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Geographic analysis of asbestos exposure and mortality in the United States

Asbestos is a mineral that is naturally occurring all over the world (asbestos.com). Asbestos use in the United States during the 20th century was commonplace in commercial, military, and residential applications for its usefulness in fireproofing and as an insulation material. Inhalation of asbestos fibers has been demonstrated to cause the respiratory disease asbestosis as well as being implicated in cases of malignant mesothelioma, a rare form of lung cancer (Lanphear 1992). Unfortunately, understanding the full impact of asbestos-related diseases both today and for the future in the United States population is difficult as asbestos exposure and its sequelae are latent and progressive, taking years or decades to manifest (Lanphear 1992).

This research project uses both geographic information systems (GIS) along with statistical analysis to determine concentrations of asbestos-related mortality in the US, analyzes both injurious exposure and mortality data for correlation, and analyzes the spatial distribution of select occupations against modern mortality for correlation. The US is the only developed country without a ban on asbestos, with 1.4 million workers directly at risk of injurious exposure to friable asbestos fibers. Accordingly, spatial analysis of both modern asbestos mortality as well as exploration of potentially predictive analytics from both select employment and exposure datasets appears significant at this juncture.

Literature Review

Inhalation of asbestos fibers has been demonstrated to cause the respiratory disease asbestosis as well as being implicated in cases of malignant mesothelioma, a rare form of lung cancer (Lanphear 1992). Asbestos exposure in occupational as well as non-occupational settings, such as home or in the environment, have been linked to asbestos-related disease (Goswami et. al. 2013). Unfortunately, asbestos-related diseases are latent and progressive, taking years or decades to manifest (Lanphear 1992). The potential future burden of asbestos-related disease in the United States has numerous implications for those sickened as well as the healthcare industry, employers, epidemiologists, and stakeholders associated with state occupational disease programs such as insurance carriers and state funds. Persons sickened with asbestos-related diseases in more rural or impoverished areas without access to care may contribute to data “shadows” or areas of underreporting (Delaunay et. al. 2015).

Occupational disease statistics are critical to understanding work-related diseases facing the workforce, the prevalence of those diseases, and their spatial distribution. Researchers have long emphasized that occupational disease prevention is the goal of both industry regulation and health initiatives (Hilaski 1980, Freund et. al. 1990, Agtus et. al. 2015). Throughout the history of occupational disease’s formal recognition in the United States, including compensation schemes for same, data deficiencies continue to plague both occupational disease surveillance and reporting (Melius et. al. 1989, Leigh 2011, Agtus et. al. 2015). There is demonstrated value in aggregating what occupational disease data is available for spatial analysis through use of a Geographic Information System (GIS) (Delaunay et. al. 2015).

Despite certain work-related diseases having been identified even in antiquity, industrial recognition of occupational disease and development of compensation schemes for sickened workers did not arise until the beginning of the 20th century (Kim et. al. 2013). Since the inception of the first occupational disease listing by the International Labour Organization (ILO) in 1925, the list of accepted occupational diseases has widened considerably (Kim et. al. 2013). Scholars agree that occupational disease continues to be a threat to the health and safety of workers not only in the U.S. but around the world (Schroeder, 1986, Kim et. al., 2013). The first dust standards limiting worker exposure to asbestos fibers were not implemented in the United States until 1971 (Egilman et. al. 2014). Analysis of both the prevalence and impact of occupational disease in the United States informs worker risk, public health initiatives, industrial regulation, workers' compensation, overall cost burden through medical treatment, and likely other areas of research and study. (Hilaski 1981, Schroeder 1986, Melius et. al. 1989, Freund et. al. 1990, Leigh 2011, Agtus et. al. 2015, Delaunay et. al. 2015, ILO 2015, Franks 2018).

Researchers note that data on occupational disease incidence in the U.S. has numerous deficiencies (Hilaski 1981, Freund et. al. 1990). For instance, there is no national reporting mechanism for occupational disease and so any researcher that wants to analyze data must aggregate it from multiple sources (Freund et. al. 1990, Leigh 2011). Different sources of occupational disease data likely have different areas of interest for that data's analysis and use. For instance, workers' compensation data wouldn't reflect true disease burden because not everyone sickened by occupational disease files a claim for benefits. Those that do file may find their claim time-barred or otherwise be ineligible for filing (Leibman et. al 1985). Another potential issue with workers' compensation claims is that state coverage of occupational diseases varies and there are no universal federal workers' compensation systems for all occupational disease (Schroeder 1986). State variances in occupational disease compensation may also affect reporting (Schroeder 1986).

