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ANALYZING TRENDS AND PATTERNS IN ADVERSE BIRTH OUTCOMES IN MASSACHUSETTS FROM 2000-2014

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Abstract

Analyzing Trends and Patterns in Adverse Birth Outcomes in Massachusetts from 2000-2014

Madeleine Haynes

This study explores spatio-temporal trends and patterns in adverse birth outcomes (ABO) in the state of Massachusetts from 2000-2014. ABO include low birth weight (< 2500 g) and preterm deliveries (gestational age < 37 weeks). This research evaluates if there are areas in Massachusetts that have experienced statistically significant increases or decreases in ABO throughout the study period. Birth data was obtained from the Massachusetts Department of Public Health and only singleton, live births were included for the analysis. The data were aggregated to census tracts, and the total number of births and the number of ABOs were calculated for each census tract for each year. In total, 1478 census tracts were included in this analysis. Births to non-Hispanic black mothers and births to non-Hispanic white mothers were separated to evaluate if trends in ABO are similar regardless of race as previous literature has identified a much higher rate of ABO in births to non-Hispanic black women. Trends and patterns of ABO were evaluated using the Space Time Cube and the Mann-Kendall statistic and a multivariate regression was conducted to identify potential correlations between socioeconomic factors and prevalence of ABO. Results of this study can be used to identify areas that are experiencing an increase in ABO to potentially allow for more effective, targeted intervention methods.

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1 Introduction

Adverse birth outcomes (ABO), which include both low birth weight (<=2,500 g) and preterm deliveries (< 37 gestational weeks) are unfortunately a common health outcome despite the many medical advances made within the past century. In fact, the rate of preterm delivery (PTD) was 20% higher in 2011 compared to 1981 (South et. al, 2011). As such, the inexplicable rise in rates of ABO has become a public health concern (Beck et al., 2010). Potential hypotheses to explain the increase in prevalence of ABO include the general cultural shift towards older age of women who are conceiving, increased rates of multiple births, elevated prevalence of early Cesarean sections and labor inductions, changes in neonatal technology, and use of assisted conception methods (Institute of Medicine, 2007; Beck et. al, 2010; March of Dimes, 2018A; American College of Obstetricians and Gynecologists, 2016). Additionally, individual women may be more likely to have an ABO dependent on their health status. Women who have chronic health problems, use tobacco, drugs, or alcohol while pregnant, experience placental problems, women who have experienced previous ABO deliveries, as well as women of lower income and educational attainment are more likely to have an ABO (American College of Obstetricians and Gynecologists, 2000; Berghella, 2007; Honein et al., 2009; U.S. Department of Health and Human Services, 2004; Goldenberg & Culhane, 2007). However, the influence of individual circumstances make it challenging to understand general trends in ABO due to lack of consistent collection of behavioral characteristics during pregnancy and exposure to circumstances that may not be measured by medical professionals (such as living condition, stress, etc.)

According to the CDC, 1 in every 10 babies are delivered prematurely in the U.S. (Reproductive Health, 2018) or, in other words, approximately 500,000 babies are delivered prematurely each year (Warren et al., 2012). It is estimated that the annual cost of care in the United States for babies that are delivered prematurely is $26.2 billion (Warren et al., 2012). Additionally, the current national rate of low birthweight (LBW) deliveries of 8.17% is above the intended rate set by the Healthy People 2020 initiative, which targeted a rate of 7.8% (National Center for Health Statistics, 2017; Tian, Tu, Tedders, 2013).

The health risks of an ABO are quite severe. The risk of infant mortality is 25 times higher for an infant born LBW and the risk of infant mortality for a baby born preterm is nearly 3 times higher compared to a baby born at a normal weight or normal term (Mathews & MacDorman, 2008). Additionally, other adverse health outcomes of a LBW delivery include increased likelihood of experiencing respiratory distress, brain hemorrhage, heart complications, and intestinal abnormalities (Tian, Tu, Tedders, 2013; Insaf & Talbot, 2016; March of Dimes, 2018B; Reproductive and Birth Outcomes, 2016). Similarly, PTD is the number one predictor of infant mortality contributing to approximately 35% of infant mortalities in the U.S. (Warren et al., 2012) and PTDs have been linked to numerous health problems and permanent disabilities (Tu, Tian, Tedders, 2013; Rosenthal & Lobel, 2011; Beck et al, 2010). Specific long-term health effects of a PTD include cerebral palsy, respiratory illness, as well as motor, cognitive, visual, hearing, behavioral, social-emotional, and growth problems (Clark et al., 2009; Beck et al, 2010; March of Dimes, 2013; American College of Obstetricians and Gynecologists, 2016).

In 2016, the rate of PTD in the U.S. was 9.85%, which rose for the second consecutive year (up from 9.57% in 2014). Similarly, for LBW deliveries the rate has also increased since 2014, rising from 8.00% to 8.17% in 2016 (National Center for Health Statistics, 2018). The rate of PTD and LBW is higher in non-Hispanic black women than in non-Hispanic white women; rates of PTD and LBW in non-Hispanic black women are 13.77% and 13.68% while for non-Hispanic white women they are 9.04% and 6.97% respectively (National Center for Health Statistics, 2018). The influence of racial disparities and the increased likelihood of having an ABO in the United States has been well documented with risk for babies born to non-Hispanic Black women being approximately two times higher than for babies born to non-Hispanic White women (CDC, 2010; Lu & Halfon, 2003; Rawlings, Rawlings & Read, 1995; Burris & Hacker, 2017; Kent et al, 2013). Additionally, many studies have investigated the correlation between a mother's socioeconomic status and the likelihood of having an ABO, with women of lower socioeconomic status having a higher likelihood of experiencing an ABO (Tu, Tian & Tedders, 2013; Lu & Halfon, 2003; Collins & Butler, 1997; McGrady et al., 1992; Schoendorf et al., 1992). This further illustrates the inequity in maternal and infant health. However, studies investigating prevalence of ABO disparities among different racial/ethnic groups have found that even when controlling for the mother's socioeconomic status and risk behaviors (i.e. smoking, drinking, etc.), babies born to non-Hispanic Black women remain more likely to be born with an ABO than babies of other races (Mathews & MacDorman, 2008; Goldenberg et al., 1996; Singh & Yu, 1995; Kramer & Hogue, 2008; Kent et al., 2013; Burton et al., 2017).

Previous studies on ABO have used a variety of spatial analysis methods to evaluate spatial distributions and temporal changes of high ABO rates. Several have implemented the Global Moran's I to identify clustering of high PTD or LBW rates. Tu, Tian, and Tedders (2013) evaluated LBW in Georgia. They first evaluated specifically LBW trends for just the year 2000 using the Global Moran's I spatial autocorrelation tool and the Anselin's Local Indicators of Spatial Autocorrelation (LISA) method in GeoDa (Tian, Tu, & Tedders). The Global Moran's I identifies if values of the variable of interests, in this case the rate of LBW, are spatially clustered or dispersed throughout the study area, while the LISA identifies local clusters of both similar and dissimilar values of the variable in the study area. LBW was evaluated throughout Georgia at two geographic scales, county and census tract. The results of the study indicated that the LBW rates were spatially clustered and, by evaluating the births specifically by race, they found that rates of LBW were higher for black women than white women (Tian, Tu, & Tedders, 2013). Another study by Tu and Tian (2013) evaluated temporal patterns in PTD rates from 1995-2010, the data was separated into four time periods (1995-2000, 2000-2005, 2005-2010, and 1995-2010) (Tu & Tian, 2013). A LISA analysis was conducted on all the time periods and patterns of clusters were visually compared to detect changes in patterns and found that again there was spatial clustering of both high PTD rates and separate clusters of low PTD rates and PTD rates were higher for black women than white women. Additionally, it was found that rates of PTD were lower in urban areas compared to rural areas of Georgia.

A similar method of identifying spatial cluster using the Moran's I was utilized by Insaf and Talbot (2016) to study LBW distributions in New York State at a census tract level where a Moran's I was calculated to measure clustering of LBW rates. Insaf and Talbot (2016) found that for New York State there was positive spatial autocorrelation (clustering) of high LBW rates in inner cities (Insaf & Talbot, 2016). Another study also focusing specifically on LBW deliveries in Southern India conducted a Moran's I in conjunction with the Getis-Ord Gi* Hot Spot Analysis to identify significant clusters of high LBW rate areas (Francis et al, 2012). This was done for every year from 2006-2010 and the results were visually compared to identify areas that were new hot spots or were persistent hot spots throughout the study period. There were clusters of both high LBW rates throughout the region as well as several high-low clusters which is unlike the results of studies utilizing similar methodologies on ABO rates.

Another study by MacQuillan et al. (2016) evaluated trends in ABO by mapping rates of both LBW and PTD across neighborhoods in Michigan. Rates were calculated for each year as three-year averages, mapped by neighborhood, and visually compared to identify changes in prevalence and the distribution of ABO throughout the study area (MacQuillan et al., 2016). This method is suitable for identifying clusters at a specific time but do not provide statistical evidence for how the patterns of ABO have changed over time.

Although the aforementioned studies demonstrate potential methods for evaluating temporal trends in birth outcomes, approaches are limited in statistically proving whether an area is experiencing any long-term trends in ABO. However, using the Mann-Kendall statistic within the Space Time Cube of ArcMap allows for comparison of the z-scores over time to identify statistically significant increases, decreases, or consistency in ABO rates over time (Abdrakhmanov et al., 2017; ArcGIS Pro, n.d). The Mann-Kendall statistic is calculated by comparing the z-score of each location; the number of standard deviations from the mean at each time step to the time step prior is calculated. If the rate and corresponding z-score are increasing through time, a positive value is assigned and if the rate and corresponding z-score decrease over time, a negative value is assigned. The space time cube is capable of representing both the spatial and temporal dimensions of data (Gatalsky, Andrienko, & Andrienko, 2014).

Other studies focusing on ABO have evaluated the trends in time but fail to include the spatial component to identify how these trends vary through geographic scales. The most common way of evaluating trends is through the implementation of a Poisson regression (Sagiv et al., 2005; Tian, Tu, & Tedders, 2013). Possion regressions are ideal for working with small frequency count data which is typical for many studies utilizing birth data (Sagiv et al., 2005). Sagiv evaluated counts of PTD and concentrations of air pollutants (PM_{10} and SO_2) through time on a daily basis from 1997-2011 in four Pennsylvania counties and the 6-week mean air pollutant rate prior to the delivery date. It was found that there was an increased risk of having a PTD with elevated exposure to air pollutants (Sagiv et al., 2005). While this method may provide useful statistical evidence of temporal patterns it lacks the spatial component necessary to fully understand what may be contributing to elevated rates of ABO in certain areas.

South et al. (2011) used a multivariate logistic regression to identify predictors of a PTD. The authors included a spatial component by separating the analysis into five geographic areas within Hamilton County, Ohio. In these regressions, the independent variables were gestational age, ethnicity, maternal age at delivery, marital status, education level, inter-pregnancy interval, first-time mother, previous PTD, chronic and pregnancy related hypertension, diabetes, smoking, and pre-pregnancy weight as well as census block level median household income. The regression was repeated for each of the five geographic areas. Results showed that previous PTD, hypertension, low pre-pregnancy weight, diabetes, and elevated maternal age at delivery were associated with the likelihood of a PTD (South et al., 2011).

Francis et al. (2012) conducted spatial multivariate regressions using both an Ordinary Least Squares Regression (OLS) as well as a Geographically Weighted Regression (GWR) to identify variables that were significantly correlated to the observed distribution of LBW in Southern India. Results showed that maternal under-education and anemia were the two most significant predictors of LBW (Francis et al., 2012). Similarly, Kramer and Hogue (2008) evaluated preterm deliveries across U.S. Metropolitan Statistical Areas (MSA) with the rate of very preterm deliveries as the dependent variable and region of the country, size of the MSA, racial segregation indices, and several socioeconomic indicators as the independent variables. It was found that the size of the metropolitan area, the region of the country that the MSA was located, education level, and racial segregation were significantly correlated (Kramer & Hogue, 2008). Insaf and Talbot also conducted four regressions, with the first regression including only individual level maternal risk factors (i.e., smoking, drug use, age), the second regression including area-level measures (i.e., percent of individuals using WIC and percent with less than a high school education), the third model accounted for racial segregation, and the fourth model accounts for all variables form the first three models (2016). Results of the regressions demonstrated that maternal smoking habits during pregnancy and racial composition of the census tract were the two most significant predictors of high LBW rates (Insaf & Talbot, 2016). The aforementioned studies utilizing multivariate regressions demonstrate potential demographic variables that have been found to be correlated to high rates of ABO in various geographic regions.

PTD was evaluated in Missouri at a county level using a multivariate regression including both individual and area-level measures (DeFranco et al, 2008). Women living in counties with the highest poverty rate had an increased likelihood of having a PTD. Carmichael et al. (2014) conducted a study on nationwide PTD prevalence for both white and black mothers using 22 socioeconomic, demographic, environmental, and health variables at the county level as the independent variables. Using these variables, they found R squared values of 0.463 and 0.55 for the two multivariate regressions for black mothers and 0.665 and 0.714 for the multivariate regressions for white mothers (Carmichael et al, 2014).

While these studies demonstrate that trends in ABOs have been analyzed spatially or temporally, none have comprehensively evaluated spatio-temporal trends in birth outcomes at a census tract level for an entire state. Major gaps in the literature on adverse birth outcomes include that most analyses do not consider long-term temporal patterns (greater than 5 years) or spatio-temporal patterns over any timespan. Additionally, no studies have comparatively investigated racial differences in trends associated with the distribution of LBW, PTD, and ABO. Furthermore, most studies focus on the potential correlation between mother level health or socioeconomic variables but few studies have evaluated the potential role that area-level socioeconomic characteristics may have on birth outcomes.

In light of the aforementioned gaps in previous research, the objectives of this analysis were threefold: (1) to identify which areas of Massachusetts (if any) experienced statistically significant increasing trends in ABO; (2) to examine the influence of race in ABO trends between non-Hispanic Black mothers and non-Hispanic White mothers; and (3) to determine the correlations between the socioeconomic conditions and birth outcomes at a census tract level. The state of Massachusetts is a unique location to conduct a study on ABO as the range of socioeconomic and environmental characteristics is vast. The state ranges from densely urban in the metro-Boston area and highly rural on the Western side of the state. Additionally, range in income and education vary greatly throughout the state making it an ideal location to evaluate the role of demographic variables on birth outcomes.

2 Methods

2.1 Data

Birth data was provided by the Massachusetts Department of Public Health (MADPH) for the study period of 2000-2014. The data contained information on all births in the state including multiples and fetal deaths. However, for the purpose of this analysis, only singleton, live births throughout the state were included. Information on the gestational age of the baby at delivery and the birth weight were the two indicators used to determine if the birth was an ABO. The data also contained information on the mother's race, education level, whether she smoked or drank during pregnancy, as well as whether or not she has specified medical conditions. The data was geocoded to a census block level and further aggregated to a census tract level due to the small number of births and ABO deliveries per census block. To meet the objectives of the study, the data was split into subsets of births to non-Hispanic white mothers and births to non-Hispanic black mothers which were evaluated separately. Each birth was coded with the baby's birth date allowing for both spatial and temporal analysis.

Additional socioeconomic information for each census tracts was obtained from the 2006-2010 American Community Survey (5-year estimates) at a census tract level on several socioeconomic factors (United States Census Bureau / American FactFinder, 2010). The selected factors were percent of individuals with a bachelor's degree or higher, percent of individuals with less than a high school diploma (or equivalent), percent of females who are unemployed, percent of individuals in poverty, median household income, per capita income, and median earnings for female workers. Additional variables for a diversity index and population density were retrieved from ESRI and were calculated based on 2010 census data (ESRI 2010 Census). The diversity index is a calculated score (0-100) given to each census tract that is indicative of the likelihood that two people chosen at random from the same area would belong to different racial groups (Esri, 2012). A score of 0 would be indicative of an area where everyone belongs to the same racial group (no diversity) and 100 would be indicative of a population which is evenly divided between two or more races (complete diversity) (Esri, 2012).

The aforementioned variables were included in this analysis as earlier research has indicated that socioeconomic characteristics can influence birth outcomes. Previous studies have used similar variables, particularly education level, household income, and the percent of the population below poverty (Insaf & Talbot, 2016; DeFranco et al, 2008; Kramer & Hogue, 2008; Kent et al., 2013; Carmichael et al, 2014). Other metrics of income were included due to disparities in the coefficient of variation (CVs) of the different variables (See Appendix B for table of CV). Population density has been used in previous studies and Kent et al. (2013) evaluated ABOs in rural and urban areas as it has been found that health outcomes are worse in these areas than suburban areas (Francis et al, 2012; Carmichael et al, 2014). The diversity index was included due to the well documented racial disparity in birth outcomes. While this variable does not directly measure white to black segregation, it is included to potentially capture racial influences (Kramer & Hogue, 2008). Maps of the included independent variables are in Figures 1-9 and their descriptive statistics can be found in Table 1.

2.2 Preprocessing

Data cleaning

Birth data was provided in excel format from the MADPH for all years. The MADPH had associated a county, census tract, and census block ID with each birth when possible, though not all births had the necessary geographic information. These fields were then concatenated to form a complete census block GEOID. Births that were missing geographic location information were excluded. Table 2 provides the number of births provided by the MADPH for each year and the number that were successfully joined to census tracts. Once joined, only singleton, live births for each year were included in the analysis. Tables 3 and 4 show the number of birth included in the analysis for each birth outcome for non-Hispanic white and non-Hispanic black mothers respectively.

Calculating rates

The raw number of PTD, LBW, and ABO births for each census tract for each year were calculated by selecting deliveries with a gestational age of less than 37 weeks, with a weight of less than 2,500 grams, or exhibiting one or both conditions respectively. The rate for PTD, LBW, and ABO were then calculated using the Empirical Bayes rates in GeoDa (Anselin et al., 2006). This is a smoothing technique that handles outliers by taking the weighted average of the crude rate and the prior estimate which is a standard, typically the regional rate or, in this case the statewide rate (Anselin et al., 2006; Auchincloss, 2012; Marshall, 1991). This method is beneficial as it produces estimations that are arguably more reliable and robust for small sample sizes in small areas (such as this study area) by using the information from the neighboring tracts (Kang et al., 2016); Tian, Tu, & Tedders, 2013). The rate for PTD, LBW, and ABO were calculated for each census tracts for each year during the study period (2000-2014) for non-Hispanic white women and for non-Hispanic black women (see Figures 10-15).

2.3 Space Time Cube

A space time cube was constructed in ArcMap to evaluate trends in rates of PTD, LBW, and ABO in each census tract for the 15 year study period. The space time cube is a 3-dimensional view of spatiotemporal data where the horizontal component of the cube represents the true physical location of data (in this case each census tract for the state of Massachusetts) and the vertical dimension represents the time at which the data point was collected (in this case each vertical step in the cube represents 1 year of birth data). Refer to Appendix A for a visualization of the space time cube.

A Mann-Kendall trend score was calculated for each location in the space-time cube, each census tract. The statistic is calculated by comparing the rate at each time step to the time step prior. By analyzing how the rates increase or decrease over time, a categorical value is associated to each tract providing the overall time-series trend pattern. The categorical assignment indicates whether the trend is increasing, decreasing, or if no trend was present and the associated confidence level assigned with that pattern (ArcGIS Pro, n.d).

2.4 OLS

An Ordinary Least Squares multivariate regression analysis was conducted for each of the three categories of birth outcomes (PTD, LBW, and ABO) for both racial groups (non-Hispanic white mothers and non-Hispanic black mothers). The average rate of each birth outcome for all 15 years was used as the dependent variable for each regression and the selected independent variables included were percent of individuals with a bachelor's degree or higher, percent of individuals with less than a high school diploma, percent of females who are unemployed, percent of individuals in poverty, median household income, per capita income, median earnings for female workers, population density and the diversity index score.

2.5 GWR

To evaluate the role of geographic non-stationarity on the relationship between the selected independent variables and the dependent variables, a Geographically Weighted Regression (GWR) was conducted for each birth outcome for both races. The GWR was developed to account for the role of spatial nonstationarity, or where the 'global' model does not fully capture the relationship between the dependent and independent variable throughout the study area (Brudson et al., 1996). The GWR is a modified application of the standard linear regression, but rather than having constant variable coefficients (such as in the OLS), the coefficients are derived based on the best fit for the local model so they consider spatial variation (Fotheringham et al., 1996). As such, an individual regression is conducted for each areal unit in the study (i.e., census tract) considering values only of local neighbors (the optimal number of neighbors is derived by the software) rather than the entire 'global' study area. The result is a local regression equation for each census tract modelling the specific relationship between the tract's dependent variable value and the independent variable values of the tract and its neighbors. This method is useful as it provides insight into how relationships between variables differ throughout the study area.

The ABO, PTD, and LBW rate for each racial group were again used as the dependent variable and the independent variables used in each regression were those found to be statistically significant in the corresponding OLS regression. Variables that were not statistically significant in the OLS were excluded from the GWR analysis. For each regression the kernel type was chosen to be adaptive, meaning the regression was based off of the optimal number of neighbors rather than a fixed distance band. The bandwidth method was chosen to be AICc meaning the number of neighbors that is used in the regression was the optimal number for the best fit and highest R squared. T-statistics were calculated for each coefficient of every independent variable in all six regressions to determine how many tracts had statistically significant regression coefficients at a 95% confidence level.

3 Results

3.1 ABO Rates

ABO rates in non-Hispanic white mothers across the state are consistently moderate with most tracts having a rate below 0.09. The highest rates of ABO are on the Western side of the state and in the Boston area as can be seen in Figure 10. Alternatively, for ABO rates in black mothers, tracts either have a very low ABO rate (less than 0.05) or very high (0.11-0.32). Tracts with the highest ABO rate are in the Brockton and southern Boston areas as well as Springfield and the Cape (Figure 11).

LBW rates follow a similar pattern for both races. For LBW in white mothers, the majority of census tracts have a value below 0.08 with very few tracts in central Boston falling in the upper bracket (Figure 12). For LBW rates in black mothers many tracts fall in the upper bracket between 0.08-0.22 with the highest LBW rates being in Springfield, Cape Cod, and Brockton/South Boston as seen in Figure 13.

