Changes in the Geographic Patterns of Heart Disease Mortality in the United States:

1973 to 2010

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Abstract

Background—Although many studies have documented the dramatic declines in heart disease mortality in the United States at the national level, little attention has been given to the temporal changes in the geographic patterns of heart disease mortality.

Methods and Results—Age-adjusted and spatially smoothed county-level heart disease death rates were calculated for 2-year intervals from 1973 to 1974 to 2009 to 2010 for those aged   35 years. Heart disease deaths were defined according to the *International Classification of Diseases* codes for diseases of the heart in the eighth, ninth, and tenth revisions of the *International Classification of Diseases*. A fully Bayesian spatiotemporal model was used to produce precise rate estimates, even in counties with small populations. A substantial shift in the concentration of high-rate counties from the Northeast to the Deep South was observed, along with a concentration of slow-decline counties in the South and a nearly 2-fold increase in the geographic inequality among counties.

Conclusions—The dramatic change in the geographic patterns of heart disease mortality during 40 years highlights the importance of small-area surveillance to reveal patterns that are hidden at the national level, gives communities the historical context for understanding their current burden of heart disease, and provides important clues for understanding the determinants of the geographic disparities in heart disease mortality.

Keywords

epidemiology; heart diseases; mapping; mortality

Surveillance studies of heart disease mortality in the United States have documented important temporal trends by race, sex, and age group during the past 4 decades.[1–3] Little

attention, however, has been given to temporal changes in the geographic patterns of heart disease mortality during this time period. The earliest published map, depicting heart disease death rates by state during the early 1950s, documents geographic disparities with the highest rates located primarily in the Northeast.[4] Subsequent studies that use a variety of geographic units (eg, county, state economic area, health service area, state) have documented geographic disparities in the rates and the rates of decline in heart disease mortality at various times,[4–13] but no studies have systematically monitored changes in the pattern of geographic disparities in heart disease mortality among US communities during this extended time period. Small-area surveillance of heart disease mortality is important because it can reveal patterns that are masked at the national level, give communities the historical context for understanding their current burden of heart disease, and inform the development of hypotheses regarding the geographic disparities in heart disease mortality.

The ability to generate statistically stable rates for geographic units with small populations has been a challenge to small-area surveillance of heart disease mortality. Relatively recent developments in statistical methodologies, in particular, the application of Bayesian techniques,[14] have enhanced the ability to produce statistically rigorous and stable heart disease mortality estimates at the local level. In this study, we use a spatiotemporal Bayesian model to examine the geographic patterns of heart disease mortality among US counties from 1973 to 2010. A similar model was used by Quick and colleagues[15] in an analysis of asthma hospitalization rates in California counties. We document 3 dimensions of the spatiotemporal trends in county-level heart disease mortality in the United States: (1) changing geographic patterns of heart disease mortality over time; (2) geographic variation in rates of declining heart disease mortality; and (3) changing magnitude of disparity in heart disease mortality among counties.

Methods

Data Sources

The study population includes all residents of the contiguous United States aged 35 years. Annual numbers of heart disease deaths per county were obtained from the National Vital Statistics System of the National Center for Health Statistics. We analyzed data from 1973 to 2010, because this period ensures complete rather than sampled death records. Deaths from heart disease were defined as those for which the underlying cause of death was diseases of the heart according to the of the *International Classification of Diseases, Eighth, Ninth,* and *Tenth Revision* (ICD-8, ICD-9, and ICD-10; ICD-8 [1973–1978]: 390–398, 402, 404, 410–429; ICD-9 [1979–1998]: 390–398, 402, 404, 410–429; ICD-10 [1999–present]: I00–I09, I11, I13, I20–I51).[16,17] The comparability ratios between each ICD revision are very close to unity for diseases of the heart; therefore, no adjustments for ICD coding changes were necessary (ie, comparability ratios=1.0126 and 0.9858 for ICD-8–9 and ICD-9–10, respectively).[16,17] Annual population counts were obtained from the bridged-race files produced by the US Census Bureau and National Center for Health Statistics.[18] Heart disease death rates per 100 000 were calculated and directly age-standardized to the 2000 US Standard Population by using 10-year age groups.[19]

Calculating Heart Disease Death Rates and Percentage Change

The county is the unit of analysis. Given changes in some county definitions during the study period, a single set of 3099 counties from the contiguous 48 states was used for the entire study period. To enhance statistical stability, we aggregated county-level, age-standardized counts, and populations into 2-year intervals (eg, from 1973–1974 to 2009–2010).