Certain industries, such as coal, oil, and gas, are acknowledged by researchers as having a higher risk of injurious exposure that can result in disease (Melius 1989, Agtus et. al. 2015, Franks 2018) so states where higher-risk employment is found would be expected to have higher incidences of occupational disease. Identifying regions of asbestos-related mortality concentration through spatial analysis could help to inform epidemiological surveillance programs and other outreach efforts. For instance, the potential effects of numerous substances used in workplaces on human health is not yet fully known (Schroeder 1986, Delaunay et. al. 2015). Peipins et. al. has written on mining exposure to asbestos-contaminated vermiculite in Libby, Montana, focusing on radiographic findings (Peipins 2003). Henley et. al. in a published study notes that, as asbestos use has declined in the US, rates of mesothelioma should also go down with time.

Another major issue identified by researchers is that occupational disease is not something that usually occupies the public consciousness. Many occupational diseases are latent, developing many years or decades after exposure and often affect lower socioeconomic demographics disproportionately (Schroeder 1986). However, researchers note that the overall cost burden to society created by occupational disease is enormous and that “workers’ compensation covers less than 25 percent of these costs” (Leigh 2011). The latency of disease and the prevailing demographics of those affected means that not a lot of public attention is paid to the issue of occupational illness and disease (Schroeder, 1986).

Researchers have approached the issue of aggregating and analyzing data on occupational disease in various ways. Leigh, in performing a cost analysis on occupational disease, obtained data from the Bureau of Labor Statistics (BLS), the Centers for Disease Control (CDC), as well as more specialized data such as estimates of “Attributable Fractions of diseases with occupational components” (1). Melius also recommends sources to mine for occupational disease data, such as “state death certificates, cancer registries, state workers’ compensation files, hospital discharge records [. . .]” (Melius et. al. p .46). Freund et. al. informs that the “current primary data source for occupational injuries and illness is the Bureau of Labor Statistics *Annual Survey* [*sic*]” (22).

Delaunay et. al. utilized the ‘micro’ and ‘macro’ approach and how the occupational disease data “related to economic activity, occupational health service coverage, compensated ODs [. . .]” (3). The ‘macro-level’ focused on the French microelectronics industry while the ‘micro-level’ looked at the application of a GIS in aggregating occupational safety and health information at a secondary aluminum plant (3). The researchers generated thematic maps on the microelectronics activity sector in France, in the French Rhone-Alpes region, and in the Grenoble area of France. At the 'micro-scale', a computer-aided drafting (CAD) map of the aluminum plant was created and "enriched [. . .] by layers containing agents to which workers may potentially be exposed" (5). The researchers noted that "discrepancies and gaps in data were visible that would normally not be detected in the traditional formats" (5). This supports my hypothesis that integrating and illustrating occupational disease data using a GIS can help identify areas of potential underreporting.

Melius et. al. notes in their research that, because numerous data sources for occupational disease information exist, it is important for a researcher to be sure the data available is useful and appropriate for the intended analysis. "Conditions related to occupational disease exposure must be included in the data system and must be found with some regularity in the geographic area under surveillance. Second, information on the occupational or employment setting of persons in the data system must be included or accessible in some manner" (Melius et. al. 1989). Agtus et. al. notes that the wide variety of data sources yield numerous potential pitfalls concerning integrity and validity (Melius, p. 607). This shows that the selection of data for analyzed will require decisions on what parameters and types of reports/incidences will be deemed acceptable. For the purposes of showing discrepancies or gaps in occupational disease reporting in the United States, it appears best to retrieve data from the Bureau of Labor Statistics, the National Institute on Occupational Disease and Health, and the Centers for Disease Control. A rich, albeit unfortunate, opportunity for data aggregation and analysis presents itself in the case of occupational disease.