For PTD rate in white mothers, again most tracts have a rate of less than 0.07 however the tracts with the highest rate are distinctly located in Western Massachusetts and small portions of Boston (Figure 14). The highest rate of PTD for black mothers are still located in Springfield, Worcester, Cape Cod, and Boston/ Brockton (Figure 15).

Figures 16-18 show that the rate of each birth outcome between the two races follow a relatively consistent pattern regardless of race from 2000-2014.

3.2 Space Time Cube

Trends in ABO deliveries between the two racial groups exhibit very different spatial patterns (Figures 19-24).Counts of tracts exhibiting trend patterns is shown in Table 5. For non-Hispanic White women there were 120 tracts with an increasing trend and 57 with a decreasing trend, while for non-Hispanic Black women there were 107 with an increasing trend and 85 with a decreasing trend. Overall location of trend patterns varies as well. ABO rate in non-Hispanic white women increased primarily around Lowell, Newburyport, Gloucester, Templeton, Scituate, Sheffield, east of Worcester and scattered areas throughout the southeast corner and north of Boston (Woburn) as shown in Figure 19. Decreasing trends were observed primarily in the Berlin area, and mixed patterns (tracts with an increasing trend adjacent to tracts with a decreasing trend) around Sturbridge where there were areas of increasing and decreasing trends directly adjacent to each other. Non-Hispanic Black trends in ABO were different than trends in ABO for non-Hispanic white women (Figure 20), with most noticeably the Berlin area (which had a decreasing trend for white ABO deliveries) exhibiting an increasing trend. Additionally, Ipswich, Pittsfield, Hardwick, Westwood, and areas north of Springfield (Granby) exhibited increasing trends. Several areas in Boston/Medford and Newburyport had a mixed increasing and decreasing trend.

For trends in PTD in non-Hispanic white women, the Berlin area had the most prominent decreasing trend while areas around Lowell, Newburyport, the southwest corner (Sheffield/Stockbridge), Scituate, Williamstown, and north of Cambridge/Medford had an increasing trend (Figure 21). In total for non-Hispanic white PTD trends, there were 137 tracts with an increasing trend and 60 with a decreasing trend. Figure 22 shows that for non-Hispanic black PTD trends, again the Berlin area was increasing whereas for white mothers the pattern was a decreasing trend. Other areas that had an increasing trend included Ipswich, Pittsfield, New Braintree, Dedham, and north of Springfield (Granby/South Hadley). Leominster and Medford had mixed trends with both increasing and decreasing tracts adjacent to each other. Taunton and areas in Springfield exhibited a decreasing trend. There were 101 tracts with an increasing trend and 107 with a decreasing trend for non-Hispanic black mothers.

LBW trends for non-Hispanic white women, Figure 23, showed that the southwest corner (Sheffield/South Hadley), Taunton, Lowell, Medford, and Mendon had an increasing trend. Ipswich had an isolated decreasing trend, and LBW trends decreased in the Petersham and Ware area, but it was surrounded by increasing trends in Gardner and Granby/Amherst. Sturbridge and Southwick had mixed trends. The Berlin area which had exhibited a trend in Figures 19, 20, 22, 23, and 24 maps had no trend for white LBW deliveries (Figure 21). For non-Hispanic black mothers, the Berlin area, Ipswich, Pittsfield, Hardwick, Granby, and Dedham had an increasing trend as can be seen in

Figure 24. There were several areas of mixed trend, primarily Leominster, Newburyport, and Medford. For trends in LBW deliveries to black mothers, there were 97 tracts with an increasing trend and 80 with a decreasing trend while for LBW deliveries in white mothers there were 127 tracts with an increasing trend and 45 with a decreasing trend.

There were 9 census tracts that had a trend in at least 5 of the possible categories. 8 of these had consistent trends within the tract (increasing OR decreasing regardless of race and birth outcome) but there was 1 tract that was increasing in all birth outcomes for non-Hispanic white mothers and decreasing in ABO and PTD in non-Hispanic black mothers. This tract was located in central Worcester.

There were 19 tracts with a trend in at least four of the possible categories, 13 of which had inconsistent trends between the two races. All trends between the individual races were the same (either increasing OR decreasing but not both) but trends between races did not match. For example, several tracts around Ipswich had increasing trends in birth outcomes for non-Hispanic black women but decreasing trends in non-Hispanic white women.

One area was of particular interest; there was a cluster of approximately 7 towns around Berlin (Bolton, Berlin, Boylston, Clinton, Northborough, Hudson [2/4 tracts], Marlborough [2/5 tracts]) that had an increasing trend pattern in all birth outcomes for non-Hispanic black women and those same towns had a decreasing trend for PTD and ABO in non-Hispanic white women.

There were areas that had consistent increasing trends across all birth outcomes for non-Hispanic black women including Granby/Amherst (4/7 tracts)/South Hadley (4/4tracts), Hardwick/New Braintree/West Brookfiled/Palmer (2/3 tracts), Ipswich/Rowley, Pittsfield (5/11 tracts)/Dalton, and Dedham (3/6 tracts)/Westwood/Norwood (2/6 tracts). Locations of decreasing trends was more variable between birth outcomes.

For non-Hispanic white women there was less consistency in trend patterns through birth outcomes. Sheffield and Tyngsborough/Chelmsford (3/8 tracts) had an increasing trend in all birth outcomes while Brookfield had a decreasing trend in all outcomes. Interestingly, Sturbridge (which has 2 census tracts) had 1 tract with an increasing trend and 1 tract with a decreasing trend for all birth outcomes. Patterns were more similar between ABO and PTD trends while LBW had a different distribution.

3.3 OLS

Several variables were consistently statistically significant across models as shown in Table 6. These variables included percent with a Bachelor's degree or higher, median household income, and the diversity index. Population density was not significant in any of the models and median earnings for full-time female employees was only significant in the White PTD model.

Standardized coefficients were calculated for all models and results are shown in Table 7. For all models for non-Hispanic White women, the percent of individuals with a Bachelor's degree or higher had the highest coefficient and a negative relationship, followed by median household income (negative relationship). However, for all three models for non-Hispanic Black women, the diversity index (positive relationship) had the highest standardized coefficient indicating the greatest contribution to the model. Additionally, the percent of individuals with a Bachelor's degree or higher (negative relationship) and median household income (negative relationship) had high coefficients in the models for non-Hispanic Black women. Coefficients were consistent across models for all variables except percent below poverty which had a positive relationship in all models for non-Hispanic White women and a negative relationship in all models for non-Hispanic Black women and for population density which was a slightly positive relationship for all models except the non-Hispanic Black PTD model.

Signs of coefficients and corresponding relationships between the dependent variables and independent variables was what was expected. The relationship for the percent of individuals with a Bachelor's degree or higher, percent with less than a high school diploma, and for median household income was what was expected. These variables have a negative relationship in all models indicating that a higher educational attainment or income results in a lower ABO rate which aligns with the findings of previous literature.

The R-squared value for PTD rate in both races was lower than the models for LBW and ABO indicating that the selected variables explained less of the occurrence of PTD than the other birth outcomes. The multivariate regression for ABO occurrence in non-Hispanic white women resulted in an R^2 of 0.25. For ABO in non-Hispanic black women, the R^2 was 0.27. Similarly, the multivariate regression for LBW in non-Hispanic white women resulted in an R^2 of 0.29 while the multivariate regression for non-Hispanic black women resulted in an R^2 of 0.26. However, the multivariate regression for PTD in non-Hispanic white women resulted in an R^2 of 0.13 while for non-Hispanic black women the R^2 of 0.20. This potentially indicates that there are more individual level correlates in PTD that are not captured by aggregate variables. All regressions except PTD in non-Hispanic black women exhibited non-stationarity indicating that the relationship between the rate of the birth outcome and the selected independent variables varied throughout the state.

3.4 GWR

Comparative results of the GWR and OLS Regressions can be found in Table 8. The GWR for ABO rates in non-Hispanic white women resulted in an R-squared of 0.26 while for non-Hispanic black women the R-squared was 0.31. Similarly, the GWR for LBW rates in non-Hispanic white women resulted in an R-squared of 0.31 while for non-Hispanic black women the R-squared was 0.29. However, the GWR results for PTD yielded lower R-squared values; the GWR for PTD rates in non-Hispanic white women resulted in an R-squared of 0.16 while for non-Hispanic black women the R-squared was 0.23.

For all birth outcomes in both races the GWR resulted in higher R-squared values than the corresponding OLS model. However, all GWR models had lower AICc values than the corresponding OLS models indicating poorer model fit. Maps for the Local R-squared for each regression can be seen in Figures 25-30.

Figure 25 shows that for non-Hispanic white ABO rate, the model best explained areas in the center of the state and the lower Cape Cod area. The Boston area and upper coast had the lowest R-squared values. For ABO rate in non-Hispanic black mothers, the model was best fit in the Western side of the state and poorly fit south and slightly west of Boston (Figure 26).

The R-squared for PTD rate in non-Hispanic white mothers was very similar to that of the ABO rate, with the best model fit in central and western Massachusetts and a poor fit in the greater Boston area (Figure 27). For PTD rate in black mothers, Figure 28 shows that Western Massachusetts had the best model fit and South of Boston (Brockton) had lowest R-squared values which is very similar to the patterns seen in the R-square for ABO rate in black mothers.

The R-squared for both LBW models appears different than the previous birth outcomes. For LBW rate in white mothers, Figure 29 shows the best model fit was still in central Massachusetts, but the western side of the state had a slightly poorer fit and Boston continued to have the lowest R-squared values, but the poor model fit extended farther north of Boston than in the previous birth outcomes. For LBW rate in black mothers, the eastern side of the state continued to have the strongest model fit but the poorest model fit is no longer south of Boston, but rather around the Lowell and Haverhill areas as can be seen in Figure 30.

T-statistics were calculated for every coefficient in each of the 6 models to determine where the coefficients were statistically significant. The percent of individuals with a bachelor's degree or higher was significant in at least 88% of census tracts in Massachusetts in all three models for white mothers. 100% of the coefficients for the diversity index were significant in all three models for black mothers, while only approximately 50% of tracts had significant coefficients for the same variable in all three regressions for white mothers.

Significance

Results of the significance tests can be found in Table 9. Maps for each coefficient in all models and corresponding statistical significance can be found in the Appendix B.

4 Discussion

Our findings indicate that while trends between the two racial groups overall show different spatial patterns, there were some areas (tracts) that exhibit the same pattern between races. There were only 6 census tracts that had a trend in all three birth outcomes for both races. Trends were consistent between races and birth outcomes for each of those tracts individually, meaning that for both races and each birth outcome trends were either increasing or decreasing consistently and in each tract there were no mixed trend patterns. These tracts were primarily located around the metro-Boston area, particularly in Winchester, Boston, Milton and Reading. We find that the implementation of the space-time cube method and the assignment of trends categorizations allows for clear identification of areas experiencing increases in ABO rates which allows for more targeted public health interventions specific to the individual population and birth outcome.

Similar to previous studies, our findings indicate that rates of ABOs were consistently higher in non-Hispanic Black women than in non-Hispanic White women throughout the entire 15 year period. However, our study adds depth to the current knowledge on ABOs by demonstrating that there is a more prominent increasing trend in ABO rates of non-Hispanic White women than in non-Hispanic Black women, potentially indicating that the prevalence of ABOs is continuing to worsen regardless of race.

This study contributes to the growing body of literature on ABOs by assessing the role of census tract level demographic variables on ABOs at a statewide level. Our study found that the percent with a Bachelor's degree or higher, median household income, and the diversity index were significantly correlated to the likelihood of having an ABO regardless of race which potentially indicates that the racial disparity in birth outcomes is not due to area-level measures but may rather be influenced by characteristics of the mother's themselves. Interestingly, the adjusted R-squared values for both the OLS and GWR in PTD and ABO in non-Hispanic black women was higher than the same models for non-Hispanic white women. While previous literature has documented the racial disparity in birth outcomes between races, conclusive reasoning as to why non-Hispanic Black women are more likely to have an ABO is lacking. As such, it was expected that the models would be less capable of explaining ABO in black women compared to white women which was not the case here. The implementation of the GWR is advantageous as it can be used to identify areas throughout the state where demographic variables are particularly highly and significantly correlated to elevated ABO rates allowing for further assessment and identification as areas of need.

This study has demonstrated the powerful use of GIS to conduct a spatio-temporal analysis on a health outcome providing a methodological framework to identify areas for targeted intervention. We note several limitations to the current analyses; this analysis was limited by the availability of socioeconomic data covering the same range as the birth data that was obtained. The data that was used in this analysis as the independent variables was a 5-year estimate in the center of the data range (2006-2010) but the dependent variable was a 15 year average. It is therefore possible that the selected independent variables are not fully capable of explaining the ABO rates. Additionally, the rate of ABO, PTD, and LBW were calculated using EB rates with the intention of accounting for tracts with small counts of births. While in some areas in the state this was likely useful, it is necessary to recognize that the rates being modelled were not the raw rates for each tract and in metro-areas with high numbers of births this EB rate calculation may have not been necessary.

The methodologies employed in this analysis provide a framework for examining spatial and temporal trends in other measured health outcomes. We are the first to examine differences in spatial distributions of trends between racial groups and across birth outcomes at a census tract level for an entire state. This analysis also filled gaps in literature comparing racial trends in multiple types of adverse birth outcomes. The space-time cube in ArcMap proved very useful in providing the spatial trend data but did not provide conclusive statistical means to compare the trends between races or birth outcomes. While the OLS and GWR provided insight into which variables were statistically significant, they assumed prior knowledge on the researcher's part as to what should be included in the models in the first place.

5 Conclusions

This study was able to meet the objectives of the analysis which were: (1) to identify areas of Massachusetts that have experienced statistically significant increasing trends in ABO; (2) to examine if there are differences in frequency and location of trends in ABO between non-Hispanic black mothers and non-Hispanic white mothers to determine the role of race; and (3) to evaluate the socioeconomic characteristics of the census tracts to determine the potential correlations between the socioeconomic conditions and birth outcomes at an aggregate level.

Our findings suggest that low socioeconomic status, particularly educational attainment and income, increase the likelihood of experiencing an ABO regardless of the mother's race. There were statistically significant increases in birth outcomes for both non-Hispanic white and non-Hispanic black women though there were very few towns that showed consistent patterns across birth outcomes or races. Statewide, no patterns were presented on why trends occur where they do. This indicates that the racial disparity between birth outcomes in black and white women is not necessarily a product of the mother's geographic location, but more likely the result of her individual health or life circumstances.

Overall there were not very conclusive racial disparities in trends in adverse birth outcomes in Massachusetts from 2000-2014. Annual rates of ABO for non-Hispanic black women were consistently higher (nearly double) compared to rates of ABO in non-Hispanic white women which supports previous literature. However, there were more census tracts with an increasing trend in all birth outcomes for non-Hispanic white women than for non-Hispanic black women indicating that while rates for non-Hispanic black women continue to be elevated, they have remained temporally consistent. Additionally, there were more census tracts with a decreasing trend for non-Hispanic black women than white women. To improve model fit, a mixed level analysis including both aggregate variables at the census tract level as well as individual mother-level variables should be conducted using the data provided by the MADPH to further evaluate racial disparities in birth outcomes at the individual and area level.

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List of Tables

Table 1: Descriptive Statistics for the Independent Variables Used in the OLS and GWR.

Variable	Mean	Median	Std. Dev	Min	Max	Years	Nulls
Unemployment Rate	7.73	6.5	4.92	0	43.9	2006-2010	9
Percent with a Bachelor's Degree or Higher	37.25	34	20.43	0	100	2006-2010	10
Median Household Income	67909.5	65577	29364.16	9554	218667	2006-2010	16
Per Capita Income	33616.47	31714	14764.74	2471	124093	2006-2010	8
Median Earnings for Full Time Female Employees	45764.2	43882	12775.34	15700	104444	2006-2010	18
Percent Below Poverty	11.77	7.6	11.77	0	86.3	2006-2010	11
Percent with Less than a High School Diploma	14.17	11.2	13.02	0	100	2006-2010	13
Population Density	7269.29	3119.7	1064.15	0	110170.5	2010	0
Diversity Index	37.52	30.7	25.1	0	93.1	2010	0

Table 2: Birth data match rates

Year	Total Records	Matched with Spatial Files	Match Rate
2000	80278	76521	95.32%
2001	79759	75903	95.17%
2002	79351	75186	94.75%
2003	78887	74900	94.95%
2004	77072	70715	91.75%
2005	75532	69550	92.08%
2006	76296	70896	92.92%
2007	76688	71490	93.22%
2008	75719	70950	93.70%
2009	73773	68881	93.37%
2010	71628	67465	94.19%
2011	72837	67727	92.98%
2012	71195	64305	90.32%
2013	70459	66226	93.99%
2014	70654	67015	94.85%
Average	75342	70515	93.57%

Table 3: Birth Statistics for non-Hispanic White Deliveries.

Non-Hispanic White Birth Statistics							
Year	**Number of Births**	**PTD**		**LBW**		**ABO**	
		Number	**Percent**	**Number**	**Percent**	**Number**	**Percent**
1/1/2000	56799	2925	5.15%	2202	3.88%	3804	6.70%
1/1/2001	56100	2803	5.00%	2279	4.06%	3725	6.64%
1/1/2002	55315	2842	5.14%	2230	4.03%	3744	6.77%
1/1/2003	54616	3100	5.68%	2267	4.15%	3886	7.12%
1/1/2004	50303	2974	5.91%	2161	4.30%	3764	7.48%
1/1/2005	48905	2877	5.88%	2226	4.55%	3683	7.53%
1/1/2006	48870	2822	5.77%	2206	4.51%	3666	7.50%
1/1/2007	48809	2904	5.95%	2302	4.72%	3779	7.74%
1/1/2008	48411	2725	5.63%	2105	4.35%	3542	7.32%
1/1/2009	46413	2565	5.53%	2032	4.38%	3319	7.15%
1/1/2010	45742	2474	5.41%	2030	4.44%	3282	7.18%
1/1/2011	43351	3293	7.60%	2725	6.29%	4175	9.63%
1/1/2012	39948	2321	5.81%	1746	4.37%	2995	7.50%
1/1/2013	40904	2282	5.58%	1745	4.27%	2915	7.13%
1/1/2014	41096	2340	5.69%	1781	4.33%	2997	7.29%
Total	725582	41247	5.68%	32037	4.42%	53276	7.34%

Table 4: Birth Statistics for non-Hispanic Black Deliveries.

Non-Hispanic Black Birth Statistics							
Year	**Number of Births**	**PTD**		**LBW**		**ABO**	
		Number	**Percent**	**Number**	**Percent**	**Number**	**Percent**
1/1/2000	5552	555	10.00%	506	9.11%	715	12.88%
1/1/2001	5667	506	8.93%	439	7.75%	673	11.88%
1/1/2002	5715	549	9.61%	545	9.54%	745	13.04%
1/1/2003	5675	521	9.18%	519	9.15%	706	12.44%
1/1/2004	5584	552	9.89%	489	8.76%	726	13.00%
1/1/2005	5704	559	9.80%	528	9.26%	742	13.01%
1/1/2006	6070	603	9.93%	567	9.34%	809	13.33%
1/1/2007	6136	551	8.98%	552	9.00%	758	12.35%
1/1/2008	6320	488	7.72%	518	8.20%	695	11.00%
1/1/2009	6611	532	8.05%	539	8.15%	732	11.07%
1/1/2010	6492	519	7.99%	552	8.50%	752	11.58%
1/1/2011	6759	661	9.78%	657	9.72%	880	13.02%
1/1/2012	6501	506	7.78%	525	8.08%	711	10.94%
1/1/2013	6690	558	8.34%	551	8.24%	762	11.39%
1/1/2014	6819	508	7.45%	514	7.54%	715	10.49%
Total	92295	8168	8.85%	8001	8.67%	11121	12.05%

Table 5. Number of census tracts with statistically significant increasing and decreasing trends in rates by race and birth outcome.

	Confidence Level	ABO		PTD		LBW	
White							
Increasing	99%	8	120	12	137	12	127
	95%	56		62		46	
	90%	56		63		69	
Decreasing	99%	5	57	5	60	1	45
	95%	21		21		24	
	90%	31		34		20	
Black							
Increasing	99%	5	107	7	101	8	97
	95%	58		44		52	
	90%	44		50		37	
Decreasing	99%	6	85	10	107	5	80
	95%	42		45		36	
	90%	37		52		39	

Table 6: Results from the OLS Regression analyses.

	ABO		PTD		LBW	
	White	Black	White	Black	White	Black
Adjusted R2	0.246	0.270	0.128	0.200	0.293	0.256
Percent with a Bachelor's Degree or Higher	-0.000312**	-0.000281**	-0.000228**	-0.000156	-0.000192**	-0.000231**
Median Household Income	-0.00000**	-0.00000**	-0.00000**	-0.00000*	-0.00000**	-0.00000**
Diversity Index	0.000113**	0.001080**	0.000085**	0.000837**	0.000093**	0.000777 **
Percent with Less than a High School Diploma	-0.000091**	-0.000104	-0.000064*	-0.000133	-0.000031	-0.000079
Percent Below Poverty	0.000200*	-0.000382*	0.000041	- 0.000480**	0.000240**	-0.000199
Per Capita Income	0.000000*	0.000000	0.000000	0.000000	0.000000**	0.000000*
Unemployment Rate	0.000133	0.001021**	0.000045	0.002724**	0.000267*	0.000696**
Median Earnings for Full Time Female Employees	0.000000	0.000000	0.000000*	0.000861	0.000000	0.000000
Population Density	0.000000	0.000000	0.000000	- 0.000000	0.000000	0.000000
Other Notes	Jarque-Bera and Koenker significant	Jarque-Bera and Koenker significant	Jarque-Bera and Koenker significant	Jarque-Bera significant	Jarque-Bera and Koenker significant	Jarque-Bera and Koenker significant

**-Statistically significant at 95% confidence
*- Statistically significant at 90% confidence

Table 7: Standardized Coefficients of the OLS Models.

