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RESEARCH ARTICLE

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# North-south gradient of mesothelioma and asbestos consumption-production in the United States-Progresses since the 1st asbestos partial ban in 1973

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**Background:** Temporal trends and broad geographical distributions of asbestos use and the incidence of malignant mesothelioma (MM) in the US still need to be studied.
**Methods:** Data on asbestos consumption and production between 1900 and 2015 and MM mortality and incidence rates between 1975 and 2015 in the US were examined. Spatial distributions of MM mortality and incidence rates and their association with climate zone were analyzed.
**Results:** Decline of MM incidence and mortality rates in the US occurred about 20 years after the peak of asbestos consumption-production in 1973. There are apparent north-south (N-S) gradients in MM mortality and incidence rates in the US.
**Conclusion:** Recent decline of MM incidence and mortality rates in the US may be associated with reduced US asbestos consumption. N-S MM gradients between 1999 and 2015 were likely related to larger asbestos requirements in building materials in the northern states.

KEYWORDS
asbestos insulation, mesothelioma, N-S gradient

## 1 | INTRODUCTION

Asbestos consumption in the US started in the late 1800s and climbed to about 803 000 metric tons in its peak usage year of 1973.[1,2] Asbestos consumption has been significantly curtailed since US EPA's first partial ban on some asbestos-containing products in 1973.[1,3] Production of asbestos materials in the US ceased in 2002, though consumption continued.[1,4] Asbestos was used mainly for its fire resistant and heat insulation properties.[5] The overwhelming majority of asbestos had been used in roofing and building products, including compounds and coatings in the US (Figure 1).[6] The chloralkali industry, which uses asbestos to manufacture semipermeable diaphragms, accounts for nearly all asbestos mineral consumption in the US since 2016.[1] Two types of common asbestos fibers are recognized, the amphibole types (crociodolite, amosite, anthopyllite, treomolite, and actinolite) and the serpentine type (chrysotile).[7,8] Though amphibole asbestos is considered much more lethal than serpentine asbestos (chrysotile), the former was much less used in industries than the latter (Figure 1).[2,7]

Since association of malignant mesothelioma (MM) and asbestos exposure was first reported in South Africa by Wagner et al,[9] a large number of studies have affirmed the relationship between asbestos exposures and MM occurrence.[10–14] Numerous studies have suggested that MM is mainly or even exclusively due to inhalation of asbestos fibers.[15,16] However, some studies argued a possible link of some MM cases to other causes.[17,18] MM generally originates in the lining of the lung or chest wall (pleura) or abdomen (peritoneum), or other sites such as the pericardium or tunica vaginalis after exposure to asbestos.[19,20] Pleural MM accounts for about 70% of all MM cases.[18,20] Mesothelial cells are very sensitive to the cytotoxic effects

Institution at which the work was performed: Rider University.

  