An unfortunate reality surrounding data on occupational disease are the various legal and political issues that arise from occupational disease and injury. From the inception of the first state workers' compensation statutes recognizing occupational disease, extensive legal and political involvement in the subject has deeply affected both historical and current surveillance reporting (Hilaski 1981, Schroeder 1986, Freund 1990). Freund et. al. particularly emphasizes how “occupational disease[s] are particularly susceptible to underreporting” (22). However, political and legal action has led to increased public understanding and better information regarding occupational disease as well. Particularly, efforts in the 1960s led to the Coal Mine Health and Safety Act of 1969 which provided a federal workers’ compensation remedy to coal miners afflicted with black lung disease (Hilaski 1981). The data obtained for analysis must be considered deficient with respect to calculating the full burden of asbestos-related mortality in the United States today. However, value exists in evaluation of available data regarding exposure and disease reporting to determine if occupational surveillance correlates with later mortality and to identify states with higher incidence concentration (Hansell et. al. 2009, Delaunay et. al. 2015).

Researchers’ approach to analyzing occupational disease data has centered around statistical approaches. Hilaski reviewed occupational disease as its definitions by the ILO have been refined over the years and decades along with valuable insights into statistical analysis. Melius et. al. reviewed causes of death, occupation of the decedent, observed vs. statistically-expected mortality rates from a particular cause of death, and the application of age-standardized proportionate mortality ratios. The ILO notes that “as data on work-related accidents and diseases are essential for prevention, there is a strong need [. . .] to improve recording and notification systems and data analysis” (ILO, p. 2). Therefore, it will be incumbent for a researcher to ensure the data being considered for usage is appropriate while also understanding that, as no central repository for occupational disease data exists, it is nigh impossible to analyze the full burden and incidence of all known occupational disease. Instead, focus on a sub-set of occupational diseases, such as occupational pneumoconiosis, would allow research to be narrower but still useful in the overall context of identifying gaps in reported or surveilled occupational disease in the U.S.

Use of a GIS to organize, view, and map data relating to occupational pneumoconiosis incidence reports as well as relevant industry data is supported by research as well. Delaunay et. al. explored the use of a GIS to integrate multiple data sources into a presentable and comprehensible format with emphasis on disease surveillance. Pfeieffer et. al. note that GIS is a useful tool in understanding spatial relationships in disease. While their research centered on wildlife disease and epidemiology, their findings on how a GIS augmented their research is probative on the issue of occupational disease analysis. They note specifically that "epidemiological investigations gain strength from being able to incorporate information about the proximity relationships between animals at risk, and also about the context relating to the spatial distribution of risk factors" (91).

The data available for aggregation and review about occupational disease, and specifically pneumoconiosis, is primarily aspatial and/or not integrated for ease of analysis and research. Therefore, utilization of a GIS will augment the existing data and communication of same extensively. Further, Pfeiffer et. al. note that "the technology [GIS] is becoming an essential component of modern disease surveillance systems" (91). GIS will provide a modern spatial perspective on occupational disease which should prove very beneficial to researchers and stakeholders across industries and fields. Spatial analysis of occupational disease data gaps using a GIS could encourage outreach to gather more data, allowing for understanding patterns of occurrence, industrial correlations, public health and treatment issues, and numerous other associated sequelae of occupational diseases in the U.S. workforce (Pfeiffer, 2002).

Data:

Utilized in this research are asbestos-related death statistics gleaned from the Centers for Disease Control's WONDER, an ad-hoc query system that offers comprehensive public health data and information (more information available at wonder.cdc.gov). Asbestos-related death statistics were obtained for all 50 states as well as the District of Columbia for the years 2006-2016.

Also included for analysis are data obtained from NIOSH Occupational Respiratory Disease Surveillance, "Asbestos: Geometric mean exposures and percent exceeding designated occupational exposure limits by OSHA region and state, OSHA samples, 1979-2003". The data obtained from OSHA illustrates asbestos permissible exposure limits beginning in 1979 of 2 fibers per cubic centimeter (f/cc). By 1987, a reduction to 0.2 f/cc was established, and from 1995 forward the permissible exposure limit is 0.1 f/cc. For all 50 states and the District of Columbia, OSHA provides the number of samples in the period, the number that exceeded the permissible exposure limit of the time, and the percentage that exceeded the recommended exposure limit of today, 0.1 f/cc.

Additionally, 2016 employment statistics for three selected industries known for asbestos exposure, by NAIC code, were obtained from American FactFinder, US Census Bureau. These are NAIC 3366 – Ship and boat building; 21 – Mining, quarrying, and oil and gas extraction; 3324 – Boiler, tank, and shipping container manufacturing.