To further improve the statistical stability of estimated heart disease death rates, we used a fully Bayesian spatiotemporal model to estimate age-standardized, county-level heart disease death rates. By borrowing strength across both space and time, Bayesian models can produce precise rate estimates, even in areas with sparse populations. Our model, which accounts for temporal correlation of rates within a given county and spatial correlation of rates across adjacent counties, estimates heart disease death rates as a function of spatiotemporally evolving model parameters (see online-only Data Supplement). Because Bayesian models output posterior distributions for each model parameter, we were able to calculate the posterior distribution for the expected heart disease death rate for each county at each 2-year interval. From these posterior distributions, we then obtained the posterior median (ie, the frequentist point estimate) and the 95% Bayesian credible interval (the Bayesian analog of a classical 95% confidence interval) for each county and each 2-year interval. Details about our model, including the specification of prior distributions and details for its implementation in a Markov chain Monte Carlo algorithm, are provided in the online-only Data Supplement.

To quantify county-specific temporal changes in heart disease death rates for the entire study period, we also used the posterior distributions of the parameter estimates to calculate percentage decline from 1973 to 2010. County-level percentage declines were considered statistically significant if the 95% Bayesian credible interval for percentage decline excluded zero.

Quantifying Geographic Disparities in Heart Disease Death Rates

To assess statistically significant spatial disparities among counties, we generated local indicators of spatial association (LISA) statistics for county rates within each time interval and for county percentage declines for the entire study period.[20] As a local correlate of the Moran I, the LISA statistics indicate the degree to which counties with higher (or lower) than expected death rates tend to cluster with neighboring counties that also have higher (lower) than expected death rates. Thus, the LISA statistics highlight patterns of local and regional spatial clustering in the heart disease death rates, with statistically significant clustering being identified by counties whose 95% Bayesian credible interval for the LISA statistic excludes 0. For ease of visualizing spatial patterns, we present maps of both the modeled heart disease death rates and the LISA statistics for the beginning and end of the study period (Figures 1 and 2). Finally, we measured temporal change in relative geographic inequality in heart disease mortality among counties by using the coefficient of variation (CoV).[21] We calculated the CoV because it uses the full distribution of county-specific rates to measure the amount of geographic inequality rather than relying on the tails of the distribution for calculating a disparity ratio. The CoV is defined as the standard deviation of

county-level heart disease death rates for each 2-year time interval divided by the mean rate for the respective time period. A large CoV indicates more inequality in the rates among counties. We then assessed the temporal change (measured as percent change) in the CoV for the entire study period.

The Bayesian statistical model used in this analysis to generate the county rates and the LISA statistics was implemented using R statistical software, the maps were created using ESRI ArcMap software (version 10.1), and data management was performed using SAS.[22–24] Details for computing all the summary statistics can be found in the online-only Data Supplement.

Results

At the beginning of the study period (1973–1974), the largest concentration of high-rate counties (defined as counties in the top quintile) formed an arc stretching from the Northeast through much of Appalachia and into the Midwest (Figure 1A). High-rate counties were also concentrated along the coastal areas of North Carolina, South Carolina, and Georgia. An East-West gradient was apparent with nearly all top-quintile counties located in the eastern half of the country and the majority of bottom-quintile counties in the western half. However, small groups of low-rate counties were also observed in Alabama, Florida, and parts of Mississippi. By the end of the study period in 2009 to 2010, the strong concentration of high-rate counties in the Northeast had dissipated, and a large concentration of high-rate counties emerged in the South and southern Appalachia (Figure 1B). The East-West gradient was still largely intact with low-rate counties found primarily in the West. The declines in heart disease death rates that occurred during the study period are reflected in the lower quintile cut points in 2009/2010 in comparison with 1973/1974.

LISA maps depicting statistically significant spatial clusters of high- and low-rate counties further reveal the shift of the high-rate counties from the Northeast to the South (Figure 2). Whereas most of the high-rate clusters were in the Northeast and Midwest at the beginning of the study period, by 2009 to 2010, the vast majority of high-rate clusters were south of the Mason-Dixon line. Geographic changes in the low-rate clusters also occurred, with the disappearance of many low-rate clusters from Texas and New Mexico and the appearance of low-rate clusters in New England. Low-rate clusters in Florida and parts of the Pacific Northwest were maintained during the study period.

Video animation of temporal changes in the geographic pattern of heart disease mortality for each of the 19 2-year periods in this study demonstrates the progression of high-rate counties from the Northeast to the South, and is available in Figure I in the online-only Data Supplement.

Temporal changes in the percentage of all counties that were in the highest quintile by US Census region also demonstrate the transition of high-rate counties from the Northeast to the South (Figure 3). Although the percentage of high-quintile counties located in the North dropped dramatically from 48% at the beginning of the study to 4% by the end, and a similar

trend was observed in the Midwest (from 17% to 6%), the opposite trend was observed in the South—the percentage of high-quintile counties increased from 24% to 38%.