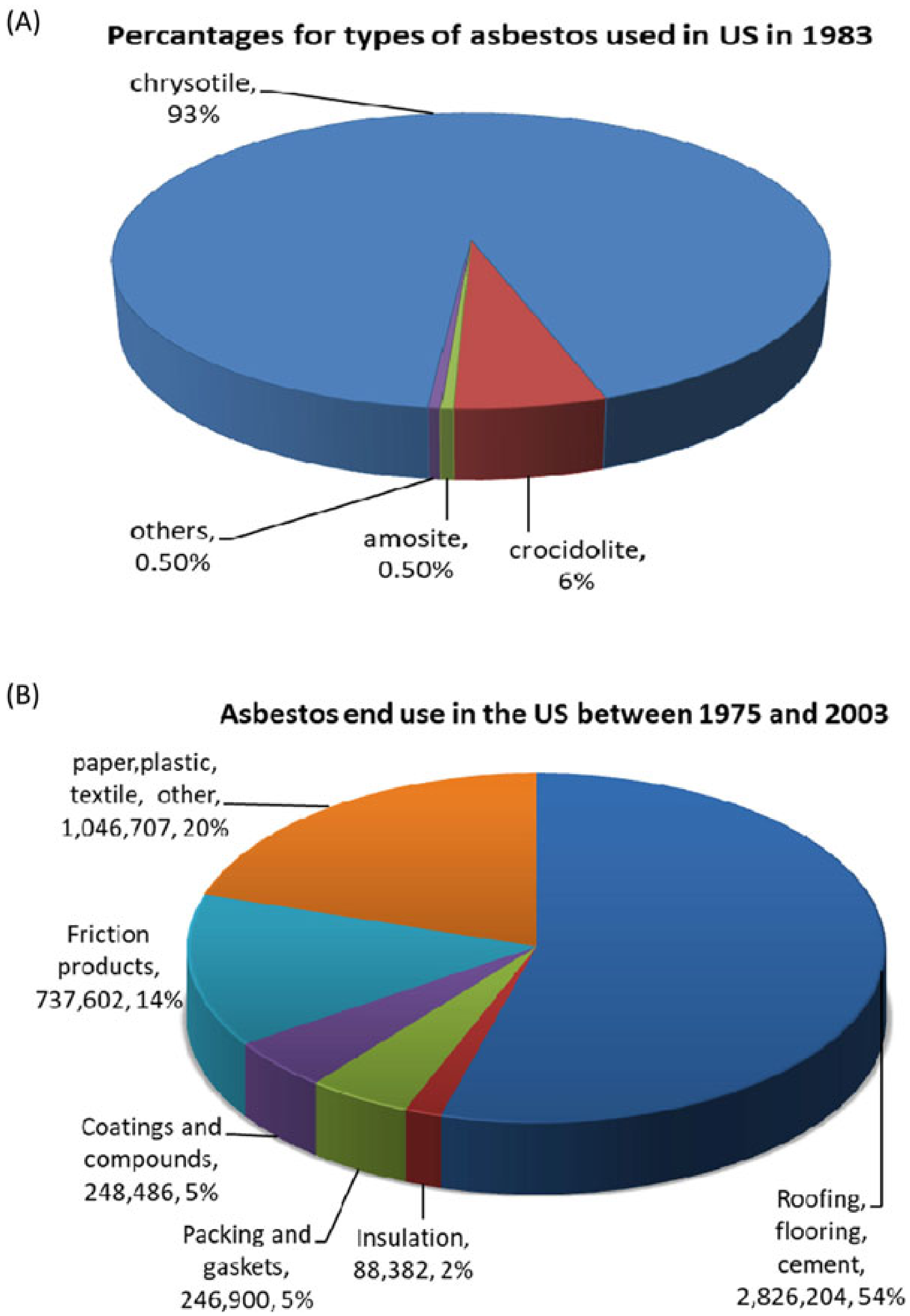


**FIGURE 1** (A) Percentage of asbestos types used in US industry in 1983, (B) estimated total amount of asbestos end-uses in metric tons and by percentage in the US between 1975 and 2003. [Color figure can be viewed at wileyonlinelibrary.com]

of asbestos. Exposure to asbestos, even in short-term and low-intensity cases, can result in DNA mutations, strand chromosomal breaks, cellular apoptosis and eventually a malignant transformation of mesothelial cells.[15,21,22] Cumulative exposures are likely to increase this risk significantly.[23]

The US EPA first banned spray-applied asbestos-containing surfacing material for fireproofing and insulating purposes in 1973.[3] Four subsequent EPA bans between 1973 and 1989 resulted in a dramatic decline in the consumption and domestic production of asbestos in the US. Curtailment of asbestos consumption since 1973 has been largely credited for the general reductions in MM incidence and mortality rates in the US over the last 15-20 years.[10,22] However, regional variations in reduction of MM mortality and incidence rates in the US are apparent.[24] Asbestos exposure at renovation sites and secondary exposure of the general public to asbestos still exist. In addition, despite the banning of asbestos from new uses, some US-manufactured and imported products, including brake linings, knitted fabric, rubber sheets for gasket manufacture, and potentially asbestos-cement pipe still contain asbestos.[1,3] 1.28 million tons of asbestos were mined in 2016 worldwide; Russia, China, Kazakhstan, and Brazil accounted for 99% of production.[1] Given an average latency period of up to 40-50 years or more between asbestos exposure and MM occurrence, asbestos exposure and MM risk for the general public will likely persist, not only in the US, but also worldwide.[25–29]

The aim of this study is to examine the temporal trends and geographic patterns of asbestos consumption, production, MM mortality, incidence and changes of MM mortality and incidence rates in the US since the first partial ban of some asbestos containing products in 1973. Past US studies have mainly focused on the MM incidences in workers directly related to asbestos industries (primary exposure) such as mining and asbestos processing facilities.[11,12] MM incidence and mortality patterns not related to these industries are relatively less researched.[17] This study is the first study, to the author's knowledge, that a North-South (N-S) gradient of MM is emphasized and an explanation is proposed. Recognition of recent trends and patterns of MM and understanding of their causes will help better predict and manage future MM risks.[30]

## 2 | METHODS

### 2.1 | Data collection

Historical production and consumption of asbestos in the US between 1900 and 2015 and asbestos end use data between 1975 and 2003 were obtained from the US Geological Survey (USGS) reports.[1,5] Location, mineralogy, name, and development status of 913 historic mines, prospects, and occurrences of asbestos and fibrous amphiboles were obtained from USGS Mineral Resources Program.[1] State average annual coal productions of the 48 states between 1960 and 2015 were obtained from the US Energy Information Administration reports.[31] Labor force data of shipyards exceeding 5000 employed capable of constructing and repairing 2000-ton naval or cargo ships in late 1943 (peak ship building activity during World War II) were obtained from Blot et al[32] 1979 article. Climate zone classification based on the International Energy Conservation Code (IECC) was obtained from the Building Energy Codes Program of the US Department of Energy (DOE) and simplified (https://www.energycodes.gov/). R-values of attics, based on minimum thickness requirements of fiberglass or equivalent material corresponding to each climate zone were obtained from the DOE's Building Energy Codes. R-value (higher in the north, lower in south) is a measure of how well a type of insulation material resists heat transfer, and has a DOE-recommended value for each climate zone in the US.

Age-adjusted historical incidence rates for MM in the US between 1975 and 2013 for both men and women were obtained from the Surveillance, Epidemiology and End Results (SEER) Program of the US National Cancer Institute. Though SEER collects cancer incidence data from population-based cancer registries, it does not cover all the US population.[33] Age-adjusted incidence rates for each of the 48 states between 1999 and 2013 were obtained from the US Centers for Disease Control and Prevention (CDC) database. Age-adjusted mortality rates using 2000 US standard population, with MM as the underlying cause of death between 1999 and 2015 for the 48 contiguous US states, were obtained from the CDC database as well. Though state average data between 1999 and 2015 are available, individual-year data for some states (10 states for mortality and 5 states for incidence rates) were not available for all analyses. Mortality rates in the CDC database were taken from death certificates of US residents; each death certificate identifies a single underlying cause of death and demographic data.