Inclusion/Exclusion criteria:

Asbestos-related diseases have very long latency periods, with disease typically not appearing until 25-40 years post-exposure or even longer (Bianchi et. al. 1997). Therefore, the OSHA exposure data from 1979-1986 was analyzed as most probative for analysis as enough time between exposure and current mortality data has elapsed for disease to manifest. The years 2006-2016 were selected from the CDC WONDER database as to most effectively capture current reported disease mortality as well as to allow for enough latency from the OSHA exposure data period.

NAIC -coded occupational employment data for ship-builders, boilermakers, and mining (including oil and gas) in the US Census Bureau American FactFinder for the 1970s was unobtainable by this researcher. It appears the specific data for these categories was not part of their data collection/reporting. Therefore, an assumption is made that ship-building employment has not significantly changed spatially over 40 years. Boilermaker employment as well as mining (including oil and gas), for congruency, was also selected at the 2016 employment spatial distribution statistics.

Mortality data was selected from years 2006 and 2016 to reflect both the most current statistics available and a look-back to 10 years prior to explore shifts in concentration as well as proportion.

Methods

To determine areas where asbestos mortality is spatially concentrated, the CDC Wonder mortality data was tabulated into a spreadsheet format for each US state, asbestos-related mortality total reported for 2006 and 2016 into separate columns, and reported population estimate for the corresponding year. Using spreadsheet calculations, a location quotient was calculated. $Lq_i = (m_i / p) / (M_i / N)$, where:

- m_i = state asbestos mortality
- p = state population
- M_i = national asbestos mortality
- N = national population

Where: $Lq_i > 1$: state death rate proportion > national death rate proportion; $Lq_i < 1$: state death rate proportion < national death rate proportion; $Lq_i = 1$: state death rate proportion = national death rate proportion.

The resultant location quotients were then formatted for joining to an appropriate US shapefile in ESRI ArcMap. Using cartographic techniques, two choropleth maps were generated for years 2006 and 2016 location quotients, respectively.

For occupational asbestos exposure correlation with mortality, the 1979-1986 OSHA dataset was tabulated into a spreadsheet listing US state, number of samples taken, the percentage of exposures exceeding the permissible exposure limit (PEL) in effect at the time of measurement and the number greater than the recommended exposure limit (REL). REL is the modern standard of 0.1 fibers per cubic centimeter (f/cc). As 0.1 f/cc is the level currently recognized as injurious, all exposure testing exceeding this threshold was classified as injurious for the purposes of this analysis. 1979-1986 data was used as this time period allows for the sufficient latency of 2-4 decades to have elapsed and theoretically manifest in modern mortality. A 95% confidence interval ($p<0.05$) is selected for all Pearson *r* analysis.

Asbestos mortality per 100,000 population, within a 95% confidence interval, obtained directly from the CDC WONDER asbestos mortality dataset is used for comparison. A preliminary investigation of the data finds that it generally follows a normal distribution; therefore, the Pearson *r* correlation coefficient appears appropriate for use. Using statistical software, simple scatterplots and the Pearson *r* are calculated.

Employment data by state for each category of employment, designated by NAIC code, was obtained via American FactFinder query and tabulated into spreadsheet format. The data was tabulated into spreadsheet format by state, employment number, and total employment for a ratio. This data was then analyzed via statistical software where simple scatterplots and the Pearson *r* were calculated against the 2016 mortality data to determine if a statistically-significant relationship exists.