	ABO		PTD		LBW	
	White	Black	White	Black	White	Black
Adjusted R2	0.246	0.270	0.128	0.200	0.293	0.256
Percent with a Bachelor's Degree or Higher	-0.326**	-0.099**	-0.290**	-0.068	-0.233**	-0.106**
Median Household Income	-0.150**	-0.119**	-0.139**	-0.088**	-0.177**	-0.147**
Diversity Index	0.147**	0.475**	0.134**	0.453**	0.141**	0.442**
Percent with Less than a High School Diploma	-0.059**	-0.023	-0.051*	-0.036	-0.024	-0.023
Percent Below Poverty	0.118*	-0.076*	0.029	-0.118**	0.165**	-0.051
Per Capita Income	0.099*	0.049	0.065	0.000	0.101**	0.086*
Unemployment Rate	0.033	0.085**	0.014	0.088**	0.076*	0.075**
Median Earnings for Full Time Female Employees	0.039	0.052	0.093*	0.057	0.026	0.047
Population Density	0.026	0.000	0.035	-0.022	0.044	0.004

Table 8: Comparative results of the GWR and OLS Models.

Birth Outcome	Race	Model	**Adjusted R2**	**Min R2**	**Max R2**	**AICc**
ABO	White	OLS	0.245656			-7738
		GWR	0.264992	0.179401	0.416911	-7755
	Black	OLS	0.270275			-4637
		GWR	0.309432	0.17393	0.407322	-4711
PTD	White	OLS	0.12833			-8100
		GWR	0.162078	0.099689	0.244728	-8147
	Black	OLS	0.199766			-5103
		GWR	0.230337	0.100799	0.341073	-5160
LBW	White	OLS	0.293233			-8269
		GWR	0.308382	0.234806	0.488826	-8307
	Black	OLS	0.255792			-5352
		GWR	0.288853	0.127458	0.374367	-5414

Table 9: Percentage of statistically significant coefficients for each independent variable for each GWR

	ABO		PTD		LBW	
	White	Black	White	Black	White	Black
Adjusted R2	0.265	0.309	0.162	0.230	0.308	0.289
Number of Neighbors	777	553	744	553	852	521
Percent with a Bachelor's Degree or Higher	92.08%	35.67%	86.62%		88.04%	42.20%
Median Household Income	59.02%	19.86%	55.34%	47.56%	36.08%	36.84%
Diversity Index	42.91%	100.00%	43.00%	100%	52.92%	100%
Percent with Less than a High School Diploma	1.17%		13.23%			
Percent Below Poverty	81.81%	6.32%		41.24%	87.77%	
Per Capita Income	44.77%				14.36%	5.84%
Unemployment		0.89%		35.05%	36.91%	6.53%
Median Earnings for Full Time Female Employees			19.43%			

List of Figures

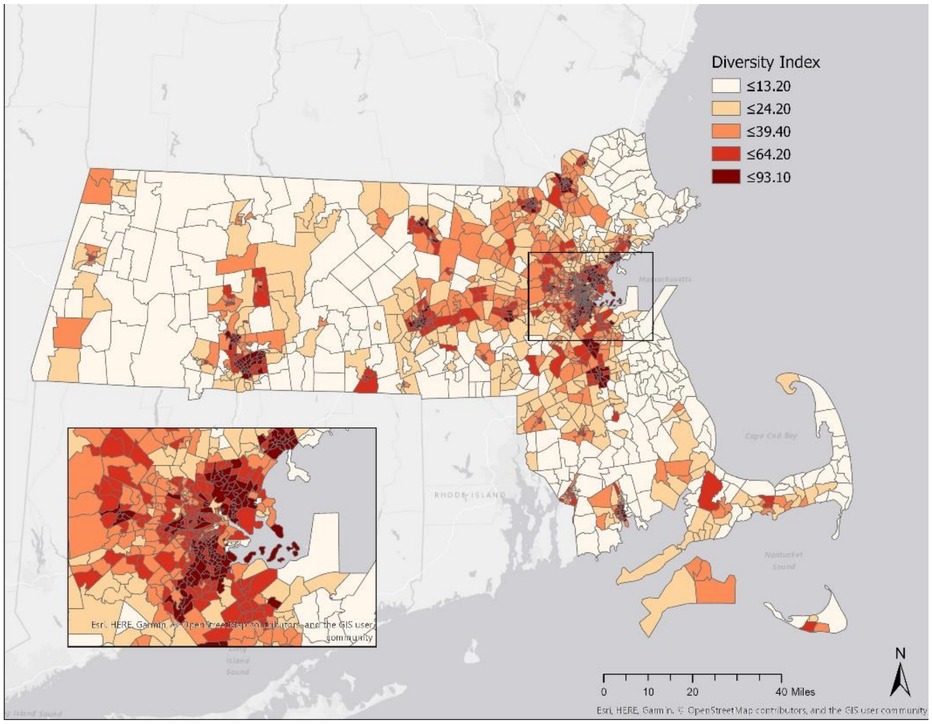


Figure 1: Diversity Index by Census Tract

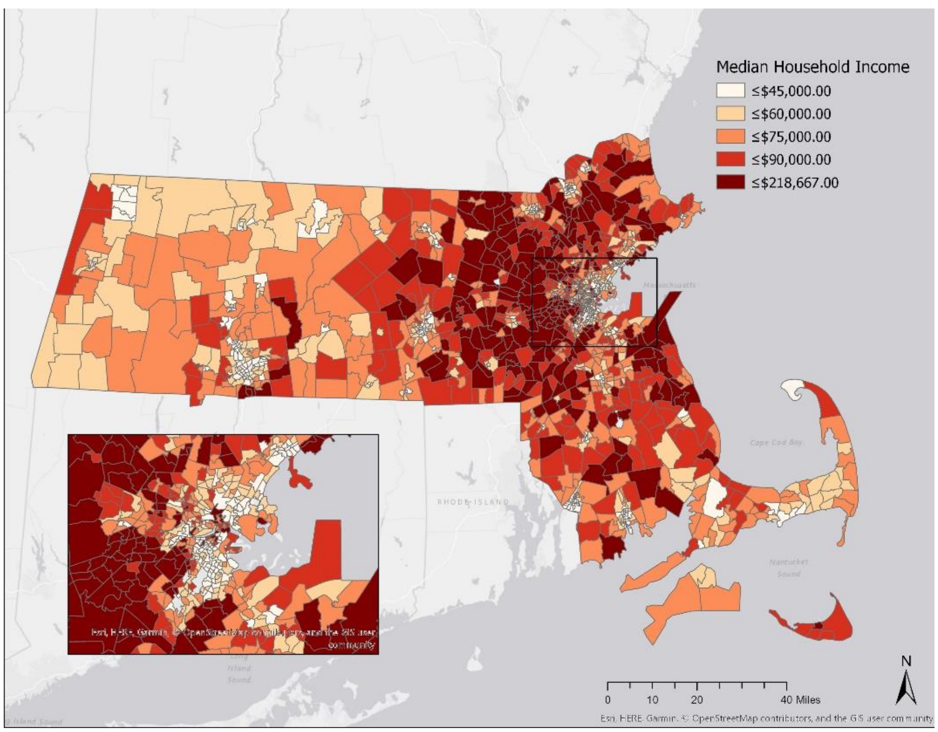


Figure 2: Median Household Income by Census Tract.

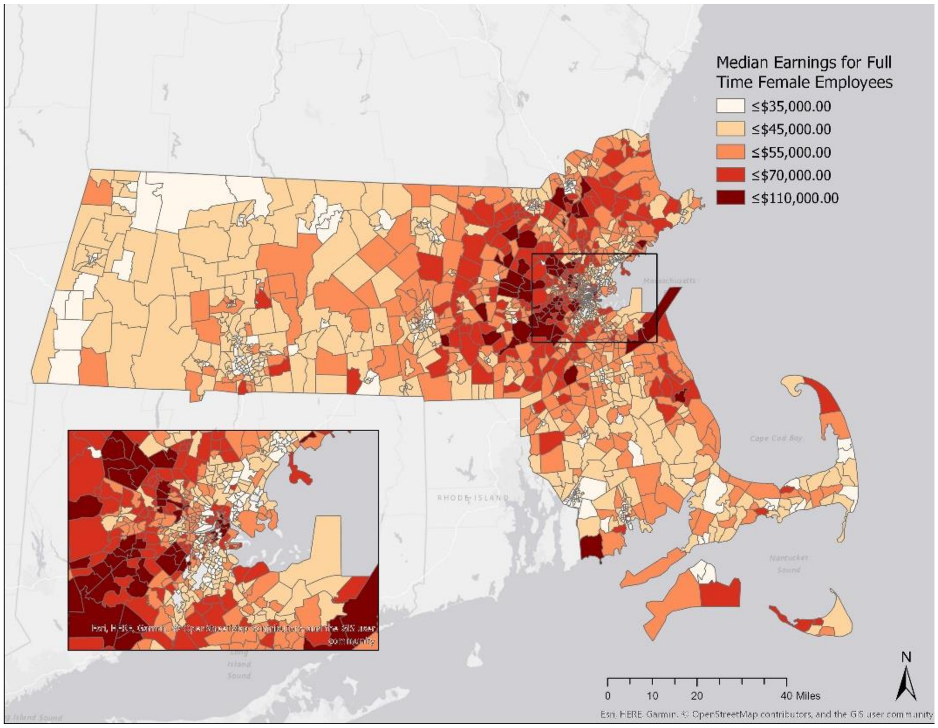


Figure 3: Median Earnings for Full-Time Female Employees by Census Tract.

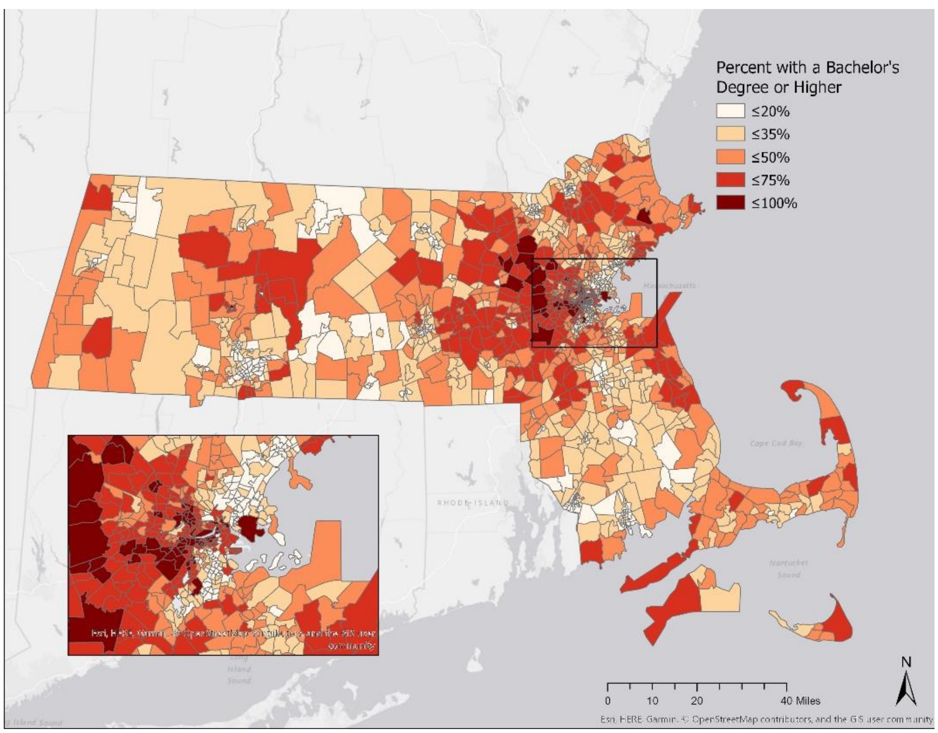


Figure 4: Percent of Individuals with a Bachelor's Degree or Higher by Census Tract.

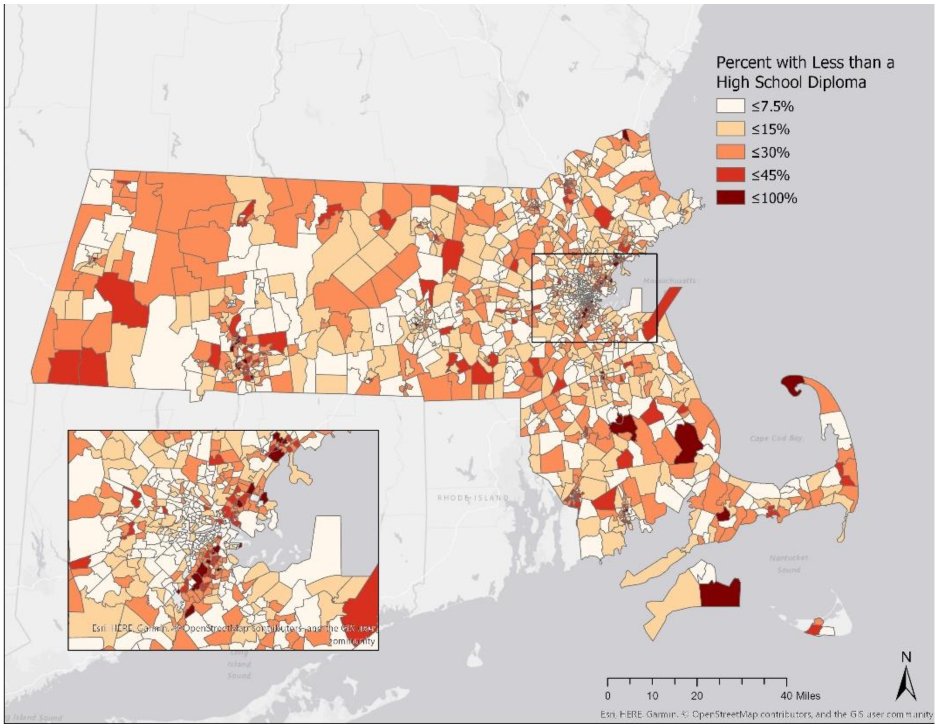


Figure 5: Percent with Less than a High School Diploma Census Tract.

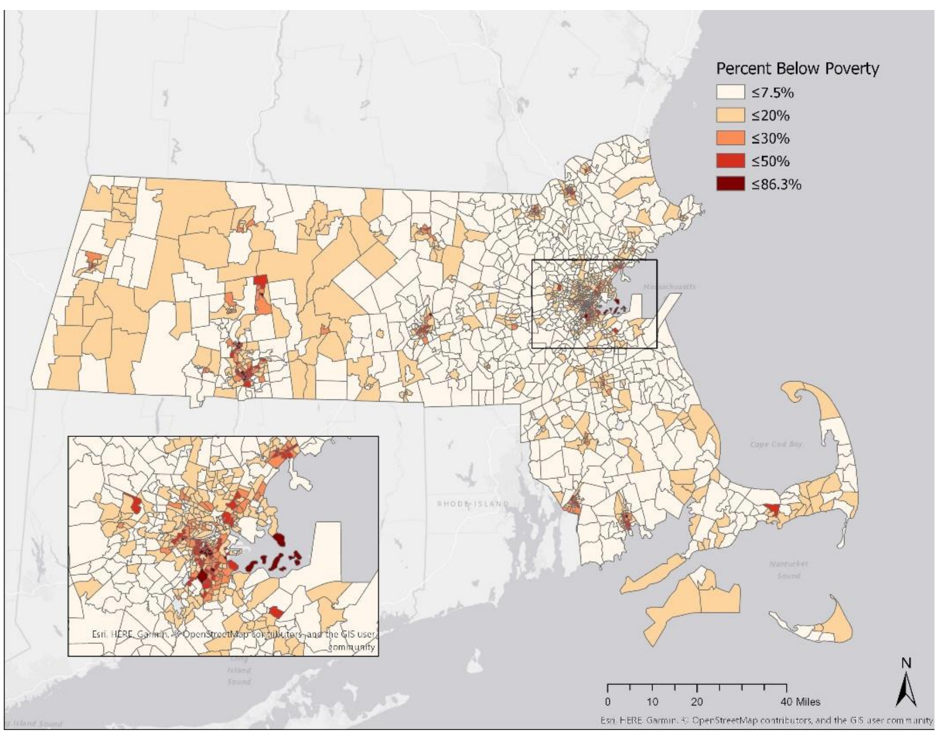


Figure 6: Percent below Poverty by Census Tract.

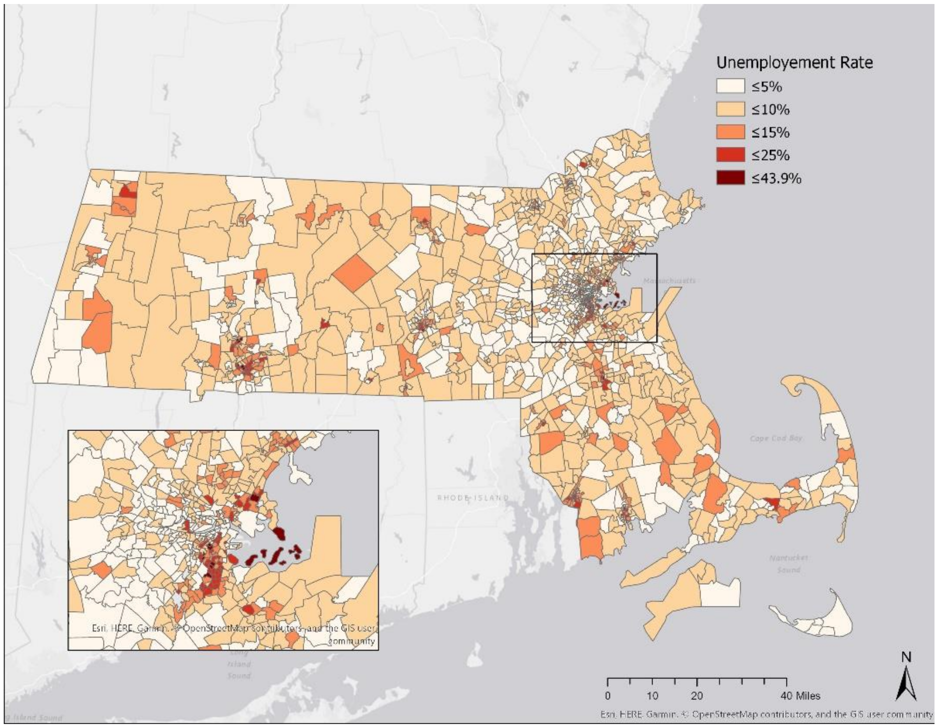


Figure 7: Unemployment Rate by Census Tract.

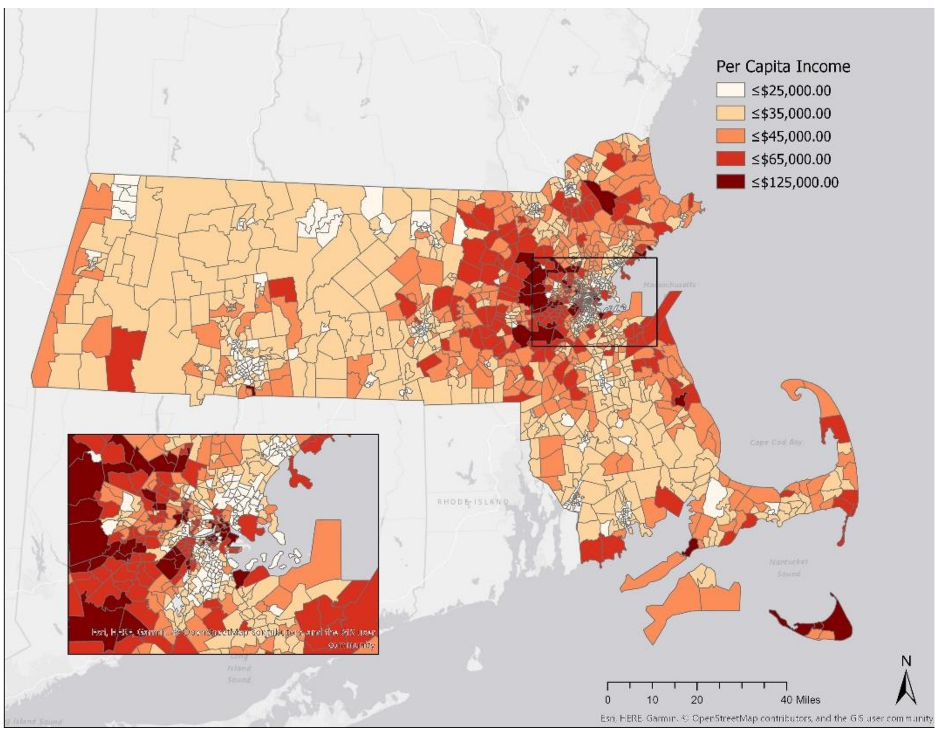


Figure 8: Per Capita Income by Census Tract.

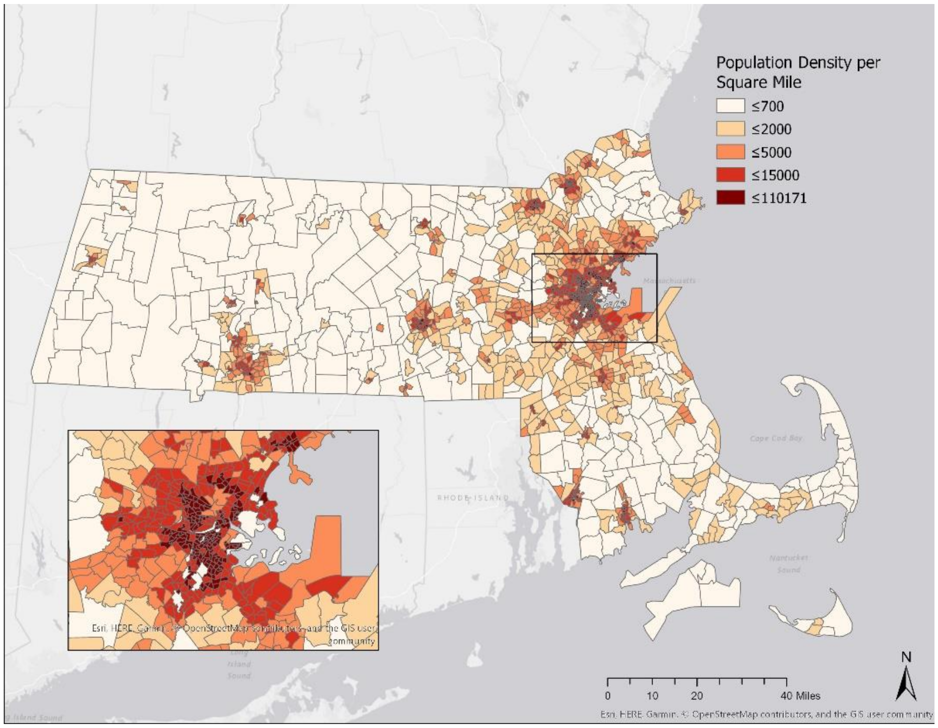


Figure 9: Population Density per Square Mile by Census Tract.