Substantial geographic variation in declining heart disease death rates was observed during the study period, with percentage declines ranging from 9.2% to 83.4% among US counties (Figure 4). Counties in the quintile with the slowest declines (9.2%–49.6%) were concentrated primarily in the southern states of Alabama, Mississippi, Louisiana, Arkansas, Oklahoma, and parts of Texas. Counties in the quintile with the fastest declines (64.1%– 83.4%) were located largely in the northern half of the country with the exception of fast declines among counties in Florida and South Carolina. The average percentage decline for the United States was 61.6%. The LISA map of declining heart disease death rates depicts a large southern concentration of counties with slow declines and a prominent concentration of fast declines in the Northeast (Figure 5).

The magnitude of relative geographic disparity in heart disease death rates among counties, as measured by the coefficient of variation, increased briefly during the late 1970s and then rose steadily from 1985 to 2010 (Figure 6). The coefficient of variation increased by an average of 3.62% each year, and the magnitude of geographic inequality doubled from the beginning to the end of the study period.

Discussion

This spatiotemporal study of heart disease mortality in the United States (1973–2010) documents a substantial shift in the concentration of high-rate counties from the Northeast to the South. The shift was accompanied by geographic disparities in the rates of declining heart disease mortality (with the slowest declines concentrated primarily among southern counties), and a 2-fold increase in the magnitude of geographic disparities among US counties. These observations highlight the importance and power of studies of small-area surveillance data to identify patterns that are masked at the national level, generate hypotheses regarding determinants of the changing geographic patterns, and provide information that can be used to tailor heart disease prevention programs and policies to communities with the greatest burden.

Previous studies provide snapshots of geographic disparities in heart disease mortality at various points in time using a variety of geographic units, age groups, and definitions of heart disease.[4,6–10] The one consistent pattern is the East-West gradient, with higher rates concentrated in the East and lower rates in the West. Only one other study that we are aware of compared the patterns of geographic disparities in heart disease mortality over time.[10] Similar to our findings, but using Health Service Areas and for a shorter time period (1979/1981–1991/1993), Pickle and Gillum[10] reported a southwesterly shift in coronary heart disease death rates for white men from West Virginia to the southern sections of the Mississippi River Valley. Our study also expands on a rich literature documenting geographic disparities in rates of declining heart disease mortality in the United States for selected time intervals. Studies have documented state-level disparities in declining heart disease death rates from 1999 to 2007,[8] geographic disparities among state economic areas in the onset of declining heart disease mortality in the 1960s and 1970s,[12] slower rates of

declines among Metropolitan Statistical Areas for black women and men in comparison with white women and men from 1985 to 1995,[5] the impact of model choice on measuring spatiotemporal disparities in heart disease mortality at the county level,[11] and the timing of declines by race and sex.[25]

In our study, the observed combination of a steady progression of high-rate counties from the Northeast to the South, together with the southern concentration of counties with the slowest declines in heart disease mortality, suggest these patterns did not occur randomly. Instead, the results emphasize the importance of place for health outcomes[26] and suggest that there may have been systematic spatiotemporal changes in conditions that affect heart disease death rates. Studies have identified many interwoven dimensions of place that have implications for the burden of heart disease, including social and economic conditions,[27–29] the built environment,[30] healthy public policies,[31] prevalence of biomedical and behavioral risk factors,[32,33] and access to quality health care.[34,35] Hypotheses for understanding the contributing factors to the observed spatiotemporal trends in heart disease mortality will need to consider spatiotemporal trends in these conditions, and migration patterns, as well.

Spatiotemporal studies of risk factor prevalences associated with heart disease mortality are scarce, in large part because of the lack of historical risk factor data at the local level. Only 3 studies that we are aware of examined temporal changes in the following 4 county-level risk factor prevalences (albeit for much shorter time periods than our study): cigarette smoking (1996–2012),[36] hypertension (2001–2009),[37] obesity (2001–2011),[38] and physical activity (2001–2011).[38] Each study used small-area estimation statistical techniques to generate county-level estimates from data that were collected at the state or national levels. Temporal changes in the geographic pattern of cigarette smoking showed similarities to the changes we observed for heart disease mortality. For instance, counties in the Northeast started out with high prevalences of cigarette smoking in 1996, but by 2012 the Northeast counties had predominantly low prevalences of cigarette smoking.[36] In general, however, these studies reported little change in the geographic patterns of these risk factors over time. For hypertension, obesity, and physical activity, counties with the highest prevalences tended to be concentrated in the South at both the beginning and end of the study periods.[37,38] The absence of changes in the geographic patterning of these risk factors could reflect the following: (1) study periods that are too short to capture meaningful change in geographic patterns, (2) imprecision of the statistical techniques, or (3) a true absence of change in the geographic patterns of these risk factors.