Results and Analysis

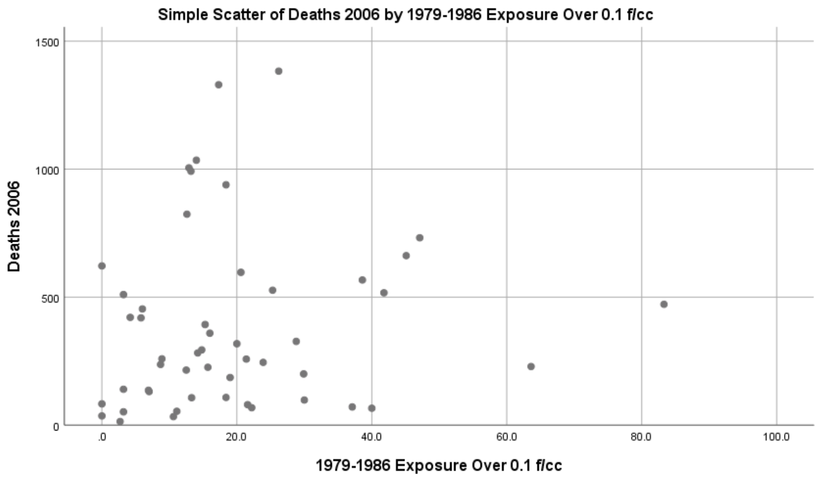

Figure 1. Scattergram for the relationship between *1979-1986 Exposure over 0.1 f/cc* and *asbestos-related deaths in 2006* (very weak, direct, linear relationship, *r* = 0.12).

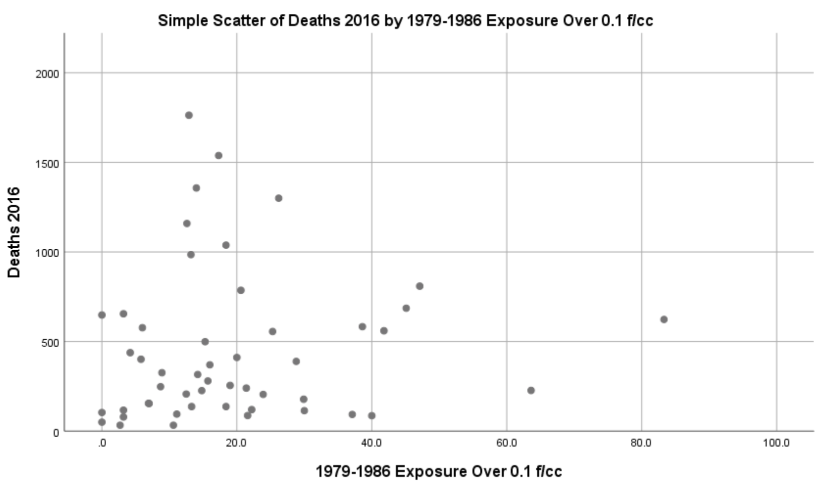

Figure 2. Scattergram for the relationship between *1979-1986 Exposure over 0.1 f/cc* and *asbestos-related deaths in 2016* (very weak, direct, linear relationship, *r* = 0.09).