### 2.2 | Statistical analyses

#### 2.2.1 | Historical trend analyses

US historical trends for asbestos consumption and production between 1900 and 2015 were analyzed. Proportions of asbestos usage were simplified into six categories according to their broad applications (Figure 1). The changing trends of asbestos consumption and MM incidence rate were compared. Regression trends for MM mortality and incidence for each of the 48 states were calculated for the period 1999-2015 for mortality and 1999-2013 for incidence. Regression coefficients represent growth (positive) or reduction (negative) of MM mortality or incidence in a state during this time period. An isopleth map using these mortality and incidence coefficients was then constructed to examine regional risk trends for MM.

#### 2.2.2 | Analyses of spatial patterns

Using ArcGIS (ESRI software), isopleth maps of state average MM mortality and incidence rates for both sexes in the 48 contiguous states were plotted using the inverse distance weighted (IDW) interpolation method to reduce the effect of a sharp state boundary for examining spatial patterns. IECC climate zones for the 48 states were generalized based on county-level data in the DOE database. State average values for IECC climate zone were obtained by summarizing IECC climate zone values of all the counties in each state weighted by their corresponding area proportions using the Zonal Statistics function in ArcGIS.

#### 2.2.3 | Rate ratios

Rate ratios (RR) and their 95% confidence intervals were calculated using age-adjusted MM mortality and their corresponding populations between 1999 and 2015 for the most northern (IECC climate zones 6 and 7) and the most southern (zones 1, 2, and 3) state groups of the 48 states using prior work on the geographic distribution of multiple sclerosis.[34] Climate zones 6 and 7, considered the “case” group, included the northern states Idaho(ID), Maine(ME), Michigan(M), Minnesota (MN), Montana (MT), North Dakota (ND), New Hampshire (NH), New York (NY), South Dakota (SD), Vermont (VT), Wisconsin (WI), and Wyoming (WY). Climate zones 1, 2 and 3, the reference group, included southern states Alabama (AL), Arkansas (AR), California (CA), Florida (FL), Georgia (GA), Louisiana (LA), Mississippi (MS), North Carolina (NC), Oklahoma (OK), South Carolina (SC), and Texas (TX). A state was included when a majority of the state area falls within the climate zone.

# 3 | RESULTS

The average annual MM mortality rate based on the CDC's database for the 48 states was 2486 deaths per year between 1999 and 2015. Maine (ME), Washington (WA), Wyoming (WY), West Virginia (WV), and New Jersey (NJ) are the five states with the highest average annual MM mortality rates during this period. The ratio of men to women's age-adjusted mortality rates between 1999 and 2015 was approximately 3.5. The average annual MM incidence of the 48 states was estimated to be about 2600 per year between 1999 and 2013.

## 3.1 | Trends of asbestos consumption-production, end uses, and MM incidence rates

Domestic asbestos production accounted for only about 10.6% of the total US asbestos consumption between 1900 and 2015 based on the USGS report.[1] Both consumption and production increased between 1900 and 1973 and declined sharply after 1973 (Figure 2B). US domestic production of asbestos ceased in 2002, and consumption of asbestos continued but at a greatly reduced level. In 2015, only about 343 tons of asbestos were used in the US, compared to over 803 000 tons during the peak year of 1973.[1] Based on end-use data between 1975 and 2003, roofing and flooring materials constituted about 54% of production usage, automotive friction products about 14%, and paper, plastics, textile and other, unknown, categories about 20% of the total asbestos consumed in the US during this period (Figure 1B).

Average MM incidence rates in men showed an increasing trend between 1975 and 1992 with a decrease trend after 1992. MM incidence rates in women increased before 1983 and stayed relatively flat (or fluctuated) after 1983 (Figure 2B). The gap between the peak of asbestos consumption and peak MM incidence rates are about 20 years (1973-1992) for men and about 11-years (1973-1983) for women (Figure 2C).

## 3.2 | Asbestos historical mining sites, prospects and occurrences

Serpentinite, the most widely occurring host rock for chrysotile asbestos in 17 US States is present throughout the Appalachians, Cascades, Coast Ranges of California and Oregon, and other mountain belts (Figure 3A). These N-S aligned regions of chrysotile and amphibole asbestos varieties were formed after the original rock was modified by thermal fluids through a metamorphic process during orogenic-tectonic activities.[8] There are also regional occurrences of asbestos in AZ, ID, and MT. These are the regions where general population exposure to ambient asbestos is still possible.

## 3.3 | Spatial distribution of MM and changes between 1999 and 2015

There is an apparent N-S gradient for the average MM mortality rates of the 48 states between 1999 and 2015 (Figures 3C and 3D). There is also an apparent N-S gradient for average MM incidence rates between 2009 and 2013 (Figure 3F). Regions of high MM mortality correspond to regions of low temperature-cold climate zones; regions of low MM mortality rates are similarly seen in regions of high temperature-warm climate zone. There are also statistically significant regression trends between state climate zone and state-average MM incidence and mortality rates (Figure 4). In addition, removal of coastal states with high shipyard activity (FL, LA, and DE) in the regression analysis increased the predictive ability of the correlation with climate zone, increasing the $R^2$ from 0.26 to 0.48 for incidence and from 0.30 to 0.41 for mortality, respectively (Figure 4). There was an overall reduction in MM incidence and mortality rates of the 48 states between 1999 and 2015. Greater reductions of MM mortality and incidence were seen in the northeast and northwest coastal states (ME, MA, WA, and NJ) (Figure 3E). Though MM mortality rates of most states declined between 1999 and 2015, there was still an overall upward trend for three states AZ, IA, and TE. MM incidence against time also showed a positive upward trend for CT, AL, NE, MO, IN, AZ, NC, and NM between 1999 and 2013 (though not all increases were statistically significant).

