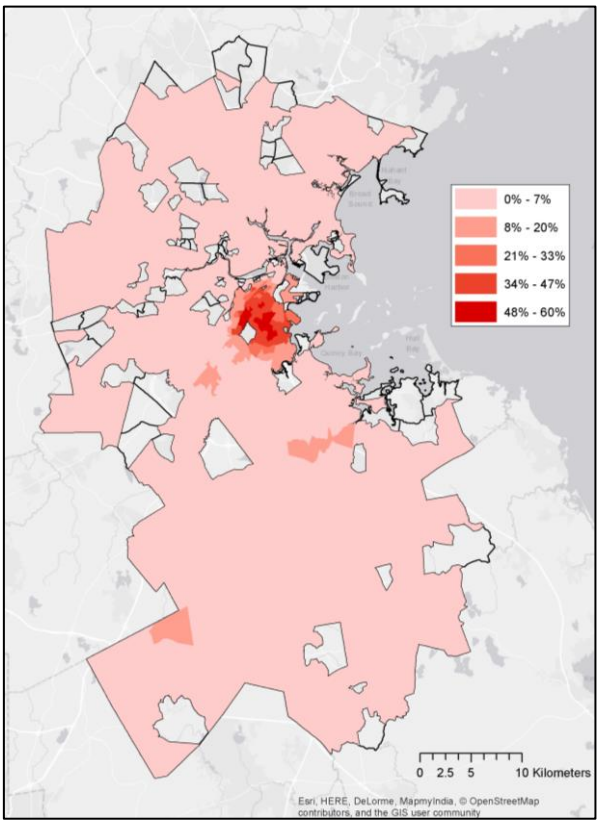

Figure 2. Results of the Emerging Hot Spot Analysis:
Percent of times a census tract was in a statistically significant hot spot

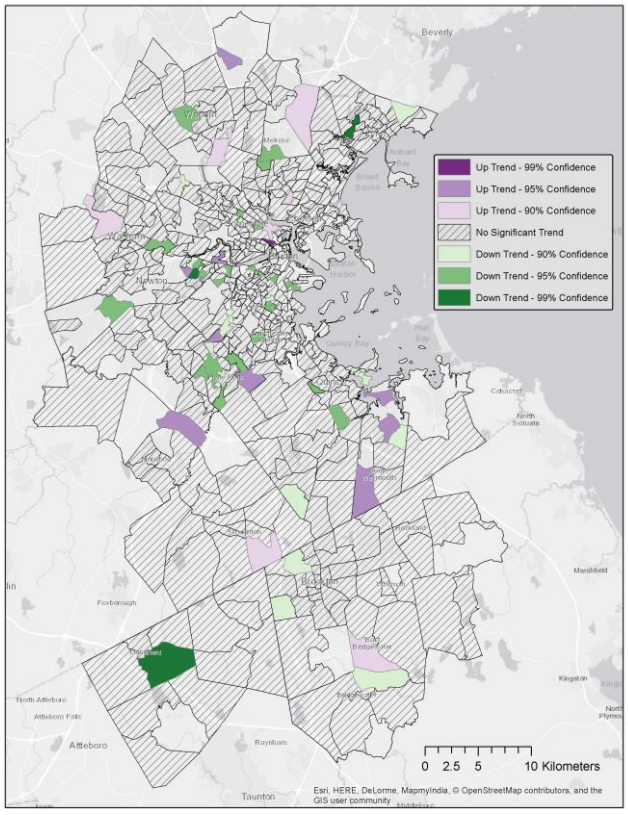

Figure 3. Results of Mann-Kendall test for each census tract

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Biography

Yelena Ogneva-Himmelberger is Associate Professor of Geographic Information Science in the Department of International Development, Community, and Environment at Clark University. Her research focuses on GIS applications for international development, food security, and public health. Her areas of expertise include spatial cluster analysis, network analysis, geocoding, and raster data analysis.

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