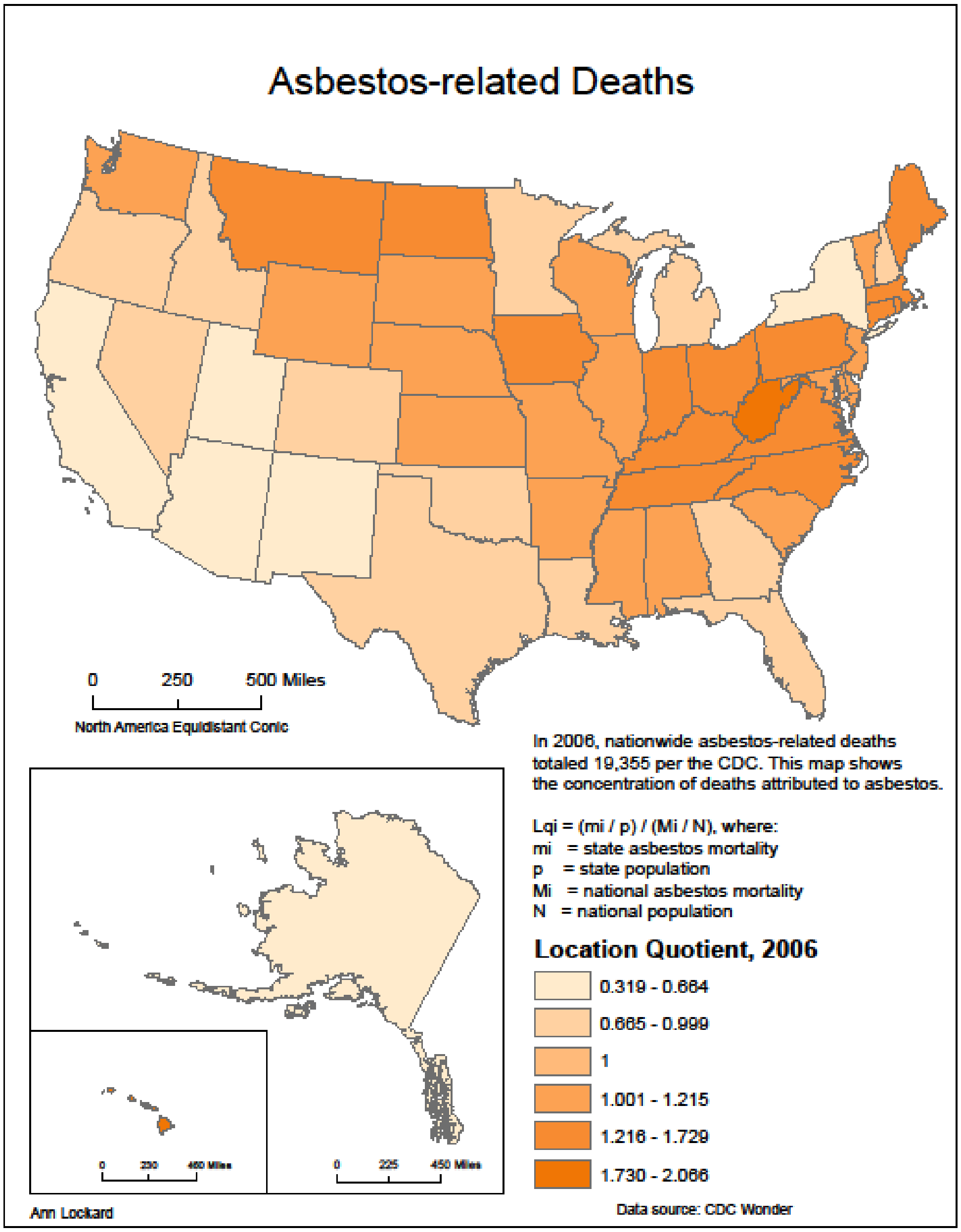

Figure 3. *Choropleth map of calculated location quotients for state asbestos-related mortality data, year 2006.*