Spatial and temporal variations in the enactment of healthy public policies, ranging from tobacco control to housing and transportation, are important to consider given the widespread implications these policies have for creating and sustaining heart-healthy living and working conditions.[31] Although historical data about the timing of state and local policy implementation can be challenging to locate, they can be very informative. For instance, state-level implementation of smoke-free indoor air legislation and increases in excise tax rates on cigarettes were both implemented initially in Northeastern and Western states during the early 2000s, but by 2014 there was still weak or no implementation of these policies in the South.[39] Smoke-free environments may be particularly relevant given

evidence that secondhand smoke affects nonsmokers' risk, and thus, population variation could arise independent of the overall smoking prevalence.

The time period of this study coincides with major regional transitions in labor and industrialization policies in the United States. Historians have noted that many of the federal and state policies to increase the industrial base in the South often had negative implications for the social and economic conditions of the region.[40,41] Given the well-documented associations between socioeconomic conditions and heart disease outcomes and risk factors,[27–30] further study is warranted to examine the potential contributions of spatiotemporal changes in socioeconomic conditions to the spatiotemporal changes observed in heart disease mortality.

The near doubling of the magnitude of geographic inequality in heart disease mortality among US counties is concerning, especially in light of the Healthy People 2020 goals to reduce disparities in heart disease mortality.[42] Increases in relative geographic disparity were initially reported by Wing et al for coronary heart disease mortality from 1962 to 1982,[43] and have been reported for cardiovascular disease and all-cause mortality in the United States and Britain.[44–46] Phelan and Link[47] demonstrate that widening sociodemographic and geographic gaps occur when there are large declines in diseases for which successful prevention activities have been established, as is true for heart disease. They argue that the ability to benefit from advances in disease prevention policies and programs is unequally distributed according to the social and economic standing of individuals and communities, thereby leading to differential rates of decline and subsequent widening of disparities. The potential for high-risk strategies for heart disease prevention (ie, interventions aimed at individual-level changes in knowledge, motivation, and behavior) to increase disparities in the burden of heart disease has been noted given the differential resources available to individuals and communities to make and sustain such changes.[48]

Strengths

An important strength of this study is the use of a fully Bayesian spatiotemporal model to produce county-level estimates of heart disease mortality during an extended time period. By borrowing statistical strength across both space (neighboring counties) and time (the preceding and subsequent time intervals), the Bayesian model produces county estimates and variances for smaller populations that are more precise than other statistical methods.[11] Our use of the LISA statistic provides an additional measure of statistical significance for documenting the spatiotemporal trends in heart disease mortality. Furthermore, this study is the first consistent and comparable long-term analysis of geographic disparities in heart disease mortality from the early 1970s through 2010.

Limitations

The reliance on death certificates for studies of geographic disparities in mortality poses several limitations. One limitation is the potential for misclassification caused by inaccuracy in the cause of death as reported on the death certificate. By using the broadest ICD category, diseases of the heart,[17] we substantially minimized the potential for misclassification that exists when death certificates are used to study subtypes of heart

disease.[49,50] Furthermore, the comparability ratios between ICD revisions for diseases of the heart are near 1.0, indicating no bias from ICD coding changes over time.[17] In contrast, the comparability ratios for several subtypes of heart disease reflect changes in the definitions, especially in the early years, which introduces bias into the temporal trends. For example, the comparability ratio for coronary heart disease was only 0.87 between ICD-8 and ICD-9, and, because of even larger changes in the definition of heart failure, no comparability ratio for heart failure was reported between ICD-8 and ICD-9.

However, the use of the broad category, diseases of the heart, also introduces a limitation—the inability to examine whether spatiotemporal trends in heart disease subtypes (eg, coronary heart disease [CHD] and heart failure) contributed differentially to the overall changes in the geographic pattern of heart disease mortality. Variations in the etiology and strength of risk factors by heart disease subtype could have implications for the determinants of the patterns observed in this study. However, given that CHD accounts for the majority of declines in diseases of the heart (94% of declines in all diseases of the heart from 2000 to 2010 were attributable to declines in CHD),[51] that CHD and heart failure share important risk factors and that CHD itself is a very strong risk factor for heart failure,[52,53] the category diseases of the heart is the most practical and reliable definition for studying spatiotemporal changes over nearly 40 years.