## 3.4 | Rate ratios

MM mortality rate ratios for the state group in climate zones 6 and 7, using the state group in climate zones 1, 2, and 3 as a referent were overall 1.29 (95% confidence interval-95%CI 1.25-1.33) for all races-both sexes; 1.29 (95%CI 1.24-1.34) for all races-male; 1.28 (95%CI 1.24-1.34) for all races-female; 1.31 (95%CI 1.27-1.36) for whites of bothsexes, 1.31 (95%CI, 1.26-1.37) for white men and 1.31 (95%CI 1.26-1.37) for white women.

# 4 | DISCUSSION

The side-by-side comparison of asbestos consumption-production and MM incidence and mortality rates after 1973 indicates an apparent decline of about 30% in MM incidence in men, starting in 1992, which is about 20 years after peak US asbestos consumption in 1973. The reversal in MM incidence in women occurred in approximately 1983, 11 years after asbestos peak consumption. There was also an overall declining trend in MM mortality rates between 1999 and 2015 as well. The paired declines of MM mortality and incidence rates following the decline of asbestos consumption and stricter worker protection regulation provide, support, albeit on an ecological basis, of asbestos exposure being the primary causes of MM incidence in the US.[30]

Between 1900 and 2015, slightly more than one-tenth of US asbestos consumption was from domestic production with the

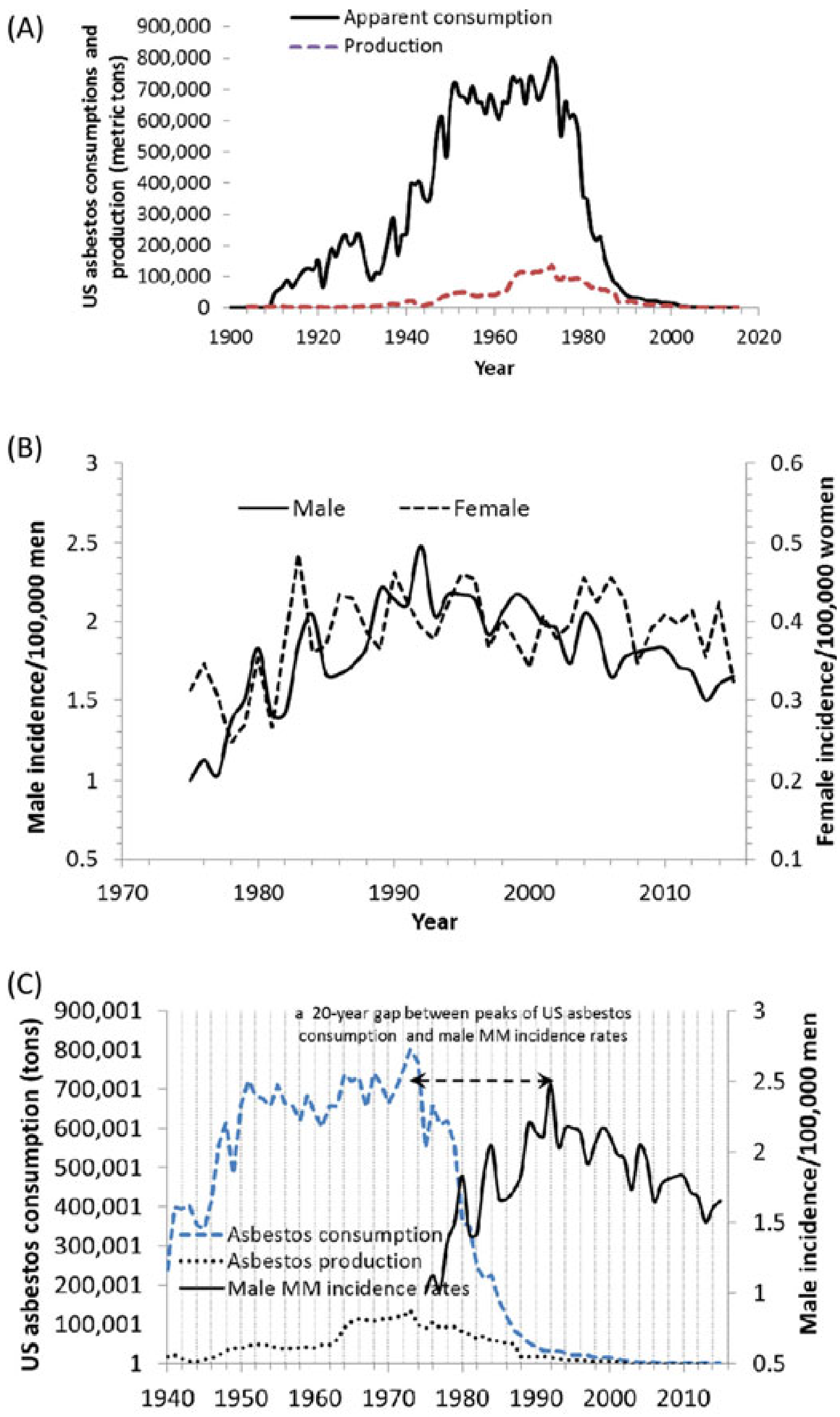


**FIGURE 2** Trends in: (A) US asbestos consumption and production between 1900 and 2015; (B) age-adjusted incidence of malignant mesothelioma (MM) between 1975 and 2015; (C) graphical depiction of a 20-year gap between the peaks of asbestos consumption and male MM incidence rates. [Color figure can be viewed at wileyonlinelibrary.com]