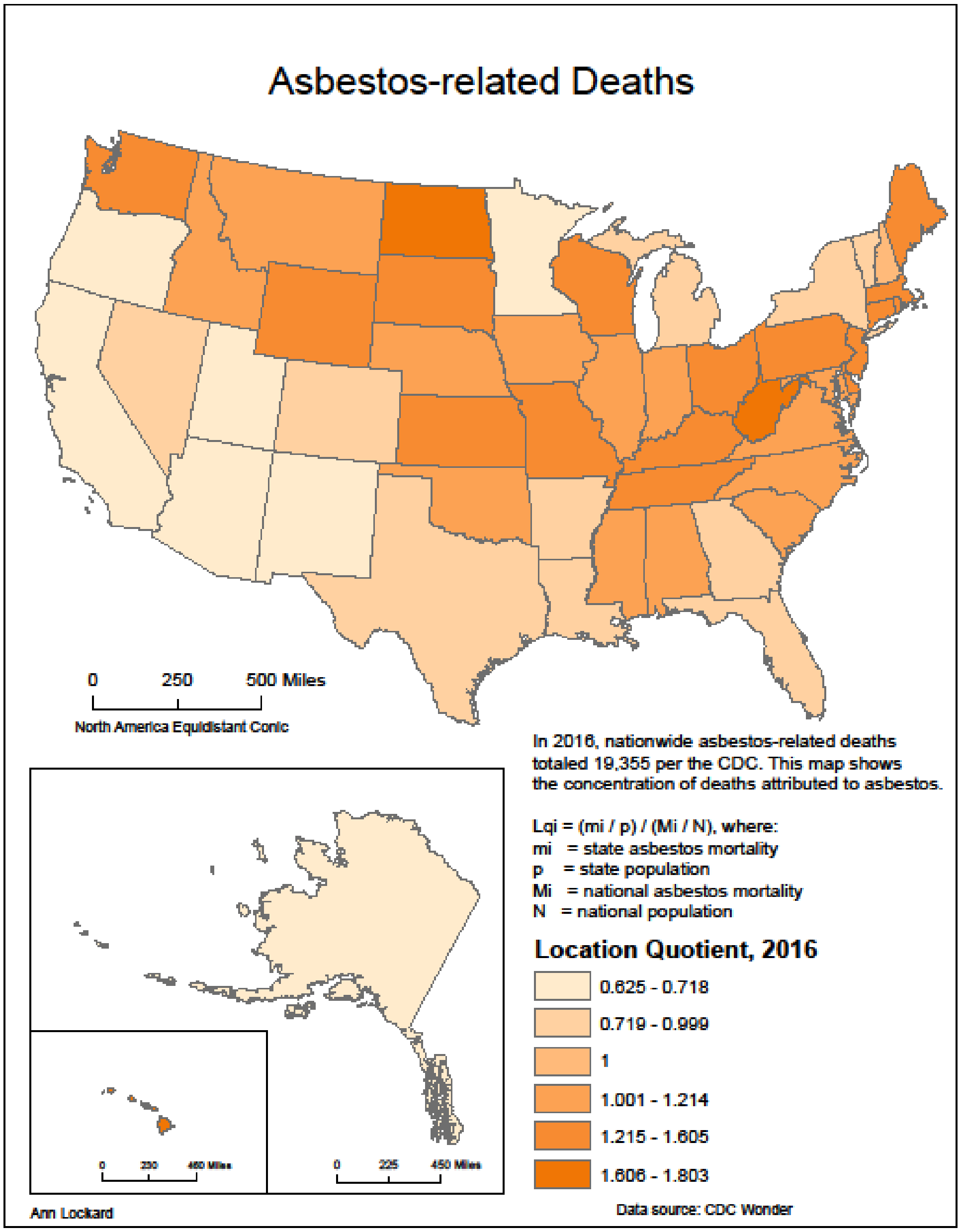

Figure 4. *Choropleth map of calculated location quotients for state asbestos-related mortality data, year 2016.*

		2016 State Mortality Rates per 100,000 population	Ship builders employment, per state, 2016
2016 State Mortality Rates per 100,000 population	Pearson Correlation	1	-.013
	Sig. (2-tailed)		.930
	N	51	51
Ship builders employment, per state, 2016	Pearson Correlation	-.013	1
	Sig. (2-tailed)	.930	
	N	51	51

Figure 5. Pearson *r* analysis *for ship – and – boat builder employment in 2016 shows very weak inverse correlation with 2016 asbestos mortality among states* (*r* = -.01)

Correlations			
		2016 State Mortality Rates per 100,000 population	Boilermaker employment, per state, 2016
2016 State Mortality Rates per 100,000 population	Pearson Correlation	1	-.027
	Sig. (2-tailed)		.852
	N	51	51
Boilermaker employment, per state, 2016	Pearson Correlation	-.027	1
	Sig. (2-tailed)	.852	
	N	51	51

Figure 6. *Pearson r analysis for boilermaker employment in 2016 shows a very weak inverse relationship with 2016 asbestos mortality among states (r = -.03)*

Correlations			
		2016 State Mortality Rates per 100,000 population	Mining employment (all types), per state, 2016
2016 State Mortality Rates per 100,000 population	Pearson Correlation	1	-.182
	Sig. (2-tailed)		.201
	N	51	51
Mining employment (all types), per state, 2016	Pearson Correlation	-.182	1
	Sig. (2-tailed)	.201	
	N	51	51

Figure 7. *Pearson r analysis of mining (including oil and gas) employment in 2016, showing a very weak inverse relationship with 2016 asbestos mortality among states (r = -.18)*

The statistical analysis of OSHA exposure data with mortality yields weak to no meaningful correlation. This is not a wholly unexpected finding; the sparseness and inconsistency of OSHA's surveillance for the 1979-1986 figure does not provide a good dataset for analysis.

Review of the choropleth map from 2006 indicates that the Mid-Atlantic and portions of the Northeast reflect higher concentrations of asbestos-related mortality. Hawaii, Montana, and North Dakota are also relatively concentrated areas of mortality. Low mortality is reflected in the southwestern US, Alaska, and New York state, the latter which appears unusual given that all adjacent states have higher location quotients. West Virginia has the highest concentration of asbestos-related deaths in the nation.