Another limitation related to the use of death certificates in this study is the inability to distinguish between geographic changes in case fatality versus incidence. Changes in case fatality would signal the relative importance of secondary prevention and access to quality care; changes in incidence would point to the relative importance of primary prevention. Nationally, >50% of the decline in heart disease mortality is estimated to be attributable to primary prevention[54]; however, the proportions could vary regionally and locally.

Finally, a limitation of the coefficient of variation is that it may be sensitive to potential changes in the skewness of the distribution of mortality over time. To test this, we calculated the coefficient of dispersion (Q3-Q1/median) and observed a nearly identical pattern over time, supporting the use of the coefficient of variation for this study.

Conclusion

The sweeping geographic changes in heart disease mortality observed over a relatively short period of time, with a shift of high-rate counties from the Northeast to the Deep South, suggest that systematic changes may have occurred in a variety of biomedical, behavioral, and socioenvironmental factors. The accompanying regional disparities in declining rates of heart disease mortality (with the slowest declines occurring predominantly in the South), and a nearly 2-fold increase in the geographic gap of heart disease mortality, highlight the importance of identifying conditions that are contributing to these disparities. Comprehensively documenting spatiotemporal patterns of heart disease mortality among communities in the United States, and exploring new hypotheses regarding the correlates of the changing geographic patterns, will enhance our ability to ensure that all communities experience optimal declines in heart disease mortality and that we narrow the existing geographic disparities in heart disease mortality.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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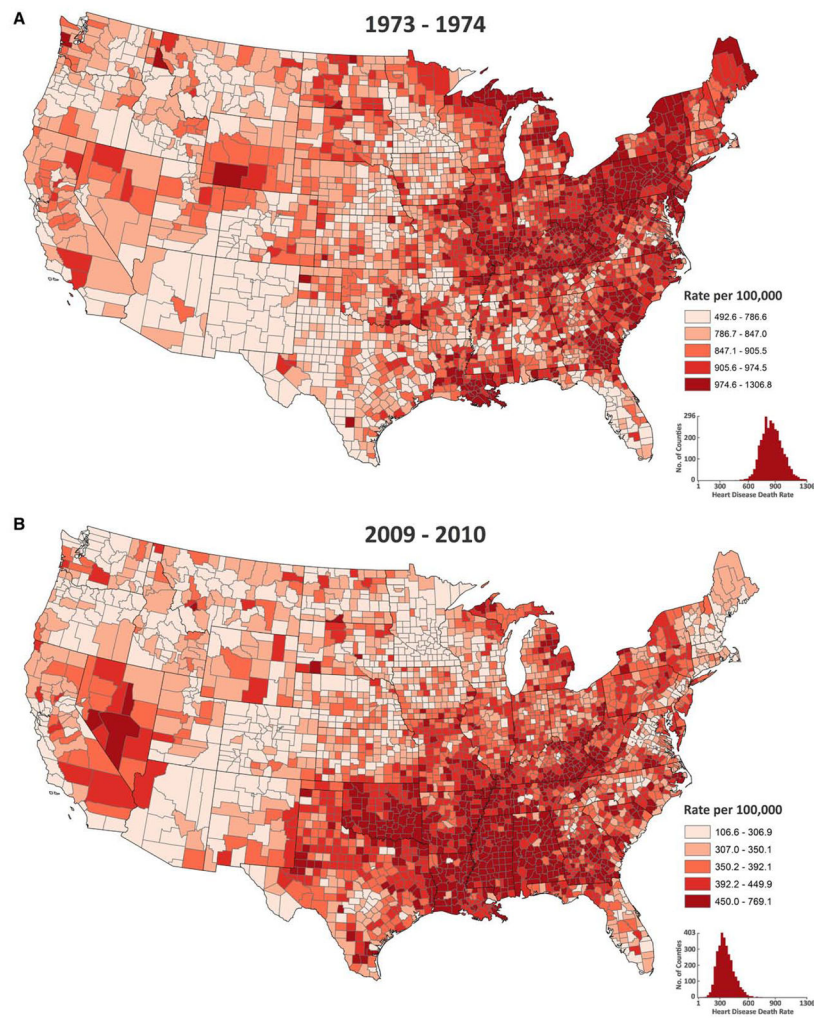
Figure 1.
Age-standardized heart disease death rates, ages 35, by county and quintile ranking for the beginning (1973–1974, **A**) and end (2009–2010, **B**) of the study period.
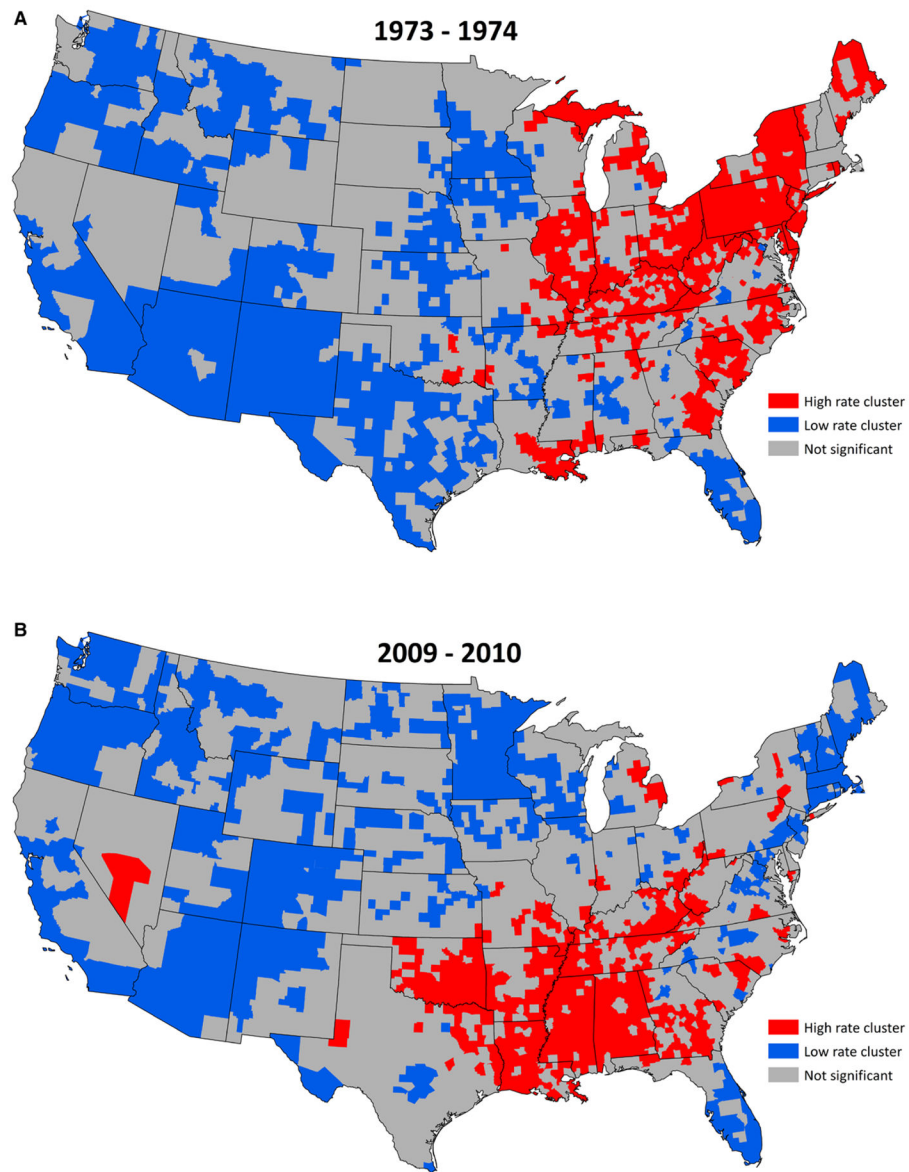
Figure 2.
Clusters of county-level age-standardized heart disease death rates, ages 35 for the
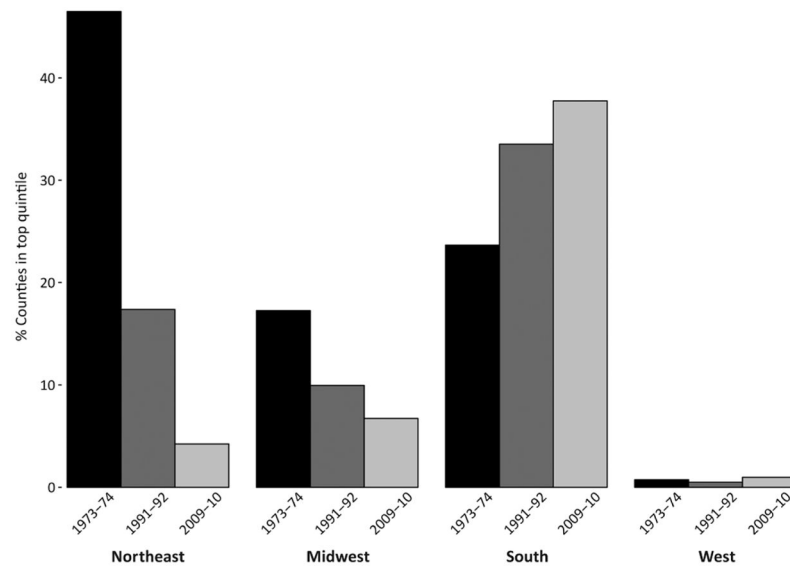beginning (1973–1974, **A**) and end (2009–2010, **B**) of the study period.