majority of the consumption from import (Figure 2A).[5] Though asbestos exposure related to historical mining, shipyard activities, and asbestos processing industries were much more dangerous to the workers involved, exposures to asbestos-related building materials would have likely involved many more people for a longer period of time.[27,35] Because more insulation materials are required in the northern states, workers there may be exposed to more asbestos through handling larger quantity of asbestos material. They may also have contaminated their homes with asbestos fibers carried on their clothes, shoes, and hair, thus, potentially exposing their families and other household members.[35,36] Additionally the general public in the north is more likely to be exposed during renovations at a later date.

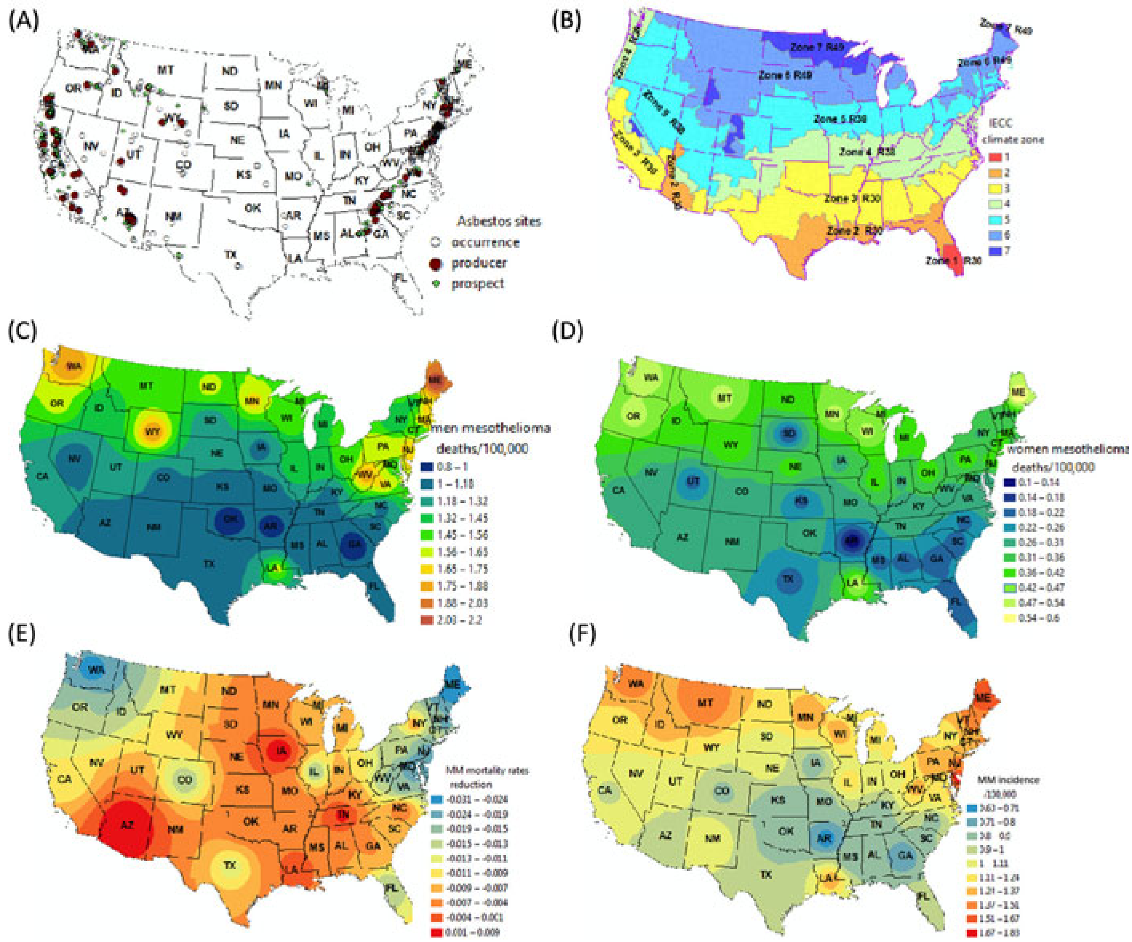


**FIGURE 3** (A) Location map of 913 historic mines, prospects, and occurrences of asbestos and fibrous amphiboles from USGS mineral resource program; (B) IECC climate zone map and corresponding R-values; (C) average age-adjusted mortality rates (AAMR) of malignant mesothelioma (MM) for men and (D) women; (E) change in regression coefficients for annual age-adjusted MM mortality rates between 1999 and 2015; (F) MM incidence between 1999 and 2013. [Color figure can be viewed at wileyonlinelibrary.com]

According to the 2010 US census survey, 58.8% of the total population and nearly half (47-50%) of the population aged 55 and older were residents of the same states where they were born.[37] Hence, the N-S difference in in-situ exposure to asbestos-containing insulation materials presents a potential explanation of a significant portion of the N-S gradient of MM mortality and incidence.

