Asthma Mortality, Puerto Rico 2010-2015

Programa de Asma de Puerto Rico

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Authors:
José A. Bartolomei Díaz, PhD, Outcome Project, LLC
Rachel Hanisch, PhD, Epidemiological Consultant

Revised by:
Ibis Montalvo Félix, MPHE, Puerto Rico Asthma Program
Krystel Ruiz Serrano, MS, Puerto Rico Asthma Program
Jessica Irizarry Ramos, PhD, Puerto Rico Asthma Program

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Introduction

Asthma

Asthma is a chronic inflammatory disorder of the airways in which many cells and cellular elements play a role: in particular, mast cells, eosinophils, neutrophils (especially in sudden onset, fatal exacerbation, occupational asthma, and patients who smoke), T lymphocytes, macrophages, and epithelial cells. In susceptible individuals, this inflammation causes recurrent episodes of coughing (particularly at night or early in the morning), wheezing, breathlessness, and chest tightness. These episodes are usually associated with widespread but variable airflow obstruction that is often reversible either spontaneously or with treatment (National Asthma Education and Prevention Program, 2007). Asthma has been recognized as an important global health issue and has become the most common chronic condition in many countries (D. H. Wilson et al., 2007).

Asthma mortality is mainly attributed to long periods of unwieldy management patterns of the condition. Poor asthma management can be caused by a series of preventable factors such as: lack of knowledge or misapplication of asthma control guidelines by health care providers, lack of a written action plan, patient's lack of awareness of the severity of the condition, and lack of access to specialists or medications (D. H. Wilson et al., 2007).

Mortality data can be used to describe numbers of deaths by place, time, and cause, and is usually studied using the underlying cause of death recorded on the death certificate. The underlying cause of death is defined as "the disease or injury which initiated the train of morbid events leading directly to death, or the circumstances of the accident or violence which produced the fatal injury", in accordance with the rules of the International Classification of Diseases (http://www.who.int/topics/mortality/en/).

National civil registration systems, known in Puerto Rico as the Demographic Registry, are the optimal source of cause of death data because they are intended to cover the entire population (D. E. Phillips et al., 2014). When a death occurs, this event is registered at the local civil registry, with medically certified information on the cause of death being included.

Countries need to know how many people are born and die each year – and the main causes of their deaths – in order to have well-functioning health systems. Information on births and deaths by age, sex and cause is the cornerstone of public health planning (World Health Organization, 2014). Likewise, cause of death data from civil registries are vital to understanding how to pinpoint the diseases and injuries that are cutting lives short and planning preventive services to avoid premature mortality. Cause of death data are also useful for informing governments about outbreaks of fatal disease (L. Mikkelsen, Lopez, & Phillips, 2015). Without such mortality data, policymakers lack reliable evidence to design effective policies, instead resulting in measures that are based on ideology, anecdotes or political considerations (L. Mikkelsen et al., 2015). The systematic neglect of civil registration and vital statistics has been identified as "the single most critical failure of development over the past 30 years." It has become increasingly clear that without reliable vital statistics we cannot monitor progress towards our development goals or national development policies (Setel et al., 2007).

Internationally, mortality statistics show that less populated countries experience a substantial range of uncertainty around their published rates, perhaps indicating a paucity of reliable vital statistics data. Populated countries that have more stable vital statistics systems, on the other hand, may not be subject to as much uncertainty in their data. Variations in rates may therefore be more likely to reflect true population changes in rates (Global Asthma Network, 2014). It was estimated that 0.40 million people died from asthma worldwide in 2015, a decrease of 26.7% from 1990, with the age-standardized death rate also decreasing by 58.8% (J. B. Soriano et al., n.d.).

In 2011, Bartolomei-Díaz, Amill-Rosario, Claudio, & Hernández (2011) reported on the state of asthma mortality in Puerto Rico from 1980 to 2007. They concluded that asthma death rates were higher in Puerto Rico than in the US general population. In 2007, asthma mortality rates were 1.77 higher in Puerto Rico than in the US. From 1980 to 1998 annual asthma mortality rates in Puerto Rico fluctuated between 3.32 and 6.56 deaths per 100,000. Asthma mortality in Puerto Rico declined after the implementation of the ICD-10 system as a means of reporting cause of death from 4.89 per 100,000 in 1999 to 2.02 per 100,000 in 2007. The progressive decline in asthma mortality rates after 1999 may be explained by changes in reporting classification, increased use of corticosteroids, and improved asthma awareness. After controlling for possible confounding variables, age and elementary education were found to increase the risk of mortality due to asthma among Puerto Ricans.

Disease Surveillance

Disease surveillance is the systematic and continuous collection, analysis, and interpretation of data, closely integrated with the timely and coherent dissemination of results and assessment by appropriate persons so that action can be taken. Disease surveillance is an essential feature of epidemiological and public health practice, as the information from surveillance efforts can be practically applied to areas of health promotion and disease prevention and control. By observing trends in time, place, and persons, appropriate action can be taken including investigative or control measures (Porta, Greenland, Hernán, Silva, & Last, 2014; Remington, Brownson, & Wegner, 2010).