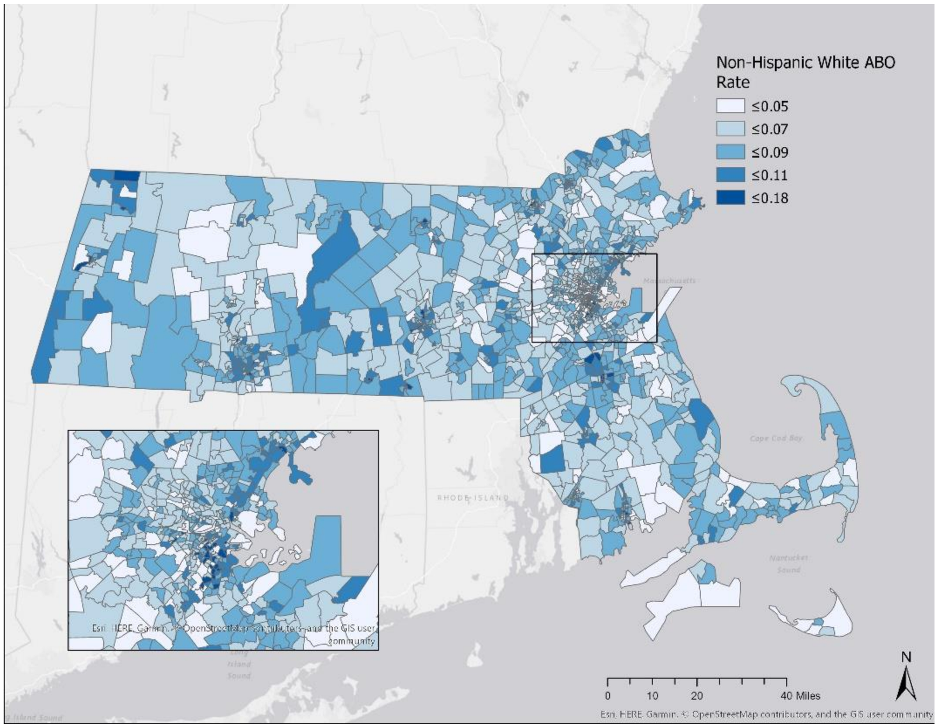


Figure 10: Average ABO Rate in non-Hispanic White Mothers from 2000-2014

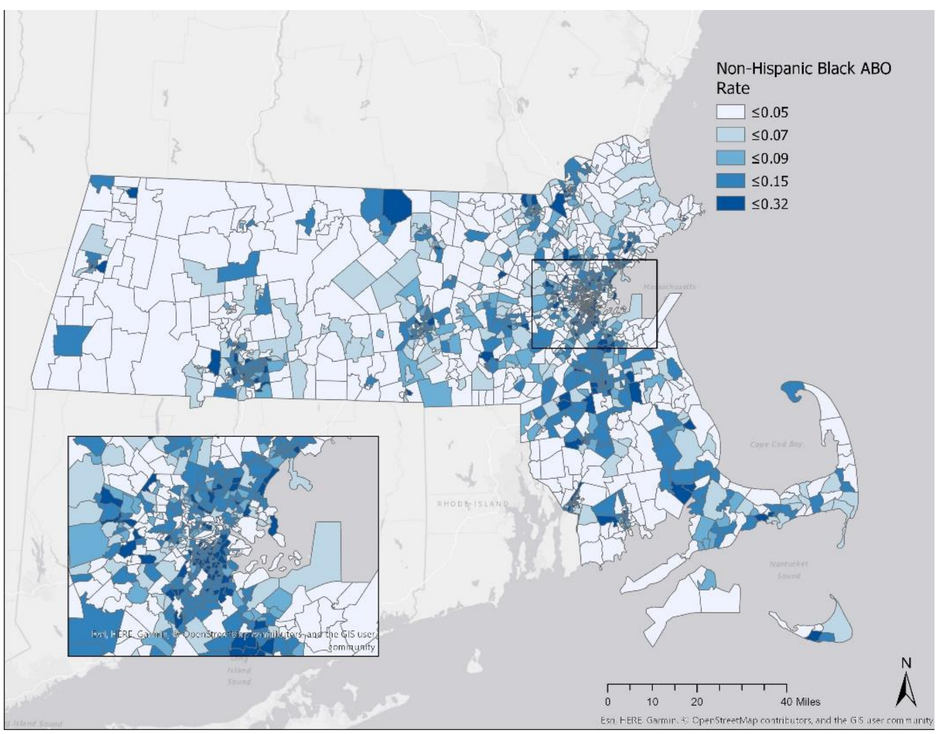


Figure 11: Average ABO Rate in non-Hispanic Black Mothers from 2000-2014

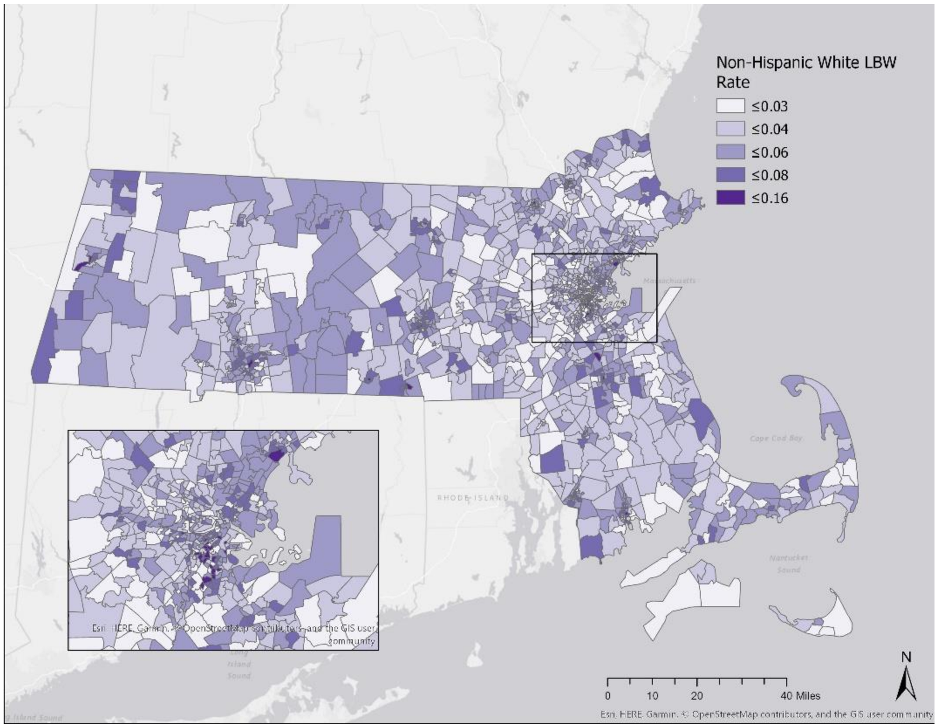


Figure 12: Average LBW Rate in non-Hispanic White Mothers from 2000-2014

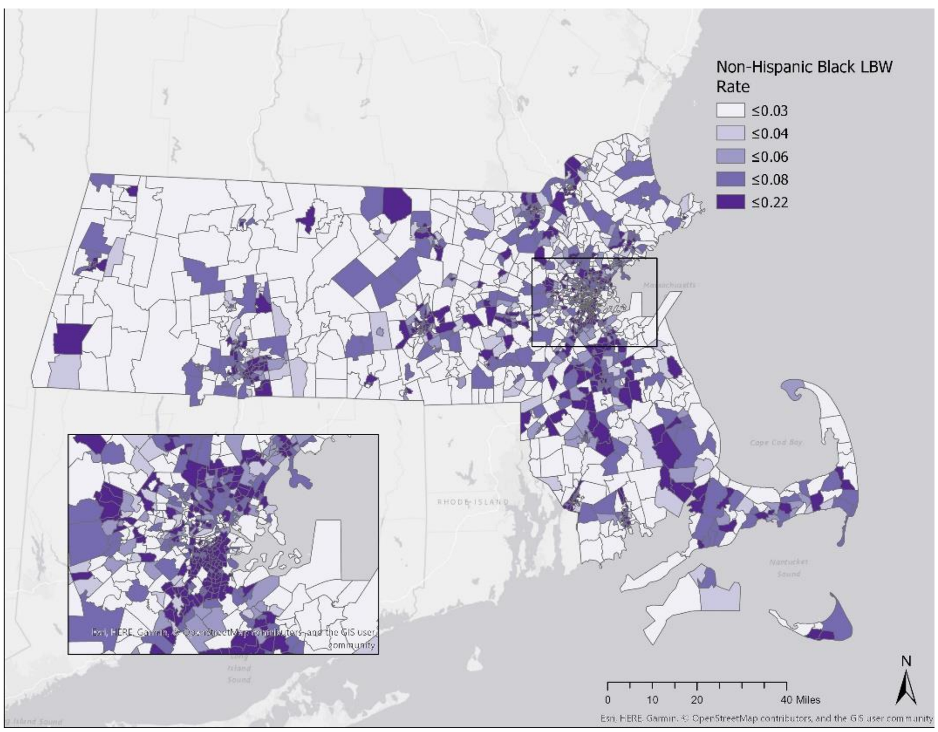


Figure 13: Average LBW Rate in non-Hispanic Black Mothers from 2000-2014

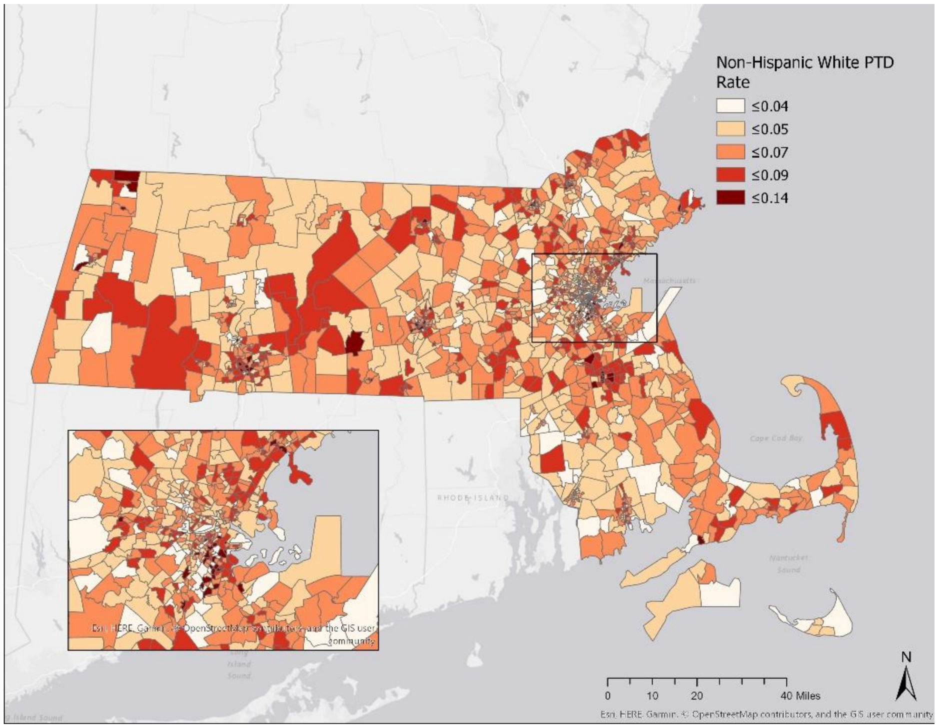


Figure 14: Average PTD Rate in non-Hispanic White Mothers from 2000-2014

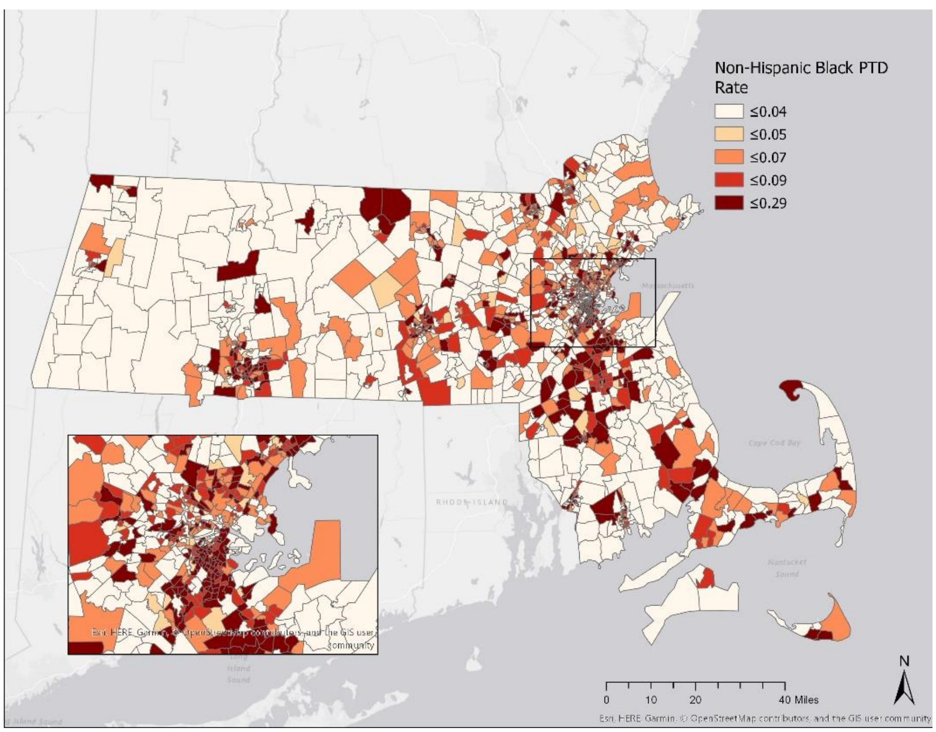


Figure 15: Average PTD Rate in non-Hispanic Black Mothers from 2000-2014

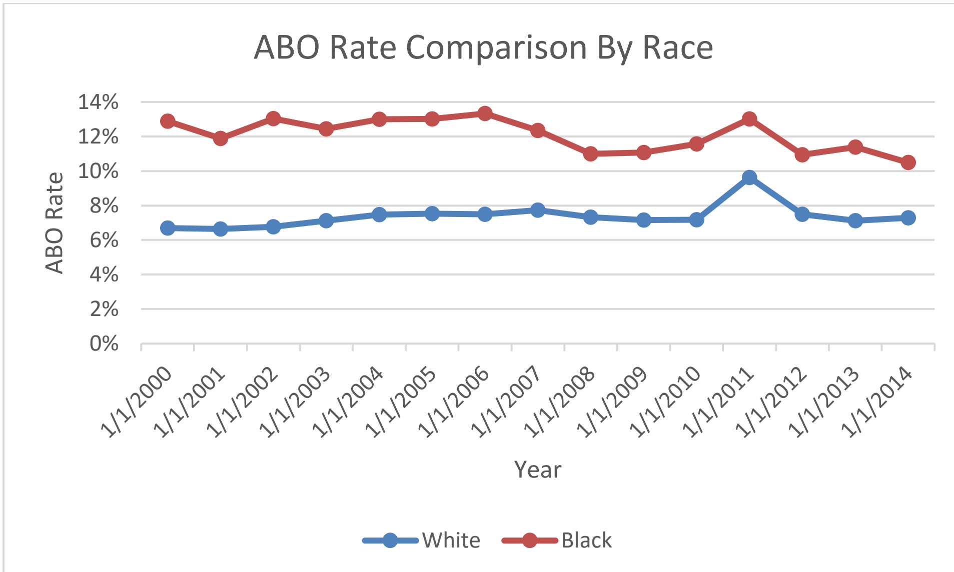


Figure 16: ABO Rate Comparison by Race

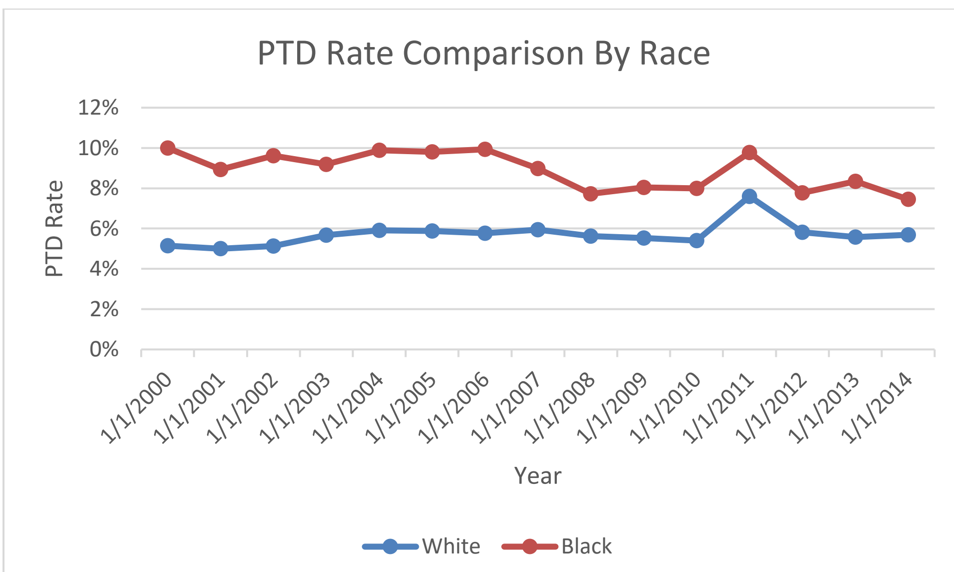


Figure 17: PTD Rate Comparison by Race

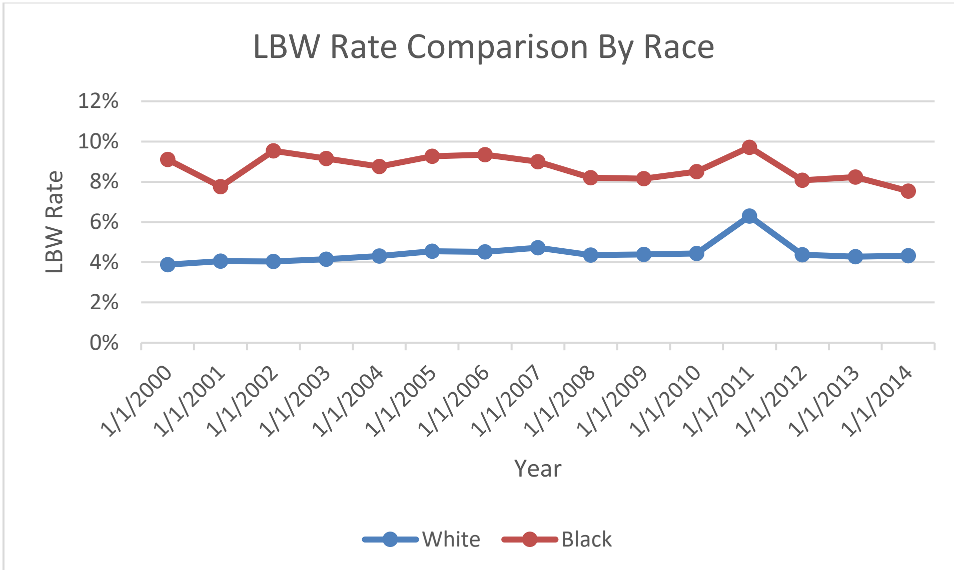


Figure 18: LBW Rate Comparison by Race

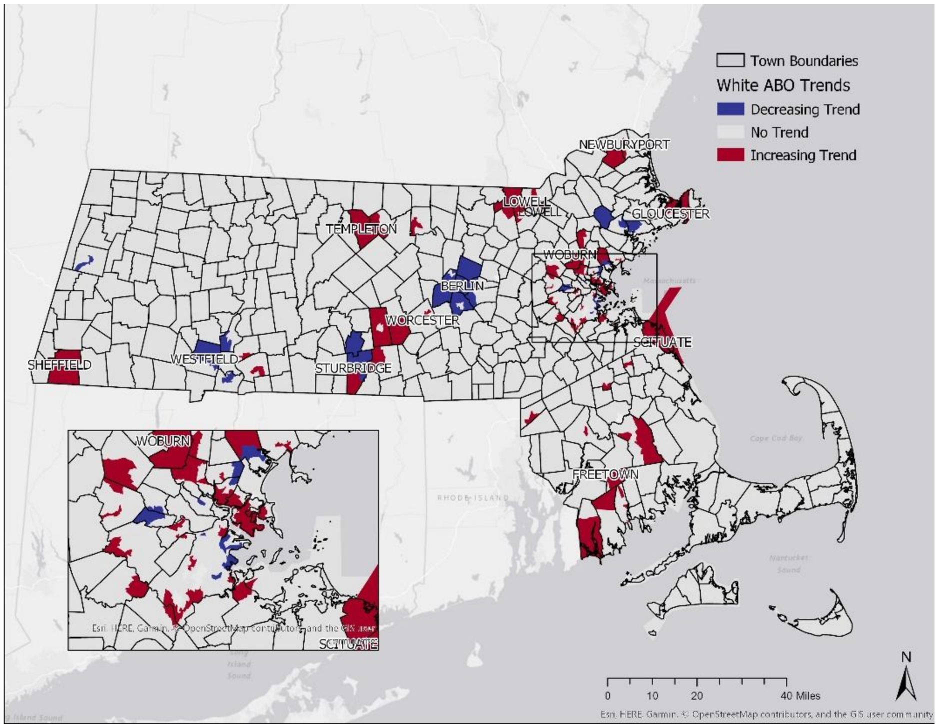


Figure 19: Trends in ABO Rate in non-Hispanic White Mothers.