Exposures to asbestos in large shipyards, asbestos processing facilities in ME, LA, WA, DE, and FL and asbestos manufacturing facilities in NJ are likely factors in the higher MM incidence and mortality rates in these states between 1999 and 2015[24,38] well above the trend line seen in Figure 4 and Table 1. WY and WV are two of the largest coal producing states in the US for decades (EIA.gov state energy data, 1960-2015; Table 1). Association of asbestos and other silicate minerals with the coal dust might explain the higher MM mortality rates of these states during this period.[39,40]

Abolition of asbestos-containing products in shipping and other industries started in 1973 and accelerated after 1977-1978 (Figure 1).[3] In addition, there were gradual improvements in safety and health regulation of coal mining. These may partially explain the greater reductions in the incidence and mortality rates between 1999 and 2013 for WV, OR, NJ, VA, MA, WI, and WA states.[41,42] Reductions of MM in these states also could imply that the N-S MM gradient will likely be more prominent in the near future, since, when these ship-building and mining states are removed from the regression models shown here, the predictive ability of the climate zone model for MM increases (Figure 4). Further exploration of industry or usage trends for asbestos may be needed to explain the findings for states that did not show an overall reduction in MM mortality (three states) or incidence (eight states) between 1999 and 2015 (1999-2013 for incidence).

There is no individual-level information about exposure to asbestos for mesothelioma cases identified in this study. The exposure to asbestos was only linked ecologically by examining industry and usage trends over time. Lack of a national registry of mesothelioma cases, with linked information on asbestos exposure in the US hinders the ability of health care professionals and researchers to analyze information about diagnosis and track disease trends, risk-factors and treatment availability.[22,24] There is a broad need for a searchable, asbestos-cancer related public database. The findings in this paper suggest the need for a US national registry of

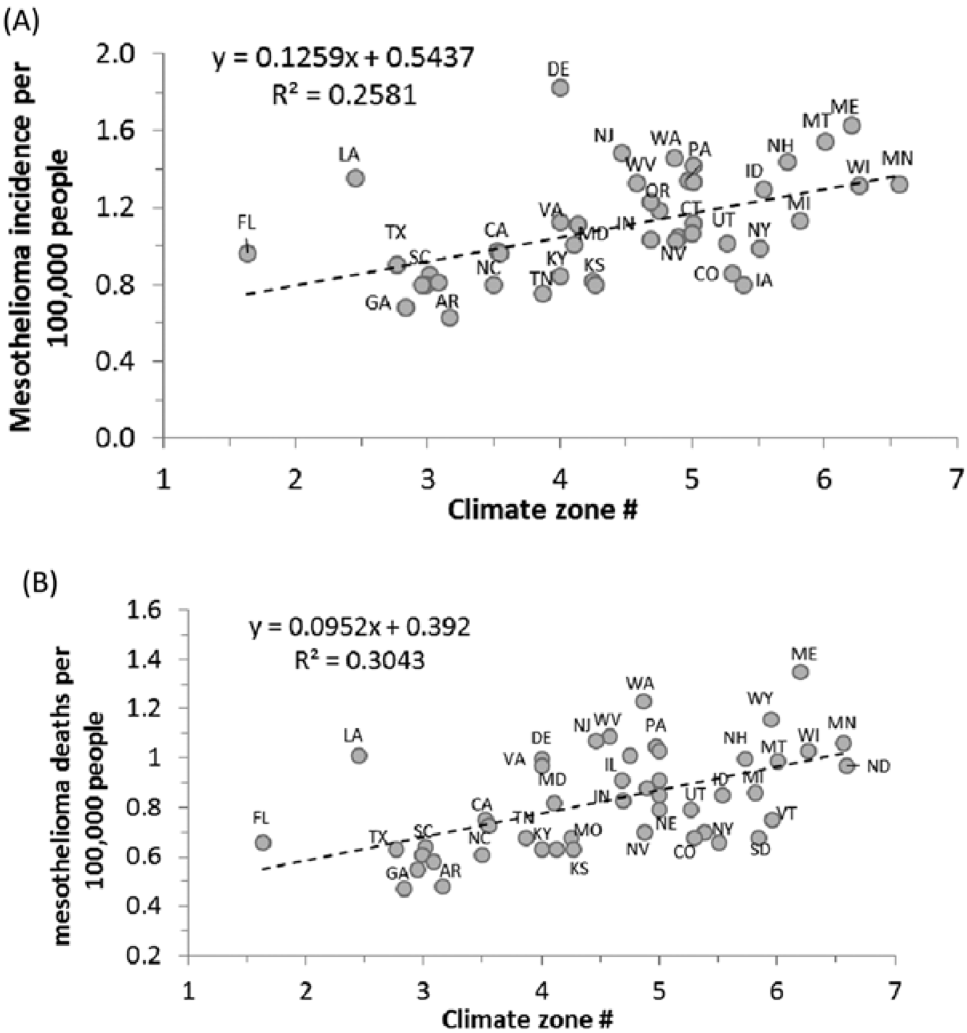


**FIGURE 4** Regression analyses of (A) age-adjusted MM incidence and (B) mortality rates against IECC climate zone values. A higher IECC climate zone # indicates a cold climate and the requirement of thicker insulation material. High shipyard employment (FL, LA, and ME) and coal production (WV, PA) can also be seen to be associated with higher mesothelioma incidence and mortality rates. Removal of three states FL, LA, and DE improves regression $R^2$ from 0.2576 to 0.4812 for the trend line of mesothelioma incidence versus climate zone in panel A

mesothelioma cases that contains information on exposure history. The collected data will not only help identify the sources of exposure to mesothelioma-causing carcinogens, but also provide the necessary information for social or economic compensation in occupational cases.