Figure 3.
Percentage of counties in the top quintile of heart disease mortality by region for the beginning (1973–1974), middle (1991–1992), and end (2009–2010) of the study period.
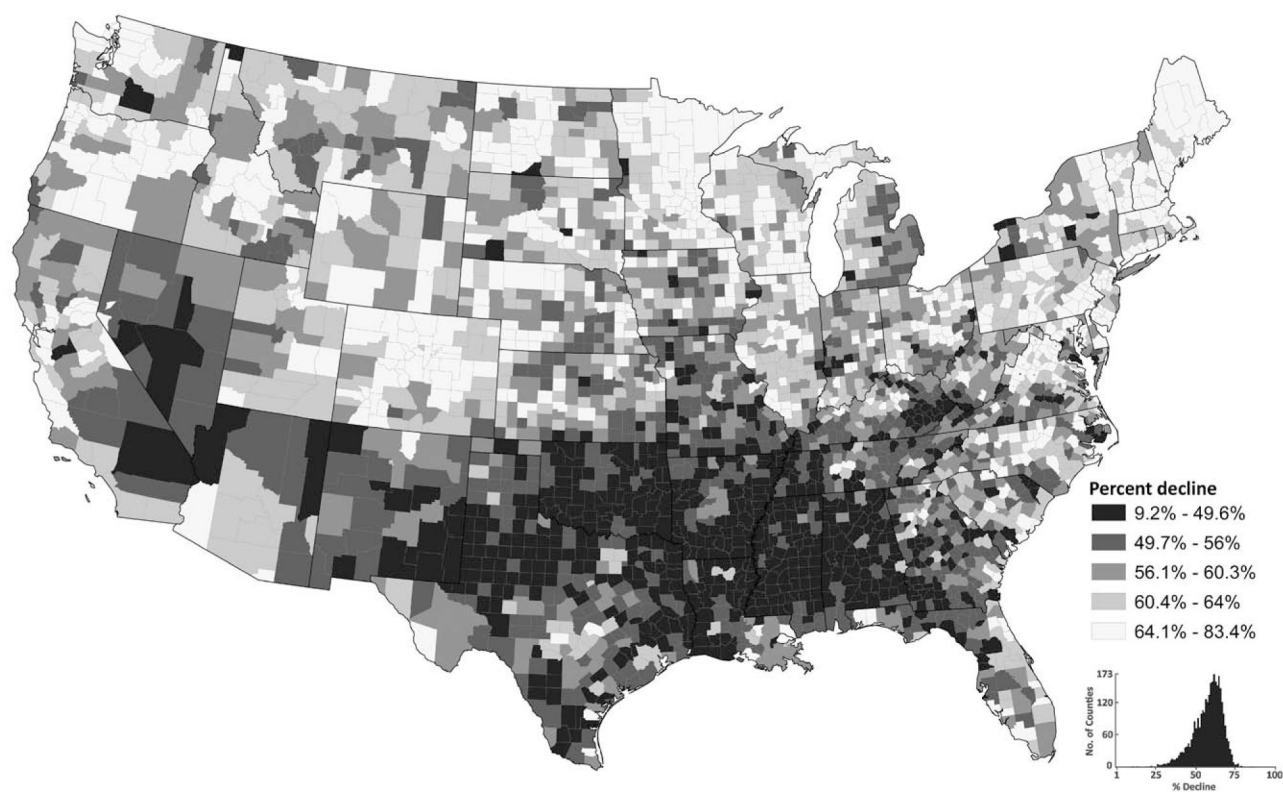
Figure 4.
Percentage decline in age-standardized heart disease death rates, ages   35, by county, from 1973–1974 to 2009–2010.
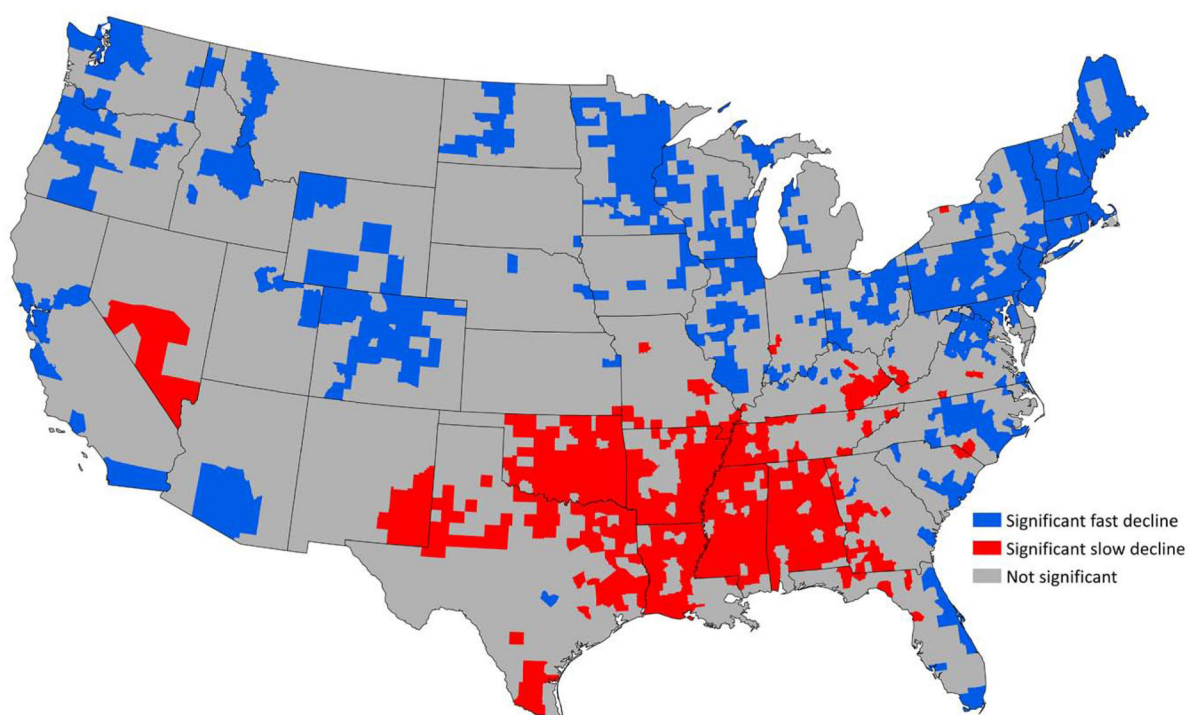
Figure 5.