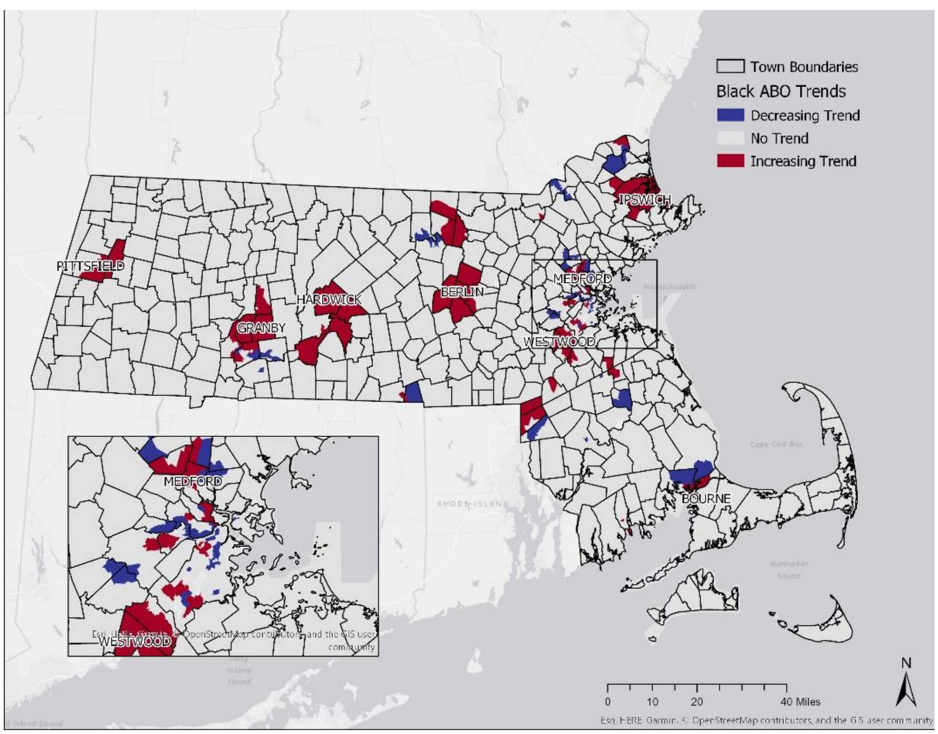


Figure 20: Trends in ABO Rate in non-Hispanic Black Mothers.

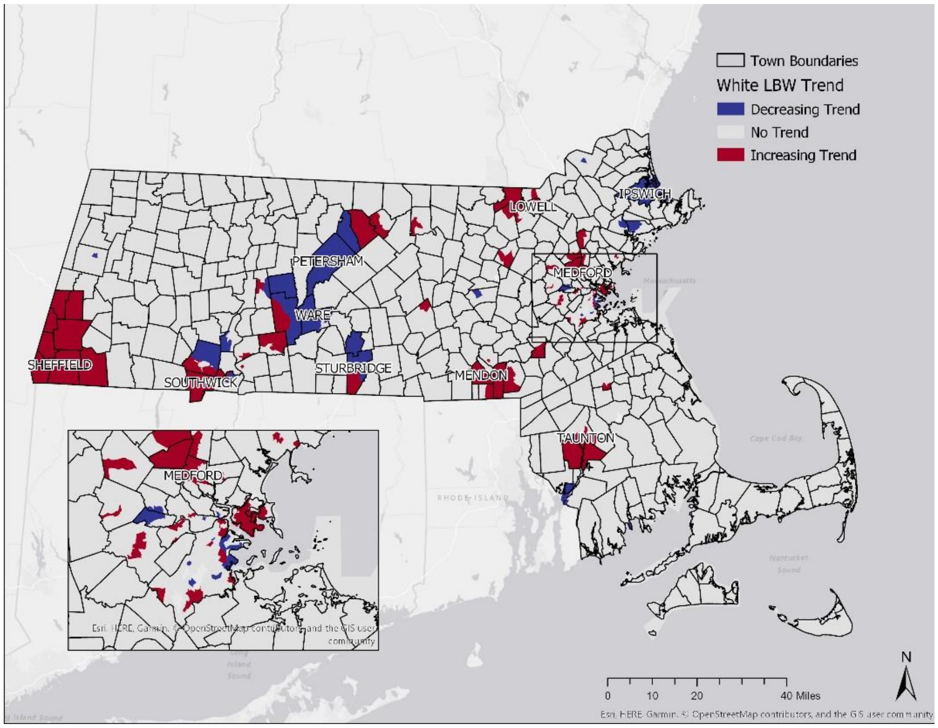


Figure 21: Trends in LBW Rate in non-Hispanic White Mothers.

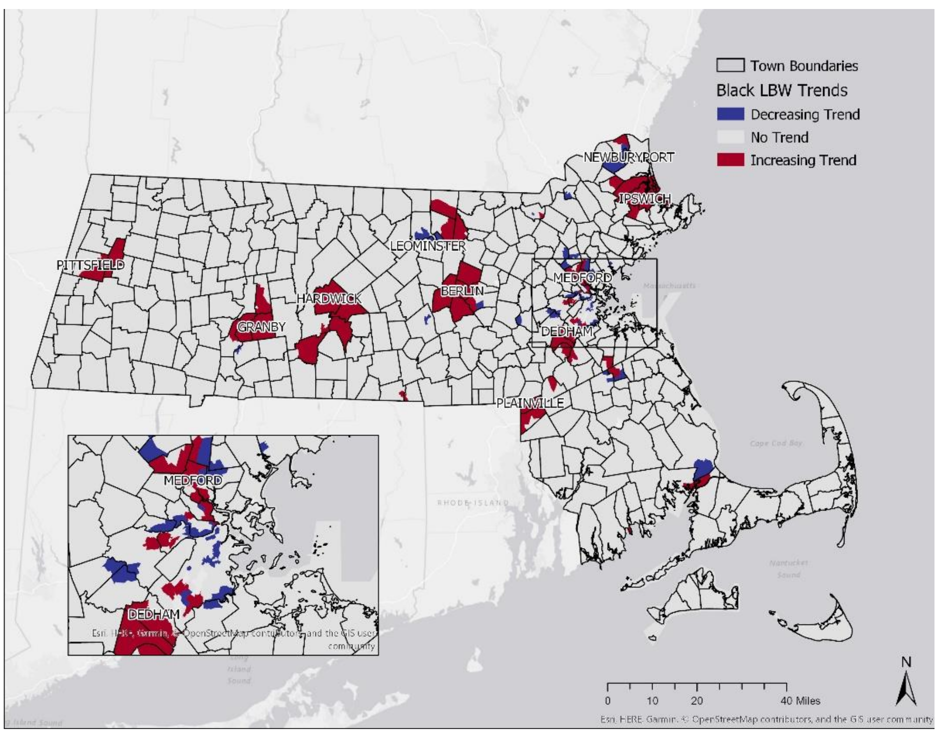


Figure 22: Trends in LBW Rate in non-Hispanic Black Mothers.

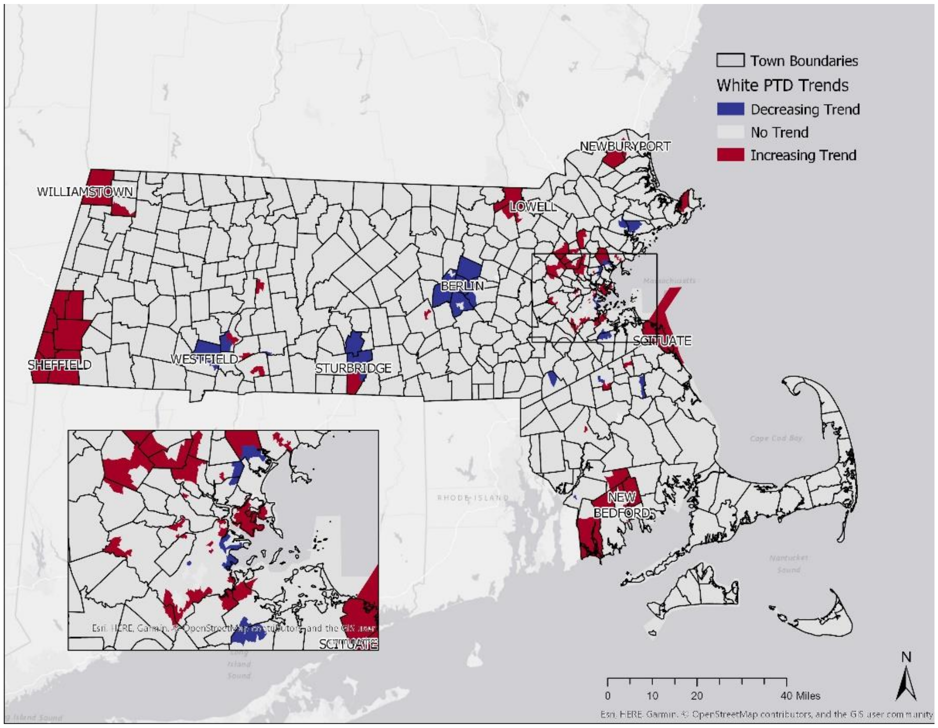


Figure 23: Trends in PTD Rate in non-Hispanic White Mothers.

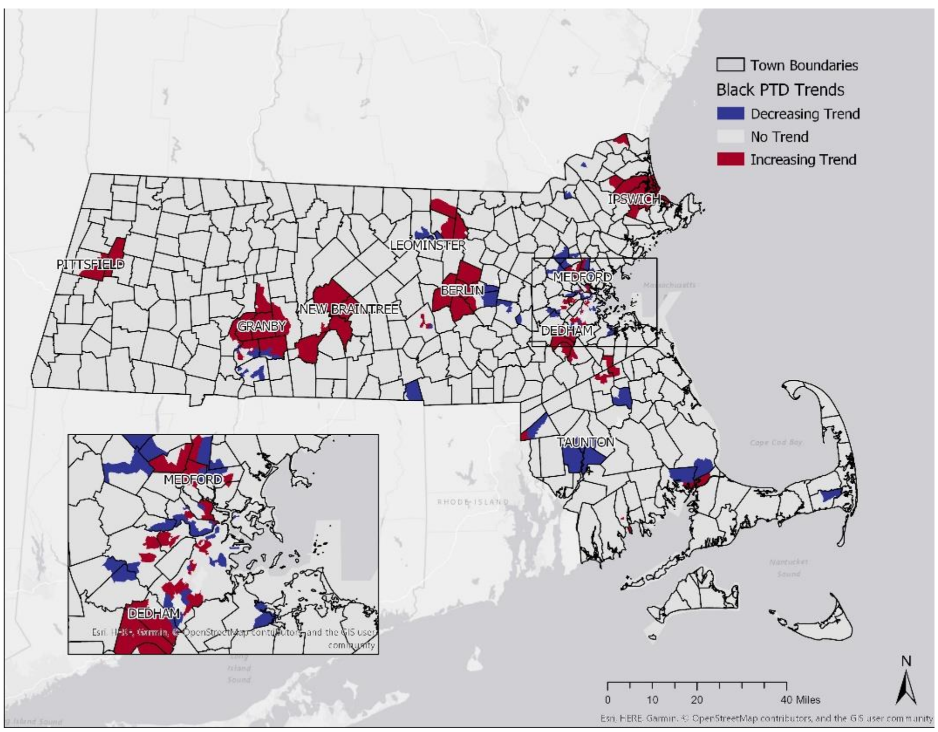


Figure 24: Trends in PTD Rate in non-Hispanic Black Mothers.

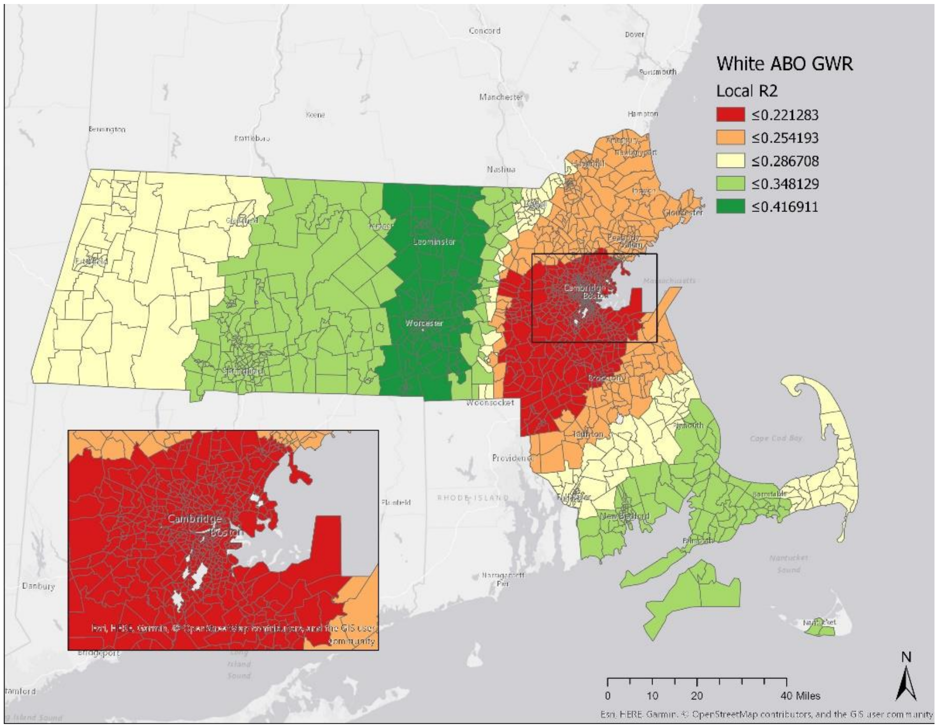


Figure 25: Local R-Squared for the ABO Rate in White Mothers.

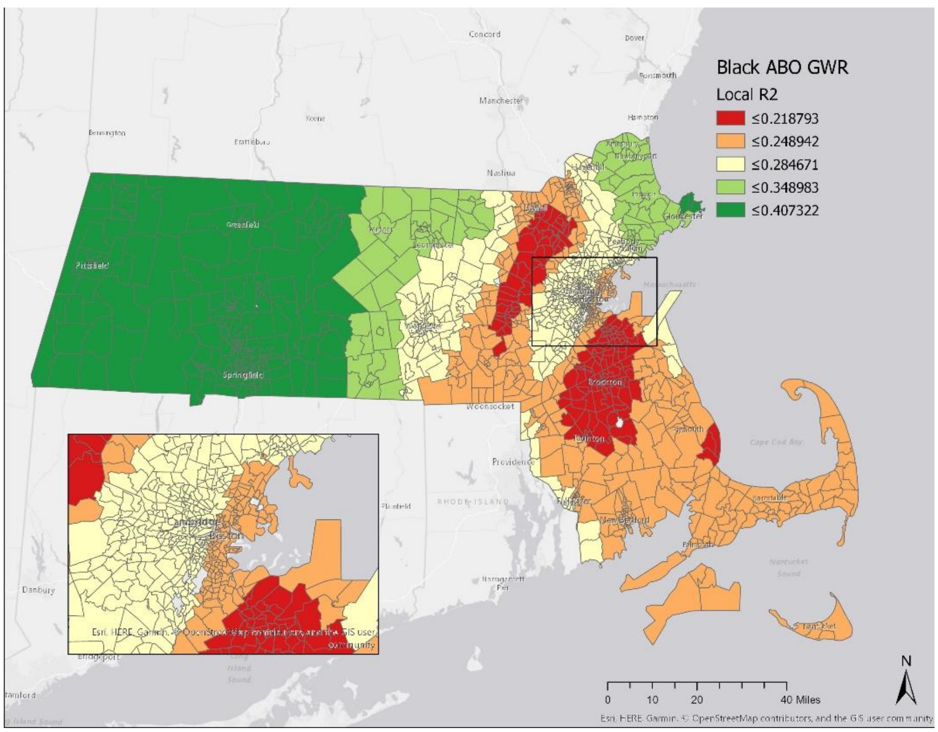


Figure 26: Local R-Squared for the ABO Rate in Black Mothers.

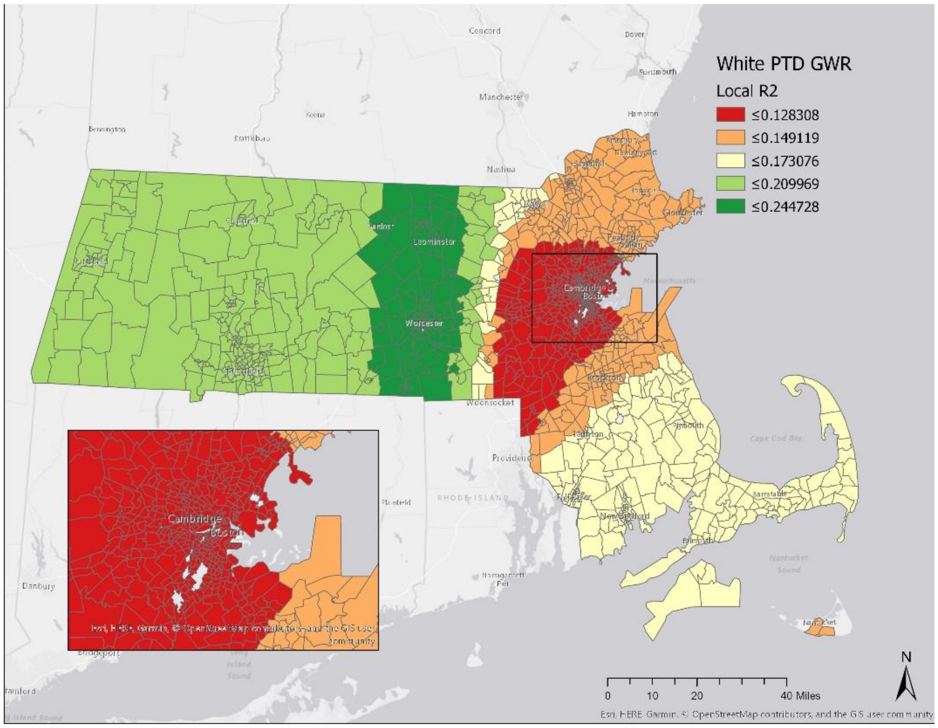


Figure 27: Local R-Squared for the PTD Rate in White Mothers.

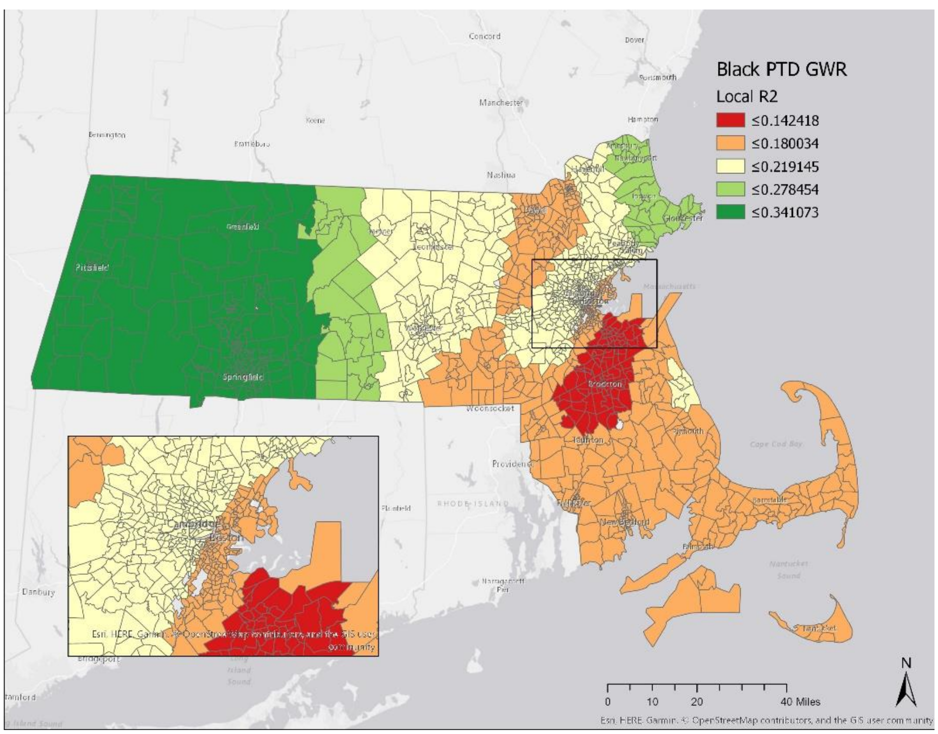


Figure 28: Local R-Squared for the PTD Rate in Black Mothers.

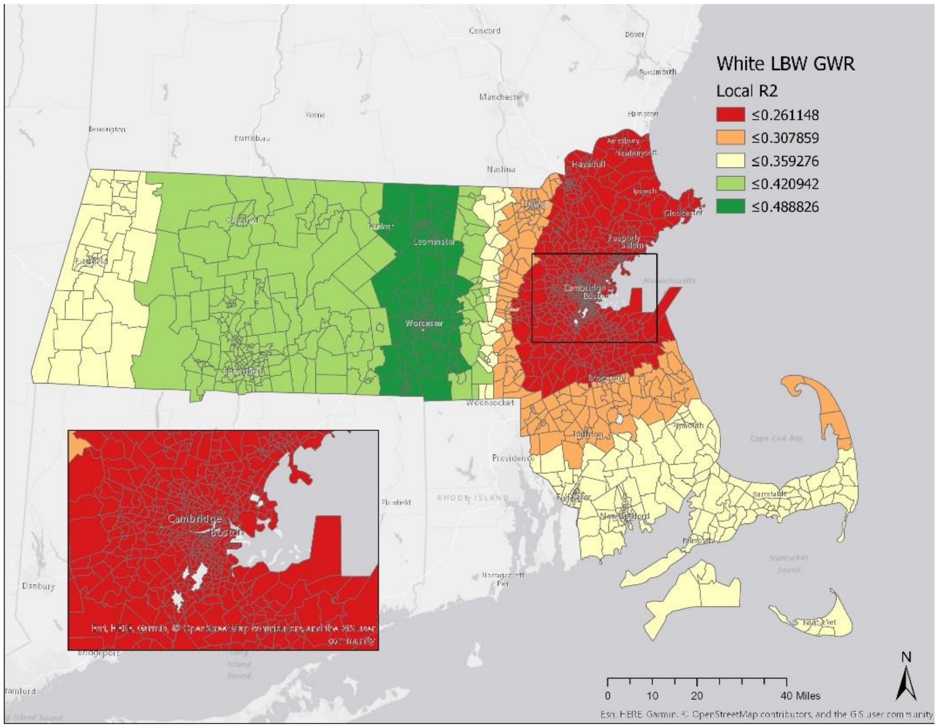


Figure 29: Local R-Squared for the LBW Rate in White Mothers.