Some limitations to the present study are important to recognize. As noted above, this is an ecological study, and does not use individual-level data on asbestos exposure. Though asbestos is the main known cause of MM, there may be other risk factors in the etiology and pathogenesis of MM.[17] Contributions to MM spatial disparity by simian virus 35, mineral erionite, radiation exposure, and genetic predisposition need further study.[41–44] MM incidence data are not available for all the 48 states between 1999 and 2015. Latitudinal differences in levels of vitamin D and heat shock protein and their association with temperature might also affect the pathogenesis of MM, and the N-S gradient presented here.[45]

Decline of MM incidence in men started in approximately 1992, about 20 years after USEPA's first partial ban in 1973 on asbestos application. This gap is smaller, about 11 years, for women. Apparent N-S gradients of MM incidence and mortality rates exist in the 48 contiguous states. MM mortality rates between 1999 and 2015 in the low-temperature states in IECC climate zones 6 and 7 are more than 29% higher than that in high-temperature states of IECC climate zones 1, 2, and 3 in the US. States (ME, WA, NJ, WY, and WV) with larger shipbuilding yards, asbestos processing or manufacturing facilities and coal mining industries (combined with their locations in cold climate states) had the highest MM mortality rates and also larger reduction of MM mortality during the period of 1999 and 2015. However, there are still states with an overall increase in MM mortality between 1999 and 2015 and incidence from 1999 to 2013. The author believes that a significant portion of the N-S gradient of MM mortality and incidence is related to the greater number of workers required in the past for

**TABLE 1** State average age-adjusted mesothelioma mortality and incidence rates and related environmental factors

| STATE | AAMR | MAAMR | FAAMR | AAIR | CLZone | #Asbe | Shiprank | Coalrank |
|---|---|---|---|---|---|---|---|---|
| Maine (ME) | 1.35 | 2.47 | 0.54 | 1.63 | 6.2 | 18 | 38(12) | |
| Washington (WA) | 1.23 | 2.24 | 0.46 | 1.46 | 4.9 | 34 | 222(2) | 2634(19) |
| Wyoming (WY) | 1.16 | 2.07 | | | 5.9 | 12 | | 172108(1) |
| West Virginia (WV) | 1.09 | 2.17 | 0.28 | 1.33 | 4.6 | 0 | | 123666(2) |
| New Jersey (NJ) | 1.07 | 2.14 | 0.36 | 1.49 | 4.5 | 38 | 71(8) | |
| Minnesota (MN) | 1.06 | 1.94 | 0.39 | 1.33 | 6.6 | 2 | | |
| Pennsylvania (PA) | 1.05 | 2.01 | 0.35 | 1.35 | 5.0 | 40 | 109(4) | 68494(4) |
| Massachusetts (MA) | 1.03 | 2.05 | 0.36 | 1.34 | 5.0 | 4 | 109(3) | |
| Wisconsin (WI) | 1.03 | 1.85 | 0.43 | 1.32 | 6.3 | 3 | 25(15) | |
| Oregon (OR) | 1.01 | 1.85 | 0.42 | 1.19 | 4.8 | 24 | | |
| Louisiana (LA) | 1.01 | 1.83 | 0.42 | 1.36 | 2.5 | 0 | 42(11) | 1660(22) |
| Delaware (DE) | 1 | 1.98 | 0.27 | 1.83 | 4.0 | 1 | 15(20) | |
| New Hampshire (NH) | 1 | 2.01 | 0.27 | 1.44 | 5.7 | 0 | 20(16) | |
| Montana (MT) | 0.99 | 1.66 | 0.45 | 1.55 | 6.0 | 19 | | 25316(10) |
| North Dakota (ND) | 0.97 | 1.86 | 0.31 | | 6.6 | 0 | | 18401(12) |
| Virginia (VA) | 0.97 | 1.91 | 0.3 | 1.13 | 4.0 | 28 | 73(7) | 30324(7) |
| Rhode Island (RI) | 0.91 | 1.86 | 0.27 | 1.43 | 5.0 | 1 | 19(18) | |
| Illinois (IL) | 0.91 | 1.72 | 0.36 | 1.23 | 4.7 | 0 | | 46148(5) |
| Ohio (OH) | 0.88 | 1.69 | 0.31 | 1.05 | 4.9 | 0 | | 30982(6) |
| Michigan (MI) | 0.86 | 1.62 | 0.33 | 1.13 | 5.8 | 7 | | |
| Connecticut (CT) | 0.85 | 1.6 | 0.32 | 1.12 | 5.0 | 1 | 11(21) | |
| Idaho (ID) | 0.85 | 1.53 | 0.33 | 1.30 | 5.5 | 8 | | |
| Indiana (IN) | 0.83 | 1.57 | 0.3 | 1.04 | 4.7 | 0 | 17(19) | 26433(9) |
| Maryland (MD) | 0.82 | 1.62 | 0.3 | 1.01 | 4.1 | 23 | 76(5) | 2664(18) |
| Nebraska (NE) | 0.79 | 1.36 | 0.35 | 1.07 | 5.0 | 0 | | |
| Utah (UT) | 0.79 | 1.46 | 0.21 | 1.02 | 5.3 | 7 | | 13929(15) |
| Vermont (VT) | 0.75 | 1.45 | | | 6.0 | 22 | | |
| California (CA) | 0.75 | 1.38 | 0.3 | 0.98 | 3.5 | 300 | 242(1) | 7(29) |
| Arizona (AZ) | 0.73 | 1.32 | 0.26 | 0.97 | 3.5 | 108 | | 7301(16) |
| Iowa (IA) | 0.7 | 1.27 | 0.29 | 0.80 | 5.4 | 0 | | 375(26) |
| Nevada (NV) | 0.7 | 1.19 | 0.29 | 1.03 | 4.9 | 6 | | |
| South Dakota (SD) | 0.68 | 1.36 | | | 5.8 | 6 | | |
| Missouri (MO) | 0.68 | 1.26 | 0.26 | 0.82 | 4.2 | 4 | | 2473(20) |
| Tennessee (TN) | 0.68 | 1.29 | 0.22 | 0.75 | 3.9 | 0 | | 4891(17) |
| Colorado (CO) | 0.68 | 1.27 | 0.24 | 0.86 | 5.3 | 11 | | 16885(13) |
| Florida (FL) | 0.66 | 1.25 | 0.21 | 0.97 | 1.6 | 0 | 47(9) | |
| New York (NY) | 0.66 | 1.29 | 0.24 | 0.99 | 5.5 | 23 | | |
| South Carolina (SC) | 0.64 | 1.3 | 0.2 | 0.85 | 3.0 | 8 | 29(14) | |
| Kansas (KS) | 0.63 | 1.23 | 0.21 | 0.80 | 4.3 | 3 | | 642(25) |
| Kentucky (KY) | 0.63 | 1.22 | 0.23 | 0.85 | 4.0 | 0 | | 113924(3) |
| New Mexico (NM) | 0.63 | 1.14 | 0.25 | 1.12 | 4.1 | 11 | | 16059(14) |
| Texas (TX) | 0.63 | 1.21 | 0.21 | 0.91 | 2.8 | 8 | 76(6) | 29060(8) |
| Alabama (AL) | 0.61 | 1.21 | 0.19 | 0.80 | 3.0 | 19 | 43(10) | 18945(11) |
| North Carolina (NC) | 0.61 | 1.22 | 0.19 | 0.80 | 3.5 | 49 | 20(17) | |