Clusters of county-level declines in age-standardized heart disease death rates, ages   35
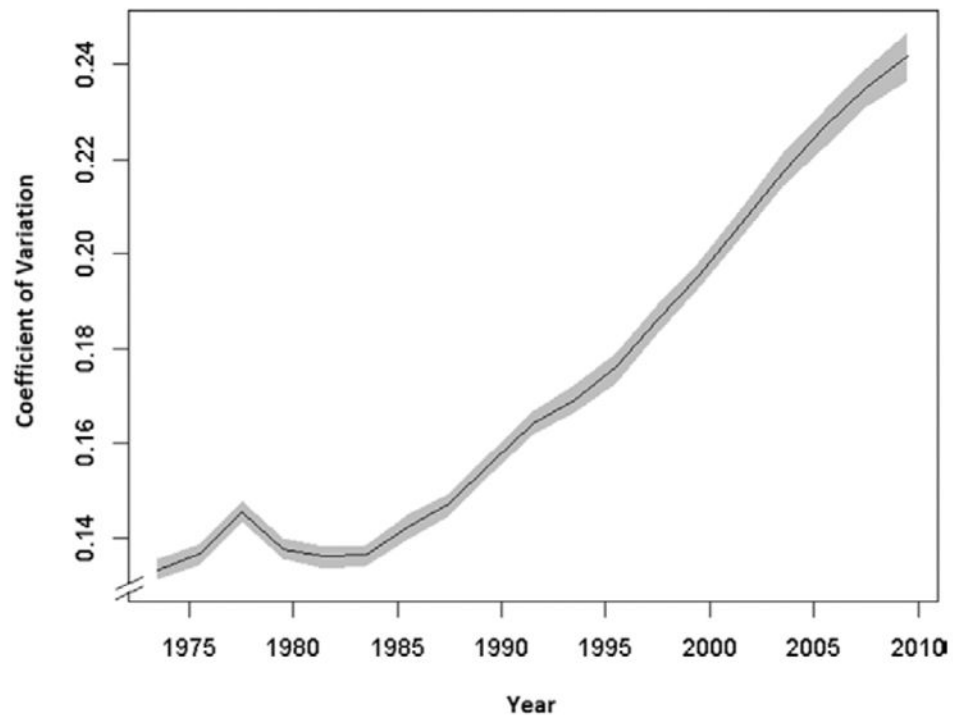from the beginning (1973–1974) to the end (2009–2010) of the study period.

Figure 6.
Temporal trend of the coefficient of variation (CoV) for age-standardized county-level heart disease death rates, United States, from 1973–1974 to 2009–2010. Larger CoV indicates greater geographic disparity in heart disease death rates among counties.