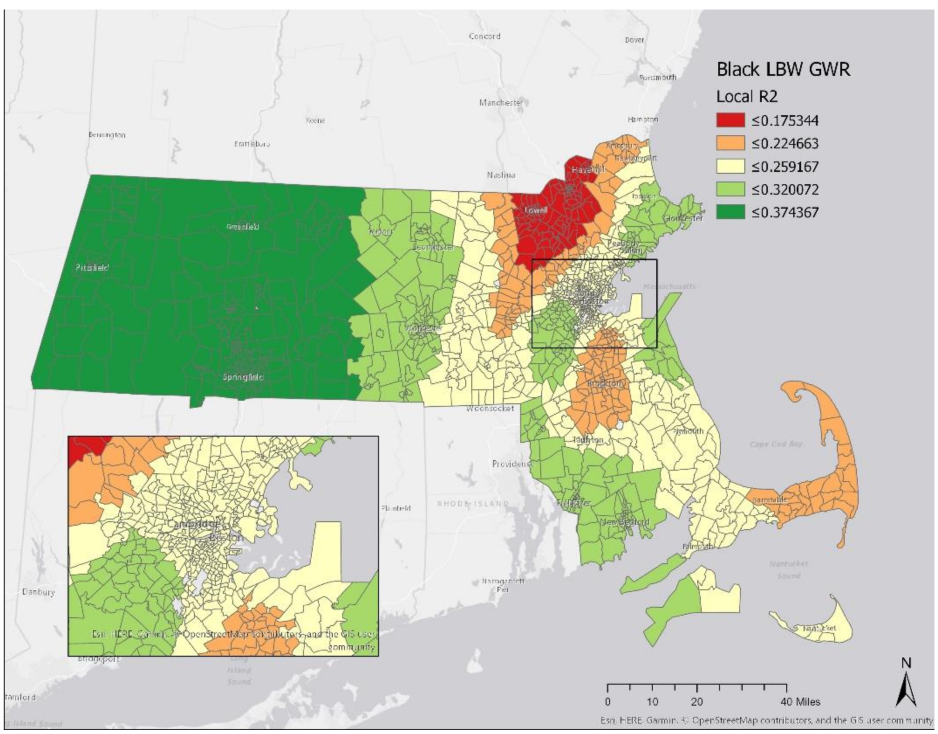
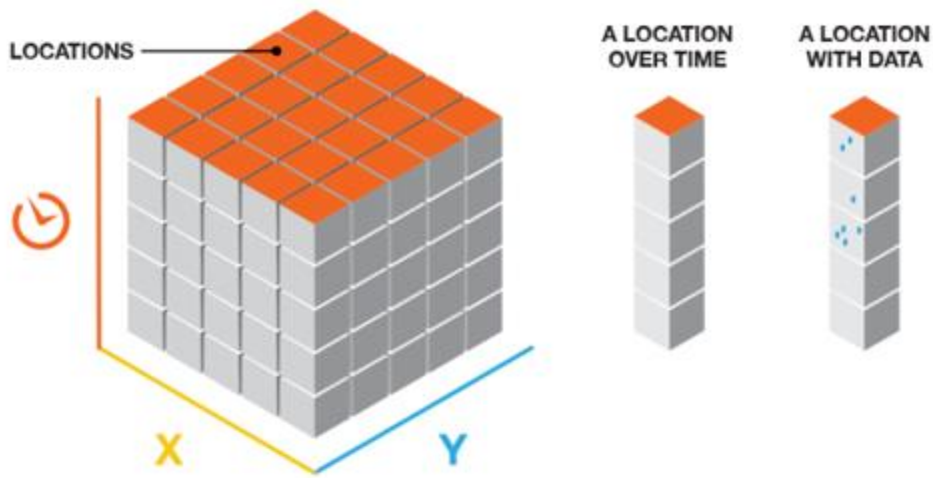


Figure 30: Local R-Squared for the LBW Rate in Black Mothers.

Appendix

Appendix A



Appendix A-1: Visualization of the Space Time Cube used in the Analysis (ArcGIS Pro, n.d)

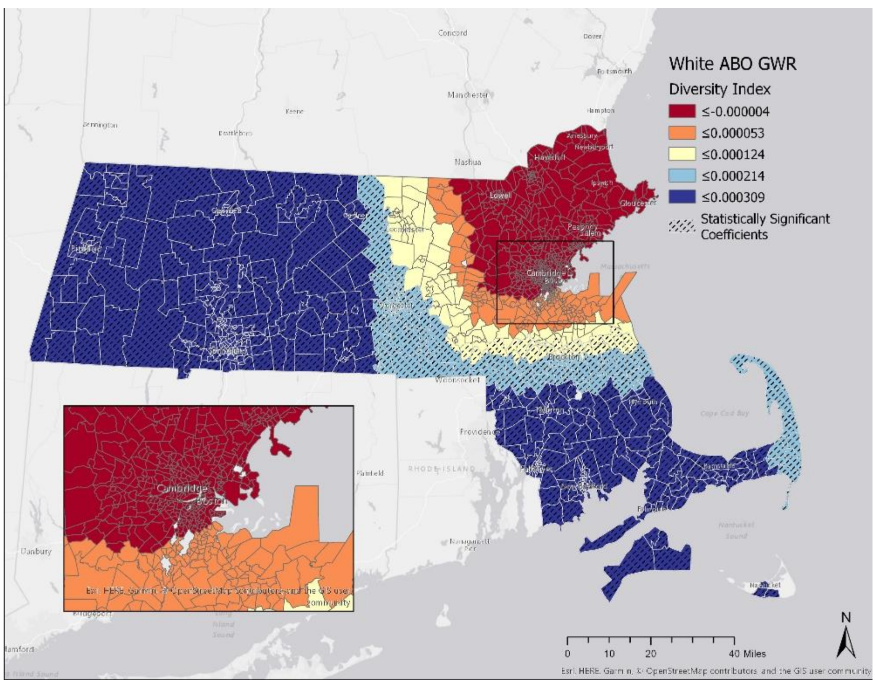
Appendix B

Appendix B-Error! Use the Home tab to apply 0 to the text that you want to appear here.**-2: Coefficient of Variation (CV) calculations for each of the AC variables used in the regressions.**

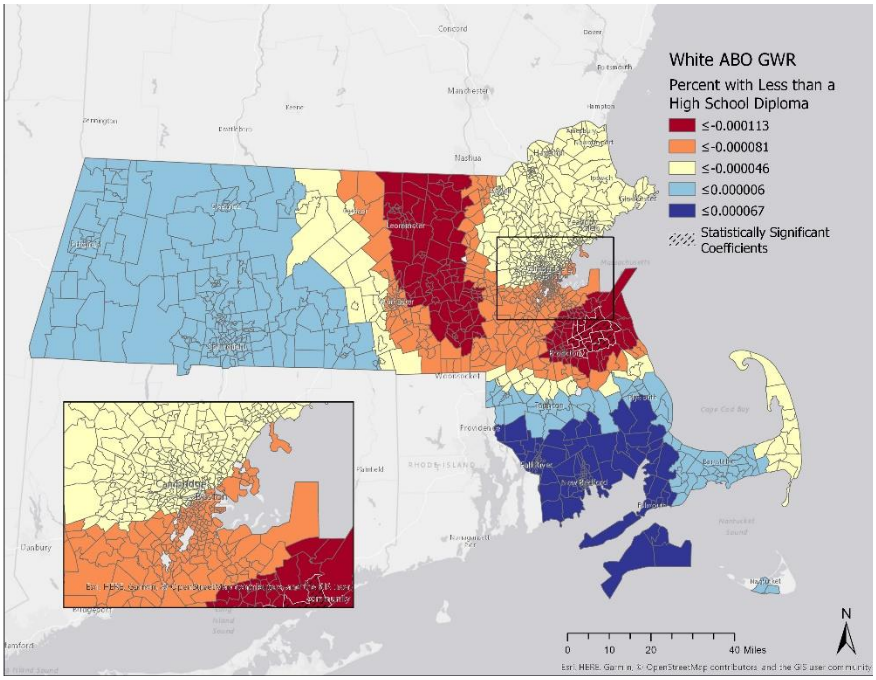
Variable	<12 (High)		12-40 (Moderate)		40+ (Low)		Number of Tracts With Data
	Number	Percent	Number	Percent	Number	Percent	
Unemployment Rate	1	0.07%	1121	76.99%	334	22.94%	1456
Percent with a Bachelor's Degree or Higher	580	39.81%	798	54.77%	79	5.42%	1457
Median Household Income	996	68.41%	449	30.84%	11	0.76%	1456

Per Capita Income	1290	88.11%	171	11.68%	3	0.20%	1464
Median Earnings for Full Time Female Employees	852	58.60%	573	39.41%	29	1.99%	1454
Percent Below Poverty	21	1.42%	959	65.02%	495	33.56%	1475
Percent with Less than a High School Diploma	1	0.07%	226	15.50%	1231	84.43%	1458

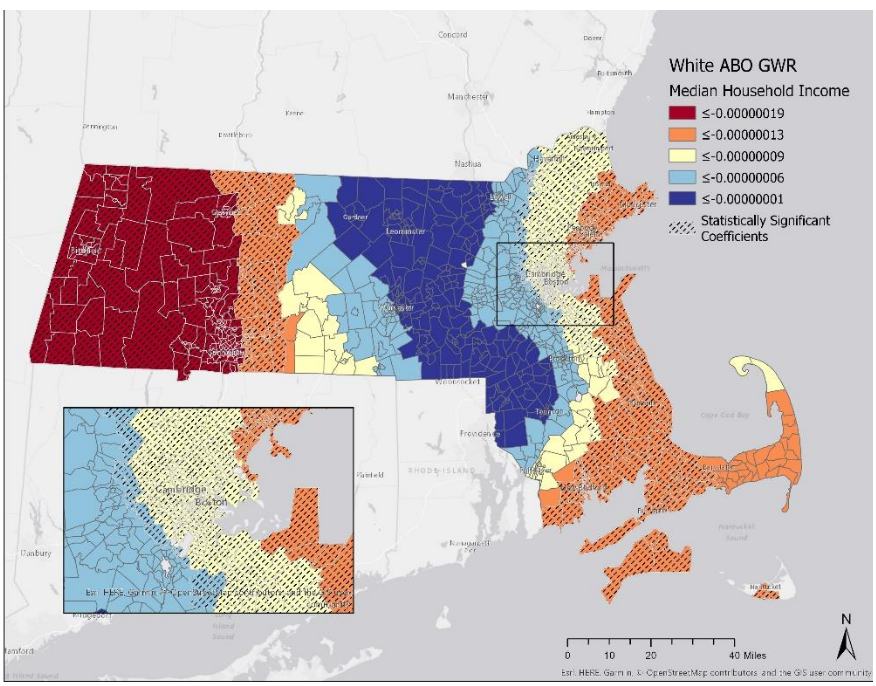
Appendix C



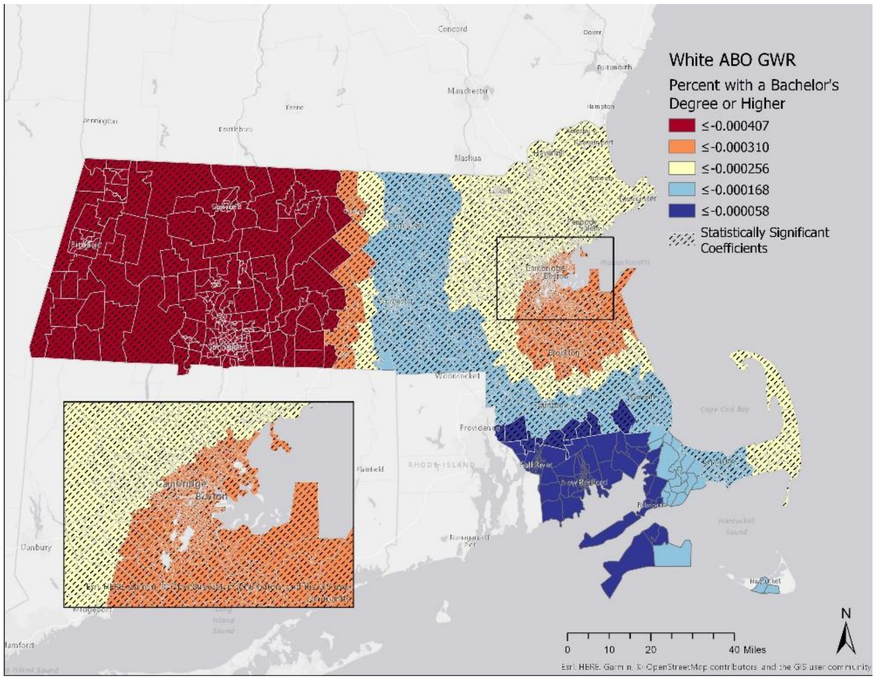
Appendix C-1: Coefficients and statistical significance for the diversity index in the White ABO GWR.



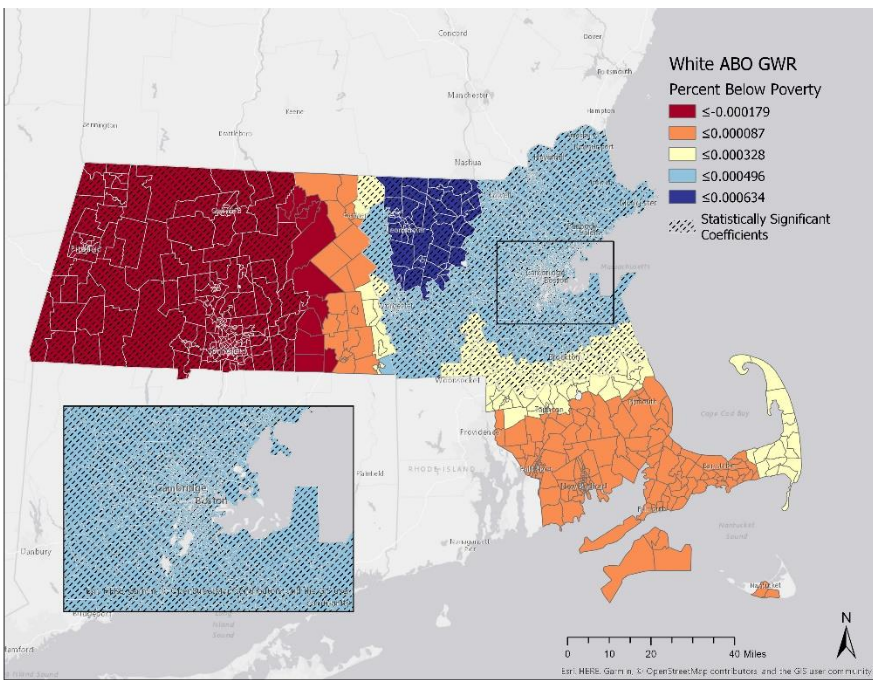
Appendix C-2: Coefficients and statistical significance for the percent with less than a high school diploma in the White ABO GWR.



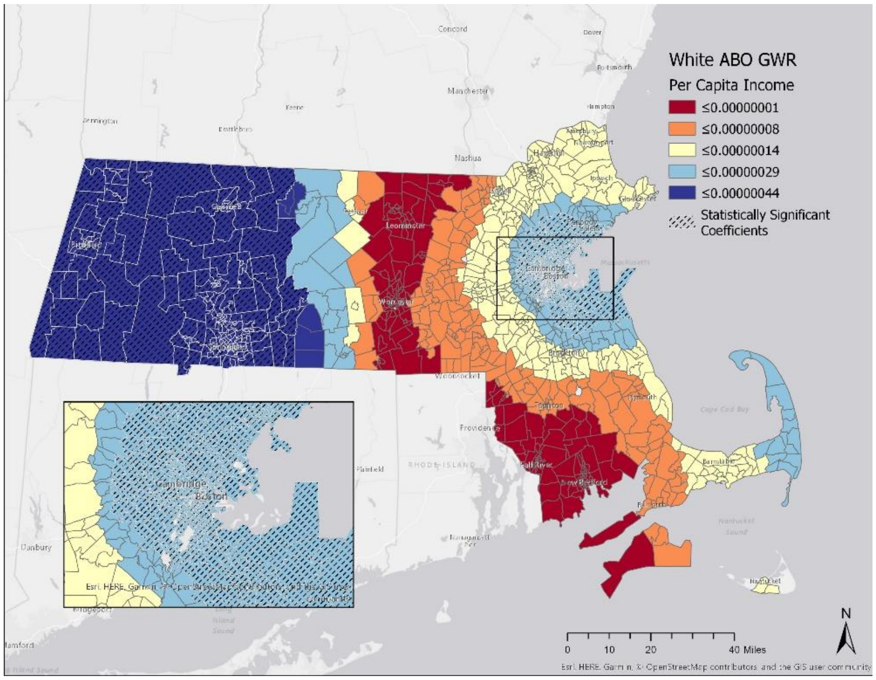
Appendix C-3: Coefficients and statistical significance for the median household income in the White ABO GWR.



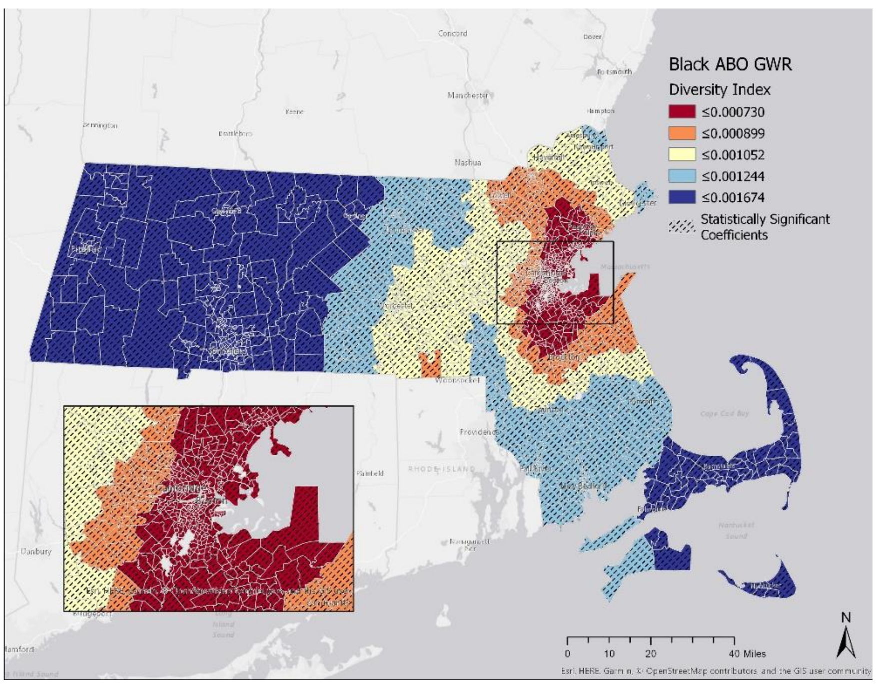
Appendix C-4: Coefficients and statistical significance for the percent with a Bachelor's degree or higher in the White ABO GWR.



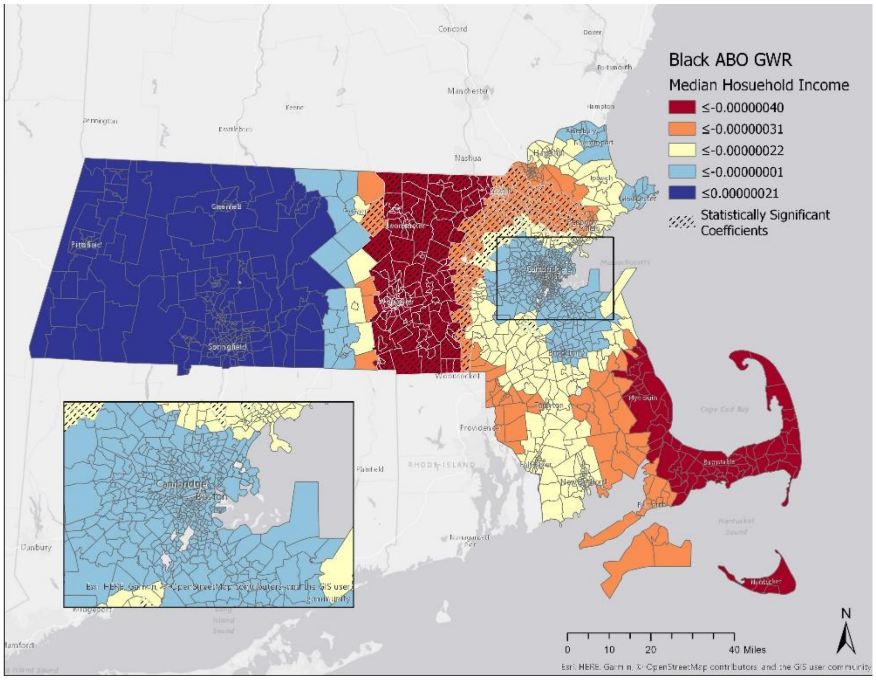
Appendix C-5: Coefficients and statistical significance for the percent below poverty in the White ABO GWR.