(Continues)

**TABLE 1** (Continued)

| STATE | AAMR | MAAMR | FAAMR | AAIR | CLZone | #Asbe | Shiprank | Coalrank |
|---|---|---|---|---|---|---|---|---|
| Oklahoma (OK) | 0.58 | 1.03 | 0.24 | 0.81 | 3.1 | 0 | | 1997(21) |
| Mississippi (MS) | 0.55 | 1.1 | 0.18 | 0.80 | 2.9 | 0 | 10(22) | 785(24) |
| Arkansas (AR) | 0.48 | 0.97 | 0.13 | 0.63 | 3.2 | 2 | | 153(27) |
| Georgia (GA) | 0.47 | 0.94 | 0.16 | 0.69 | 2.8 | 52 | 38(13) | 10(28) |

States in the tables are ordered by AAMR.
AAMR: age-adjusted mesothelioma mortality rate (deaths/100 000 people) for all races and sexes between 1999 and 2015; MAAMR: Male age-adjusted mesothelioma mortality rate; FAAMR: female age-adjusted mesothelioma mortality rate; AAIR: age-adjusted mesothelioma incidence rates/100 000 people between 1999 and 2013; CLZone: averaged IECC climate zone number; #Asbe: numbers of asbestos occurrence, historic mine and prospectus sites; Shiprank: peak shipyard employment ($\times10^3$) in late 1943 involved in the construction and repair of 2000-ton naval or cargo ships during World War II[32] and their corresponding ranks (numbers in the parentheses) in the 48 US states; Coalrank: average annual coal production between 1960 and 2015 in thousand metric tons[31] and their corresponding ranks (numbers in the parentheses) in the 48 US states. Blank cells in the FAAMR and AAIR columns indicates suppressed data in CDC database. Blank cells in the right two columns indicate no major shipyard activities or coal production in the states.

processing asbestos materials principally for insulation in the colder climate of northern states. High secondary exposure by residents living in buildings containing asbestos material in the north may also have contributed to the N-S gradient of MM in the US and might still remain a significant source of exposure in old buildings, again in colder-climate states, today.

## AUTHORS' CONTRIBUTIONS

The author, HS, is responsible for the design of the project, the acquisition, analysis and interpretation of the data, and the results and conclusions reached in the paper. He approves the publication of the final version of this paper and agrees to be accountable for the accuracy and integrity of all the work done related to this paper.

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## ETHICS APPROVAL AND INFORMED CONSENT

The paper is a statistical analysis of publicly-available data that are available on the internet, government reports and journals. There are no human subjects being involved in the study and therefore human subjects protection approval was not required.

## DISCLOSURE (AUTHORS)

The author declares no conflicts of interest.

## DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

## DISCLAIMER

None.

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