The 2016 choropleth map has notable similarities and differences from the 2006 mortality distribution. West Virginia remains in first place for mortality, with the Mid-Atlantic also yielding higher location quotients – though Virginia and Maryland drop some. Hawaii remains a high concentration state as well. The High Plains to Washington State are at or above the median location quotient for this year, with the noted exception of Minnesota (much lower). The desert southwest and Alaska remain states of low concentration and New York's position is moderated somewhat – less than but nearer to a location quotient of 1 than in the 2006 analysis. The location quotient maps of 2006 and 2016, along with the mortality dataset, reveal an incidental but important finding: asbestos-related mortality deaths reported are rising, across most states during the period and in the aggregate. The choropleth mapping and use of location quotients appears worthwhile for understanding the spatial distribution and concentration of mortality.

As with the OSHA exposure analysis, the 2016 selected at-risk industry NAIC employment statistics for ship-builders, boilermakers, and mining (oil + gas included) also yield no statisticallymeaningful relationship. This was also surprising as a relationship between the mortality data and at least one of these employment statistics was theorized as possible.

Discussion and Conclusion

This qualitative analysis of asbestos-related mortality in the United States finds that modern death rates are rising, significantly spatially variable, and that neither Occupational Safety and Health Administration dust monitoring sampling nor a focus on modern noted injurious employment statistics correlate with the spatial variance in death.

Prior studies looked at fibers per millimeter exposure as compared to the OSHA recommended exposure limit for extrapolation of disease risk (Hughes et. al. 1986). It is also acknowledged that certain industries as having a higher risk of injurious exposure that can result in asbestos-related disease (Agtus et. al. 2015). Critically, numerous studies have bemoaned the numerous data deficiencies that plague asbestos incidence in the United States (Hilaski 1981, Freund et. al. 1990, Leigh 2011). Focus has also been paid on the type of asbestos involved in exposure, which is beyond the scope of this paper (Goswami et. al. 2013). Goswami et. al. obtained data from the CDC Wonder system with a focus on mesothelioma, lung cancer, and interstitial/pleural abnormality coding, an approach mirrored in this work. Well-documented disease latency pursuant to both Lanphear et. al. and Selikoff et. al. were assumptions in the data analysis between exposure and expected mortality.

Workplace exposure monitoring for asbestos fibers for the focus period of 1979-1986 was clearly inadequate both in form and function to adequately quantify and protect workers from asbestos risk. The direct, weak correlation between worker exposure beyond the current recommended exposure limit (REL) with asbestos mortality reveals that data inadequacy, non-surveilled exposure, military exposure, and secondary/domestic exposure all play a part in the spatial distribution of asbestos mortality in a way that the limited OSHA exposure data alone cannot strongly support.

Evaluation of asbestos mortality through location quotients reveals both the rise in reported deaths from 2006-2016 as well as the dramatic differences in the spatial distribution of asbestos-related mortality. The rise in deaths is an important focus point for epidemiology and reporting. The location quotients also reveal that historical injurious exposure is impacting some state populations far greater than others.

Focus on three known higher-risk occupations based on 2016 employment data – mining, ship building, and boilermakers – occurred due to a lack of NAIC occupational data during the studied 1979-1986 study period (asbestos.com). Therefore, these occupations were selected under an assumption was that spatial concentration of these three industries had not meaningfully changed from the beginning of the studied exposure period (1979) through the year of data pull, 2016. The lack of a broad correlation between these industries in 2016 and mortality for 2006 and 2016 was surprising and lends strong additional support to other studies that discuss numerous other contributing exposure and surveillance factors.

The inadequacy of the available exposure data for 1979-1986 and the inability to correlate modern at-risk employment spatially with death, aside from a few individual state examples, leave the full epidemiological risk and burden of asbestos exposure difficult to quantify. This is especially frustrating due to the extensive risk of secondary and incidental exposure detailed in the referenced literature. As noted, this issue has plagued researchers previously and this attempt is no more successful. Further research into what impact a national registry for asbestos-related disease incidence and mortality would have may prove invaluable, especially since asbestos use remains a risk factor for over a million workers in the United States and is not outlawed (*see generally:* asbestos.com).

Recommendations for further research attempts include identification of additional extant data sets – military exposures would be useful, as would incidental exposure in resource extraction. Further investigation into the most recently-active asbestos mining operation locations with disease incidence and mortality correlations may also be useful. County-level epidemiological data would reveal more meaningful location quotients for public health monitoring, potential workers' compensation impacts, and treatment foci. A national registry for both asbestos-related disease and death, capturing at the county level with any employment classification or non-occupational suspected source identified could prove invaluable at quantifying future employee and public disease risk.

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