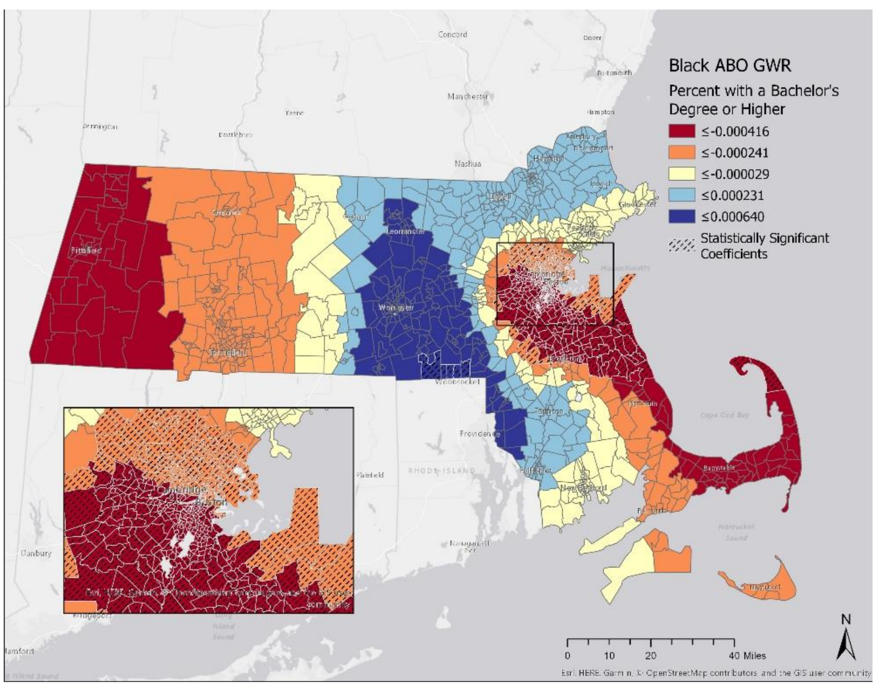
Appendix C-6: Coefficients and statistical significance for the per capita income in the White ABO GWR.



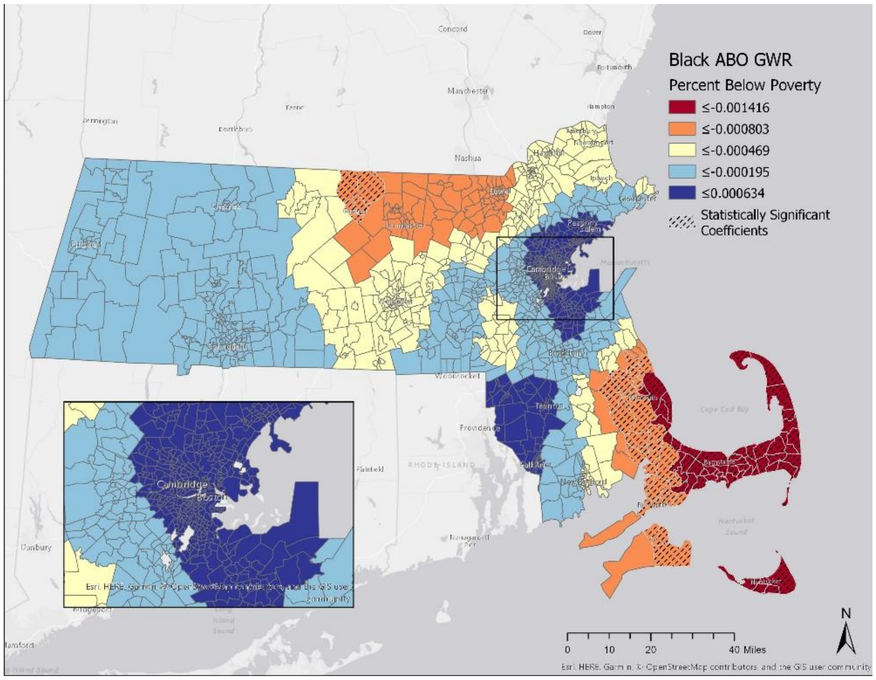
Appendix C-7: Coefficients and statistical significance for the diversity index in the Black ABO GWR



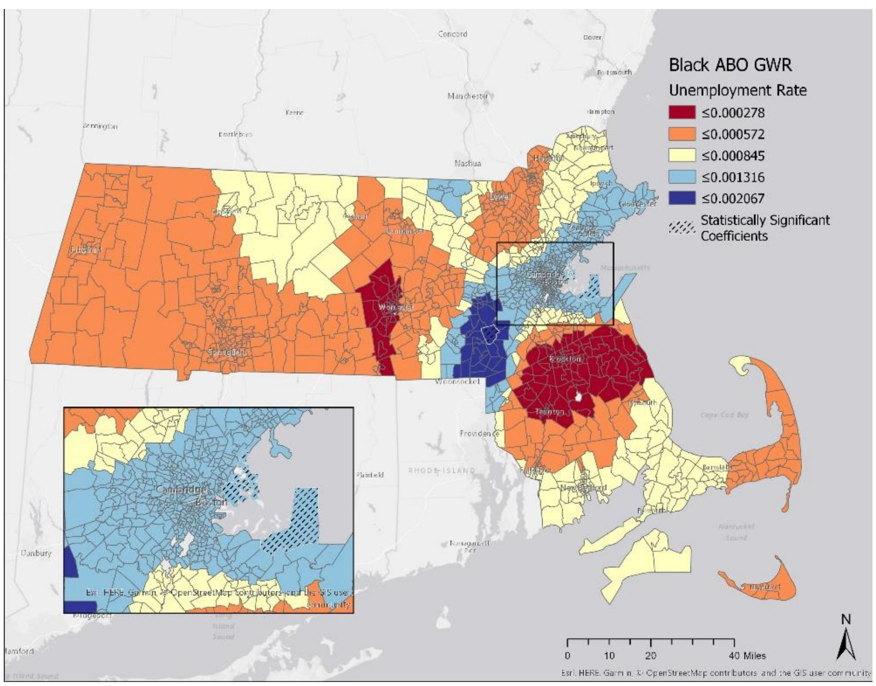
Appendix C-8: Coefficients and statistical significance for the median household income in the Black ABO GWR



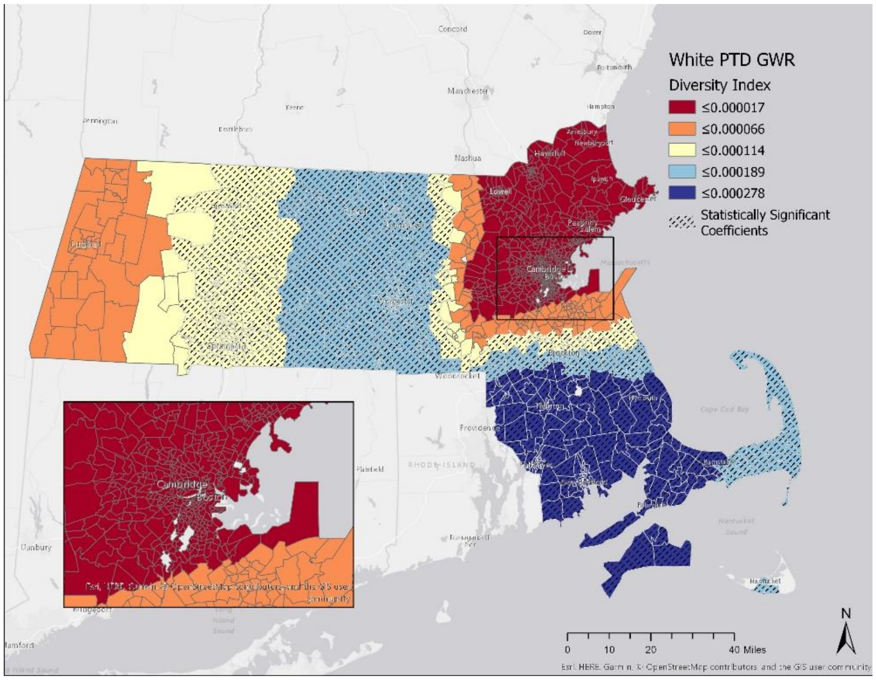
Appendix C-9: Coefficients and statistical significance for the percent with a Bachelor's degree or higher in the Black ABO GWR



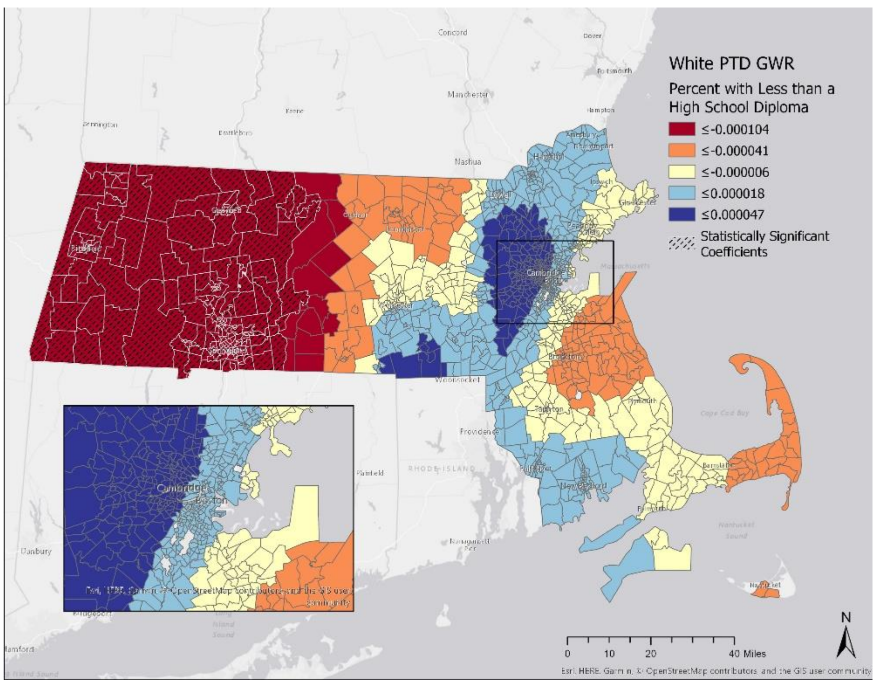
Appendix C-10: Coefficients and statistical significance for the percent below poverty in the Black ABO GWR



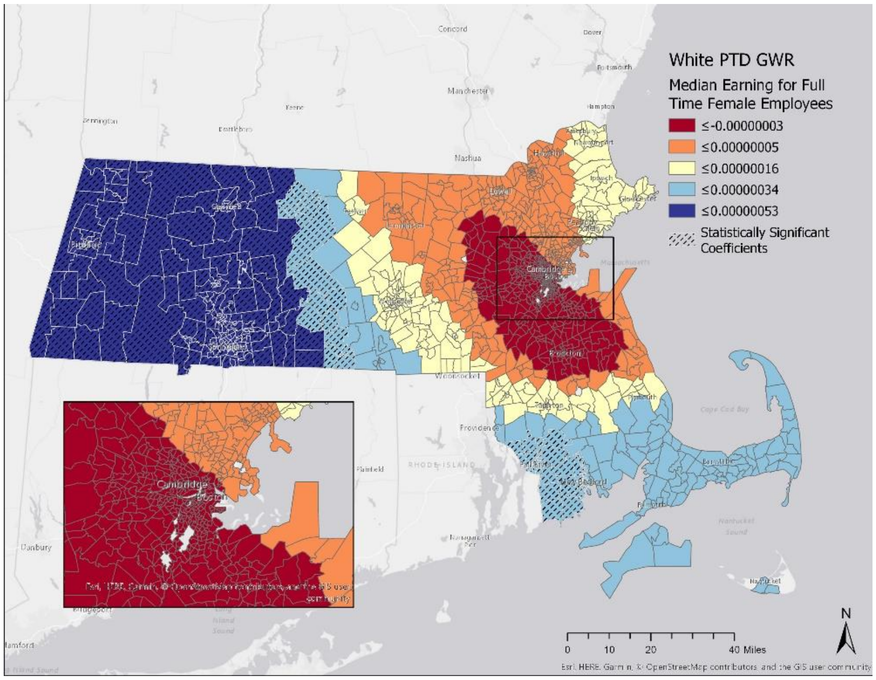
Appendix C-11: Coefficients and statistical significance for the unemployment rate in the Black ABO GWR



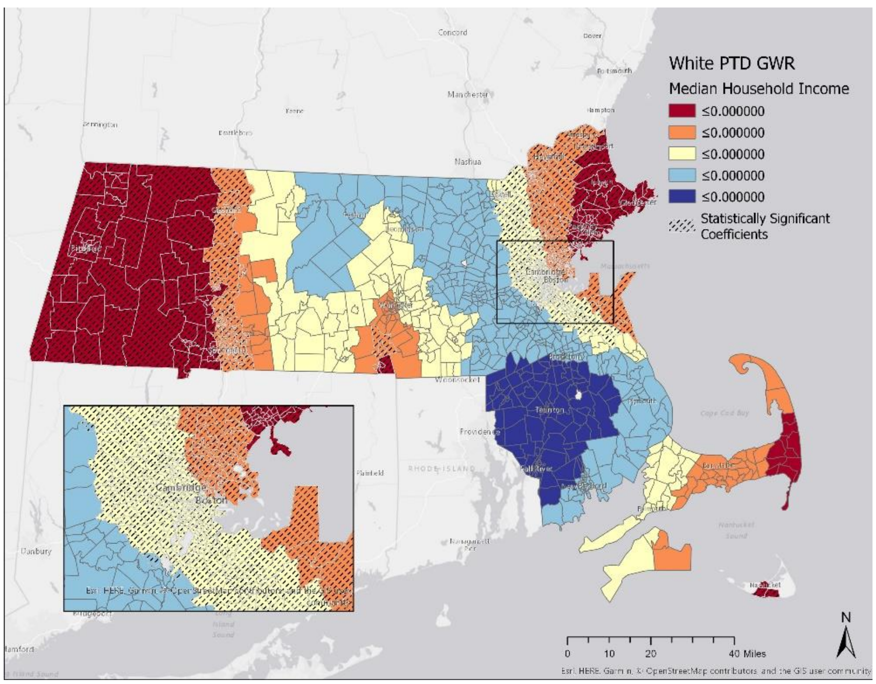
Appendix C-12: Coefficients and statistical significance for the diversity index in the White PTD GWR



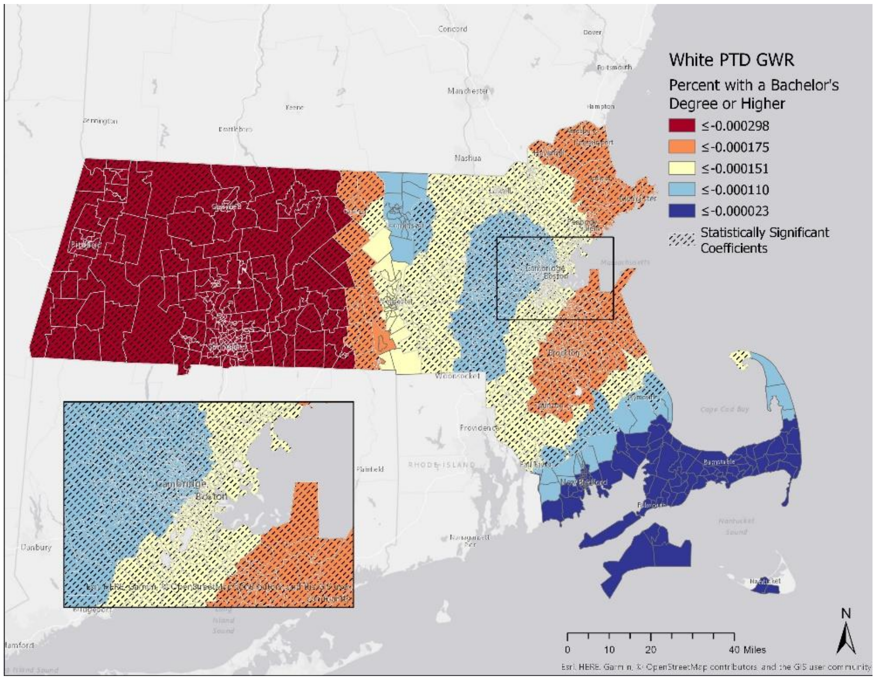
Appendix C-13: Coefficients and statistical significance for the percent with less than a high school diploma in the White PTD GWR



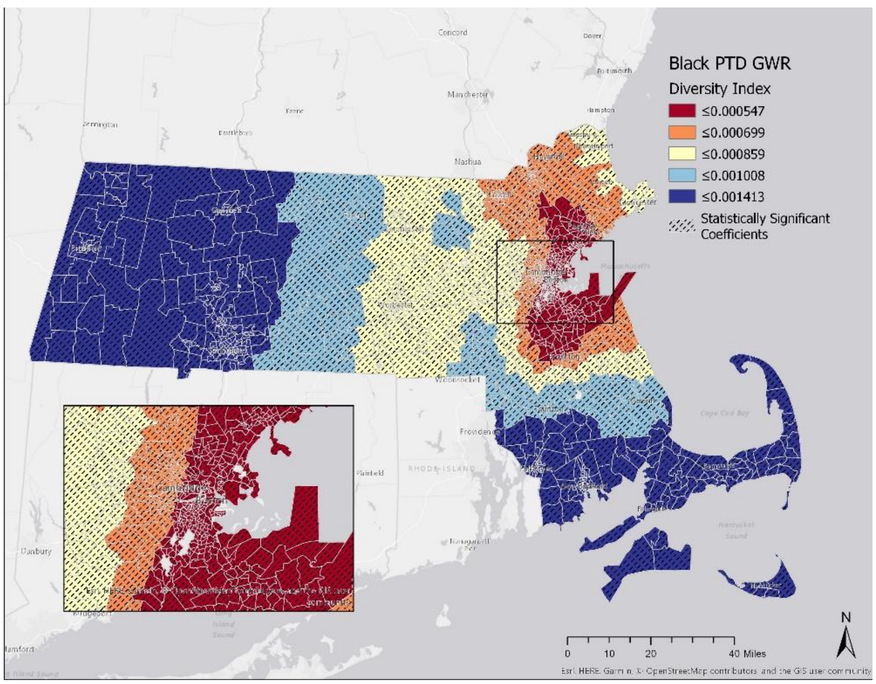
Appendix C-14: Coefficients and statistical significance for the median earnings for full time female employees in the White PTD GWR



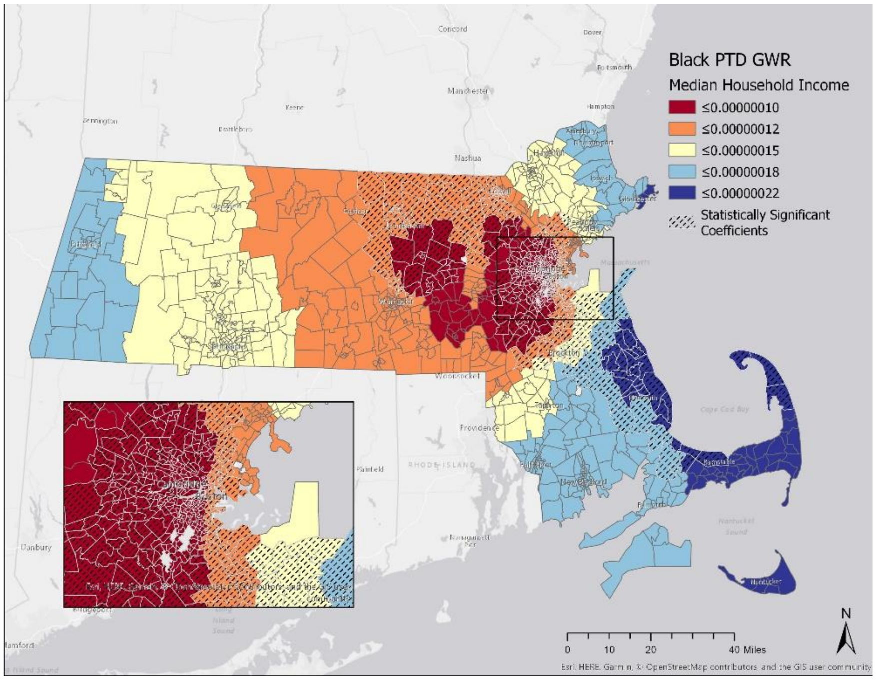
Appendix C-15: Coefficients and statistical significance for the median household income in the White PTD GWR



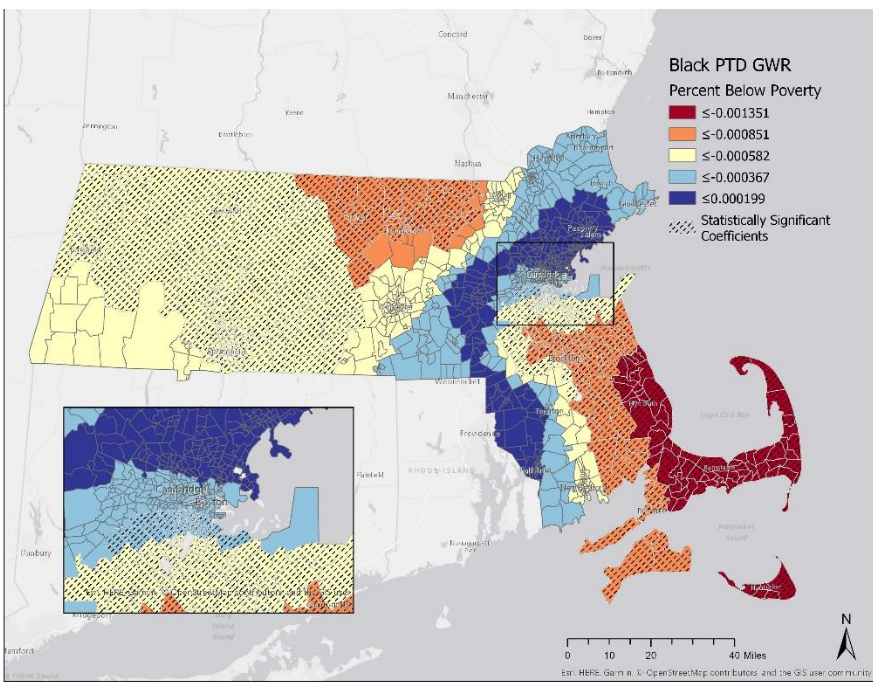
Appendix C-16: Coefficients and statistical significance for the percent with a Bachelor's degree or higher in the White PTD GWR



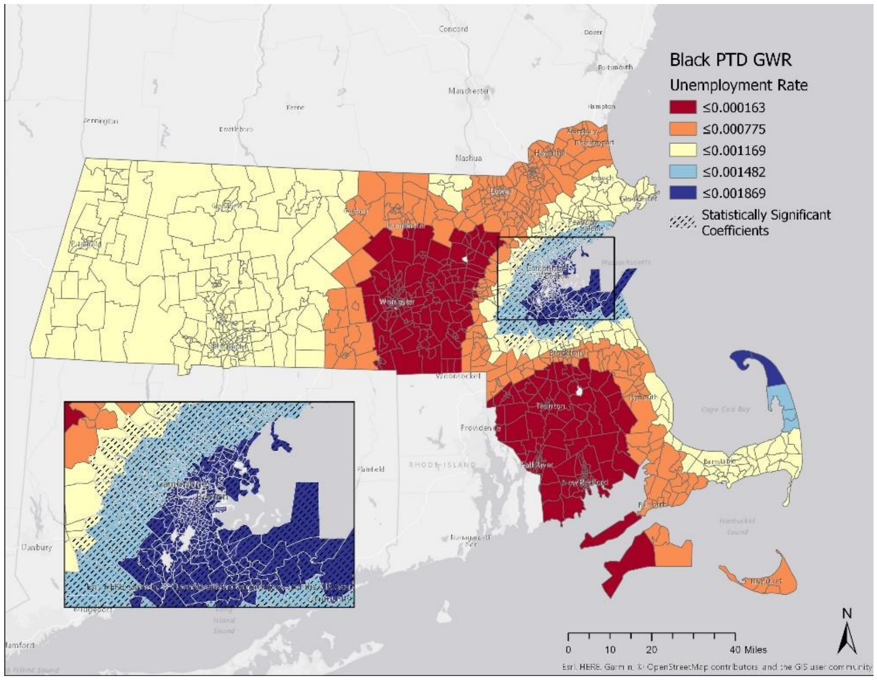
Appendix C-17: Coefficients and statistical significance for the diversity index in the Black PTD GWR



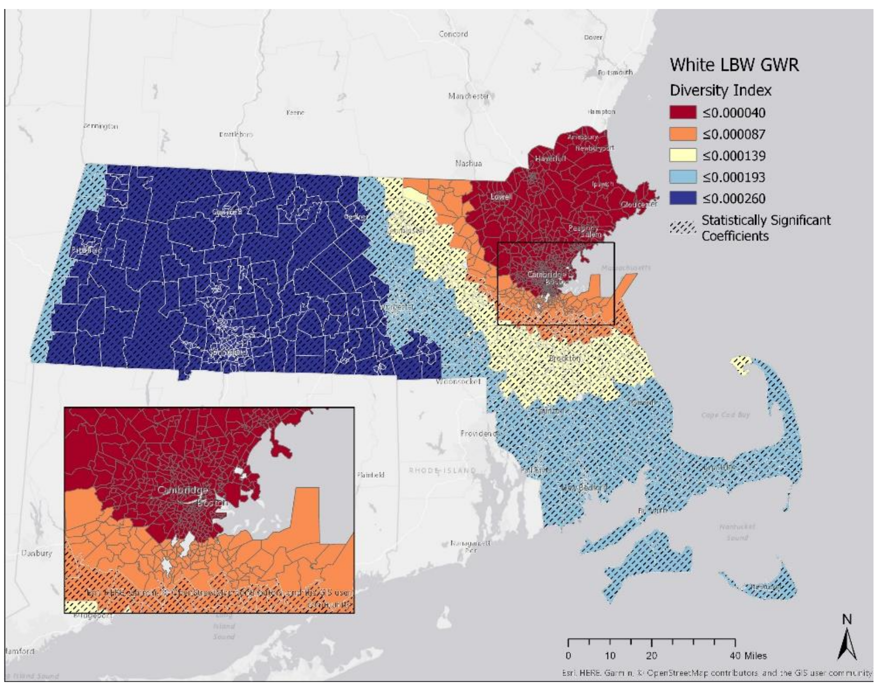
Appendix C-18: Coefficients and statistical significance for the median household income in the Black PTD GWR



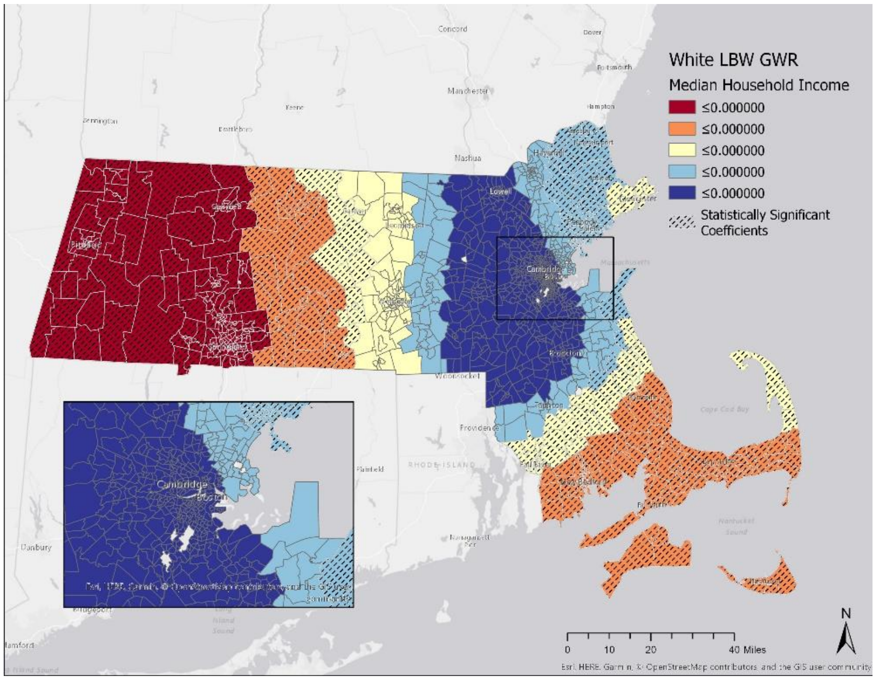
Appendix C-19: Coefficients and statistical significance for the percent below poverty in the Black PTD GWR



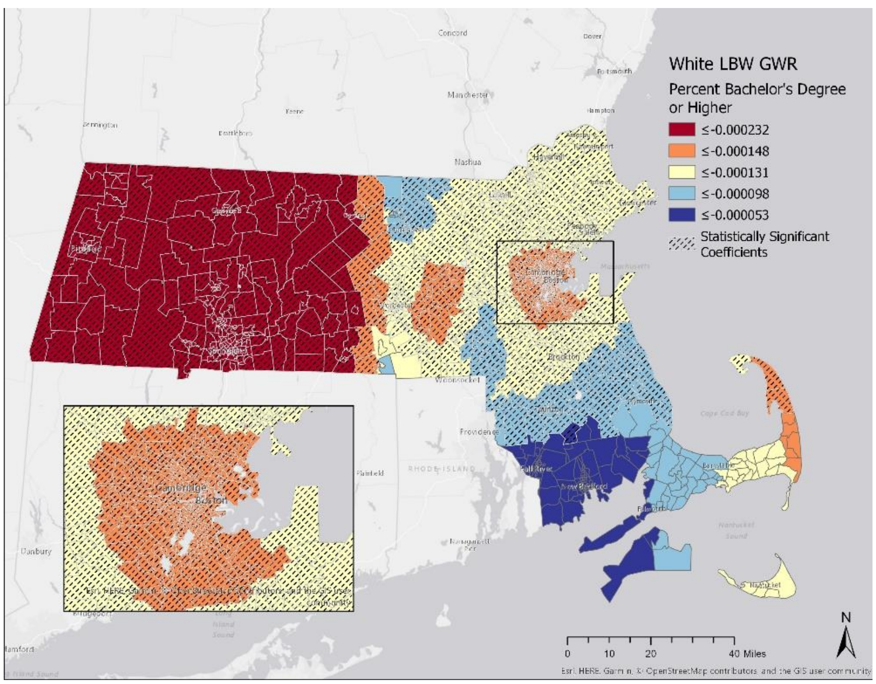
Appendix C-20: Coefficients and statistical significance for the unemployment rate in the Black PTD GWR



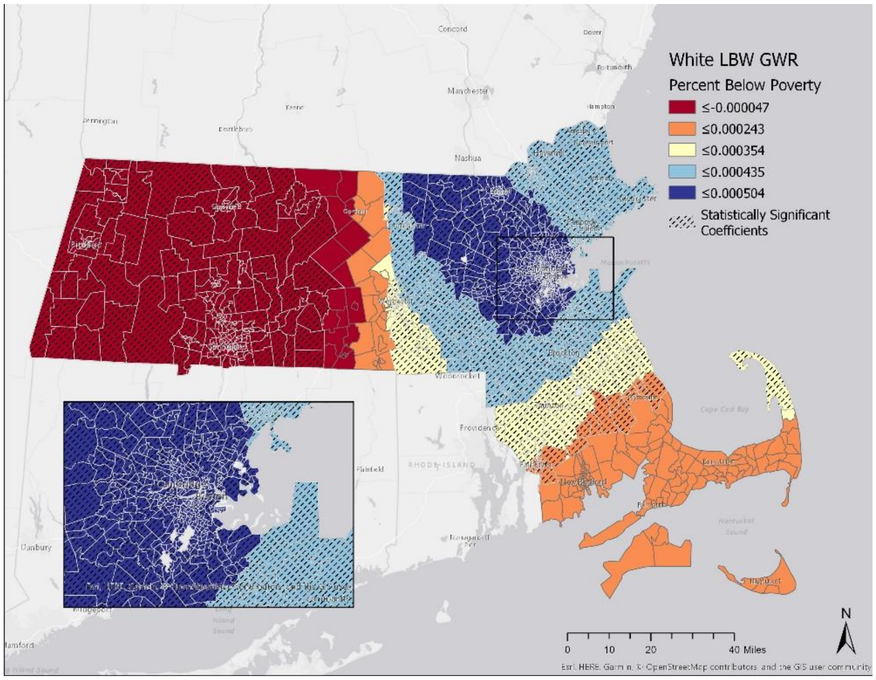
Appendix C-21: Coefficients and statistical significance for the diversity index in the White LBW GWR



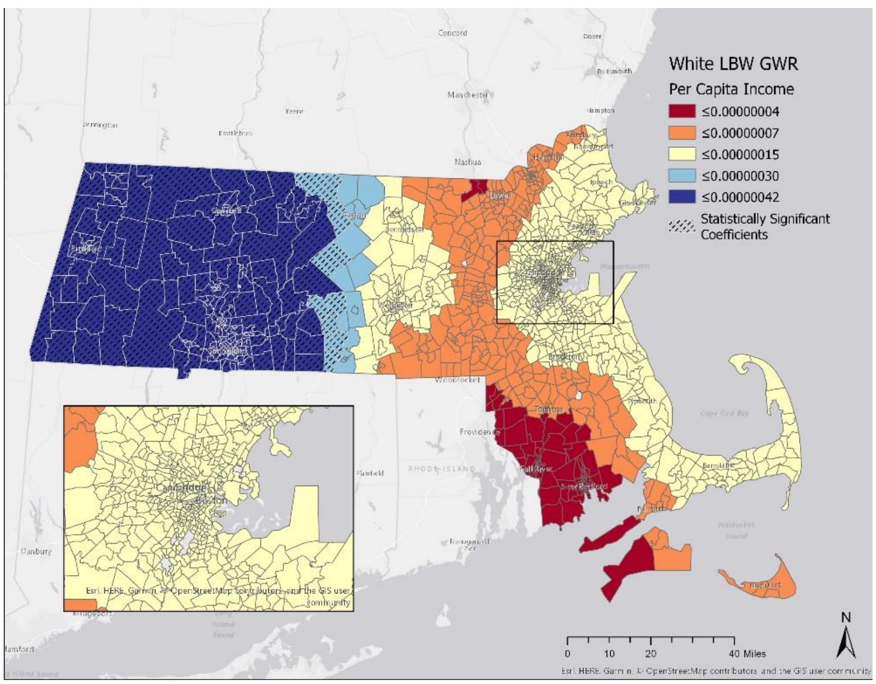
Appendix C-22: Coefficients and statistical significance for the median household income in the White LBW GWR



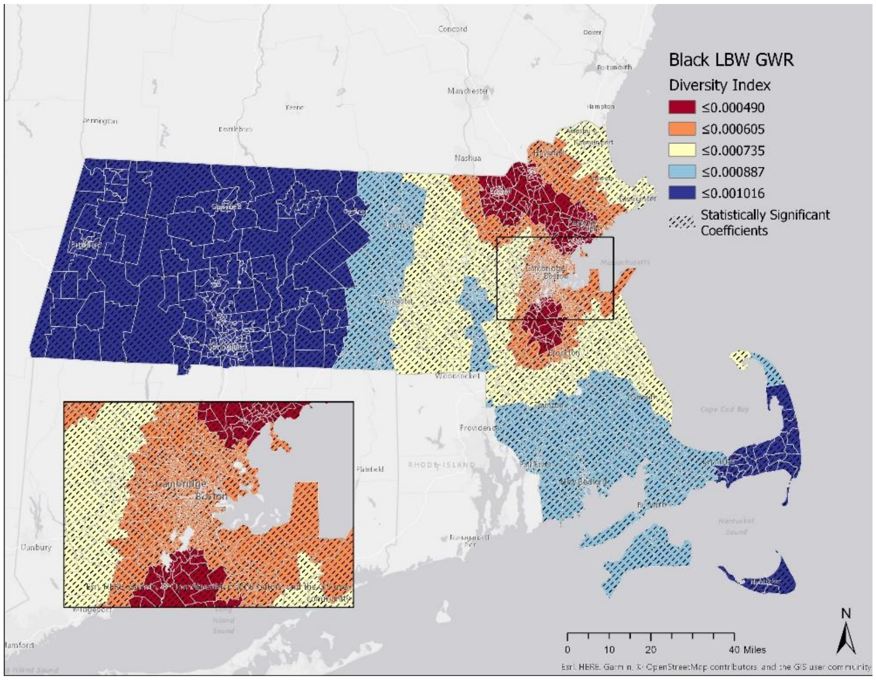
Appendix C-23: Coefficients and statistical significance for the percent with a Bachelor's degree or higher in the White LBW GWR



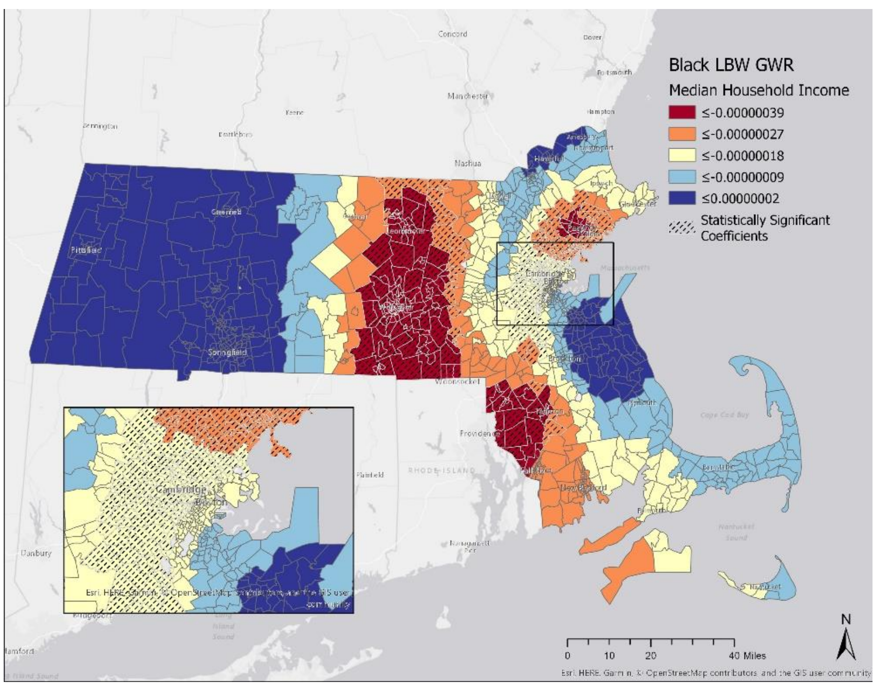
Appendix C-24: Coefficients and statistical significance for the percent below poverty in the White LBW GWR



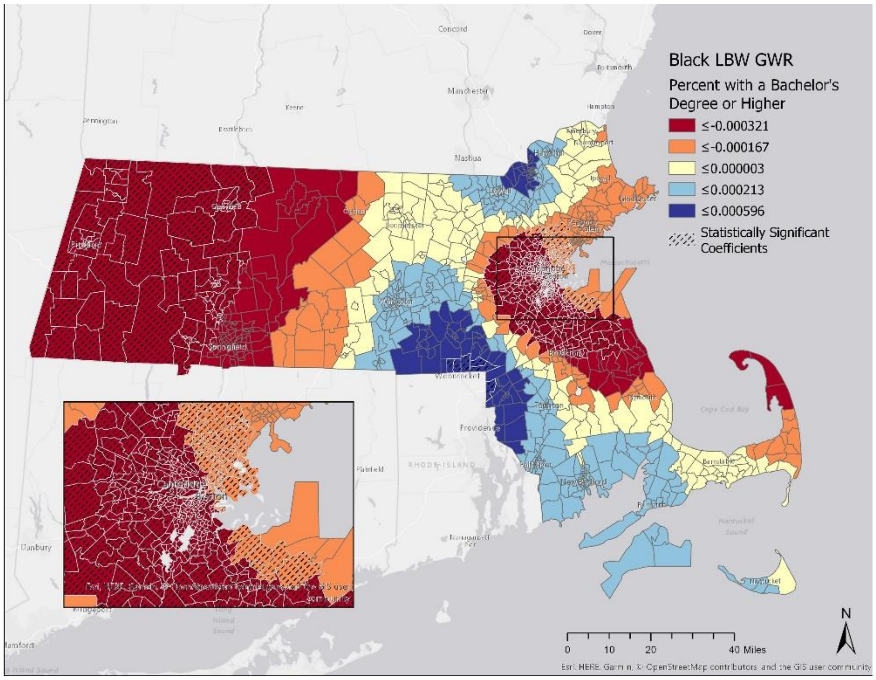
Appendix C-25: Coefficients and statistical significance for the per capita income in the White LBW GWR



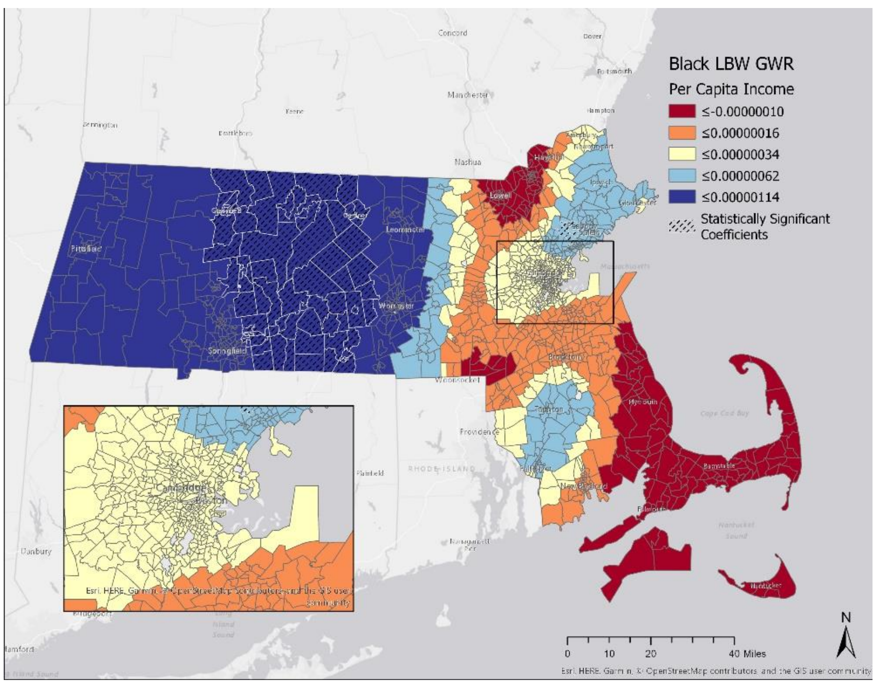
Appendix C-26: Coefficients and statistical significance for the diversity index in the Black LBW GWR



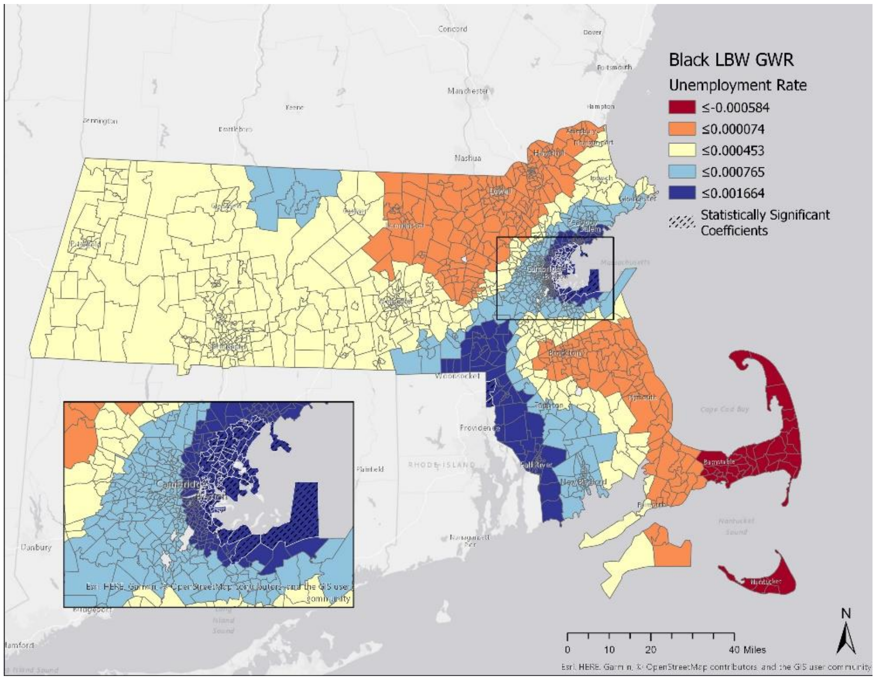
Appendix C-27: Coefficients and statistical significance for the median household income in the Black LBW GWR



Appendix C-28: Coefficients and statistical significance for the percent with a Bachelor's degree or higher in the Black LBW GWR



Appendix C-29: Coefficients and statistical significance for the per capita income in the Black LBW GWR



Appendix C-30: Coefficients and statistical significance for the unemployment rate in the Black LBW GWR