Objective

The objective of this surveillance report is to analyze asthma related death distribution by time and demographics to identify possible trends or groups at risk. This surveillance work can then be used to detect any changes in endemic rates in Puerto Rico, and to design remedial and prevention strategies for this disease.

Methods

This section provides the methods used to conduct the surveillance activities.

Population under surveillance

The population under surveillance were individuals who were residents of Puerto Rico from the years 2010 to the year 2015. Mortality data was obtained from the National Center for Health Statistics (NCHS) data set repository at https://www.cdc.gov/nchs/data_access/vitalstatsonline.htm#Mortality_Multiple. The data set was downloaded as a text fixed-width delimited file. The data files were then formatted for analysis following the documentation guidelines at https://www.cdc.gov/nchs/nvss/mortality_public_use_data.htm.

Asthma death cases were identified as those deaths coded as J45-J46 as the underlying cause of death using the International Code of Diseases 10th revision (ICD-10) . Asthma related deaths according to municipality of residence data was provided by the Puerto Rico Demographic Registry. The population data for rate calculations was obtained from the Census using their data sets Application Program Interface (API) at https://api.census.gov/data.html.

Surveillance variables

For this surveillance activity, asthma related death was studied using the following variables available from the NCHS data set.

- Sex, a dichotomous variable coded as male and female.

- Age group, a discrete variable categorized by the Census into 10-year age groups. The age group variable was coded as 0 to 14, 15 to 24, 25 to 34, 35 to 44, 45 to 54, 55 to 64, 65 to 74, 75 to 84 and 85 and older. However, results that had less than five deaths within categories were present. As required by the NCHS, wider groups were constructed to avoid possible identification of individuals. The age groups subsequently analyzed were 0 to 24, 25 to 34, 35 to 44, 45 to 54, 55 to 64 and 65 plus.

- Marital status, a discrete variable noting the marital status of the deceased. The stratification of this variable (divorced, married, never married and widow) was provided by the NCHS.

- Education, a dichotomous variable which collected information pertaining to the highest level of education received at the time of death. There were two revisions of education variables in the NCHS data set: the 1989 revision was used from 2005 to 2014 and the 2003 revision was used from 2015 onward. For the present surveillance activity, the 1989 revision was explored. The categories of education variables were: No formal education, 1 year of elementary school, 2 years of elementary school, 3 years of elementary school, 4 years of elementary school, 5 years of elementary school, 6 years of elementary school, 7 years of elementary school, 8 years of elementary school, 1 year of high school, 2 years of high school, 3 years of high school, 4 years of high school, 1 year of college, 2 years of college, 3 years of college, 4 years of college, 5 or more years of college. In order to calculate education level rates, the education level categories in the mortality data set were grouped to match those of the Census categories. The aggregation resulted in the following groups: less than high school graduate, high school graduate, some college or associate's degree, bachelor's degree and graduate or professional degree.

- Manner of death, a discrete variable that collected information regarding type of death. Manner of death was categorized as accidental, natural death, or could not be determined.

- Place of death, a discrete variable that collected information on where the death occurred. The recorded places of death were: in a hospital as an inpatient, in an emergency room or at a physician's visit, dead on arrival, at the decedent's home, at a nursing home or at another unspecified place. The code for the variables were: inpatient, outpatient or ER, dead on arrival, decedent's home, nursing home or other.

- Month of death, a discrete variable that recorded the month during which the death occurred. This last variable was coded as the name of the month.

- Municipality of residence, a discrete variable that recorded the municipality in Puerto Rico where the deceased lived at the time of death.

Statistical analysis

This section is organized into four sub-sections. Each sub-section explains the use of the statistical analysis described.

Death count by year

Death count was stratified by year and other variables to identify patterns or trends. In this exploratory data analysis, differences between groups could be due to differences in population size as well as differences in risk. Differences in death counts between groups were further evaluated using rate calculations and regression modeling strategies.

Crude death rates

Crude asthma death rates and their 95% confidence intervals stratified by year were calculated as a measure of risk from 2010 to 2015. In addition, group-specific asthma death rates were calculated by sex, age group, marital status and educational attainment. Specific death rates for the other previously mentioned variables were not calculated due to lack of specific population denominator information. As asthma death is a rare event, 5-year periods were used to evaluate deaths by demographic variables. Death rate is an estimate of the proportion of a population that dies during a specified period of time, and can be applied to whole populations, groups, or sub-populations. (Porta et al., 2014) The numerator used for the Puerto Rico asthma death rate was the number of persons in Puerto Rico who died from asthma during the 2010-2015 period and within a specific group (Ex. age group). The denominator was the entire Puerto Rican population from the same group used to calculate the numerator during the same time period. To conduct the education rate calculation, a subset of those aged 25 years and older during the 2010 to 2014 time period was selected.

Age standardized death rates

Standardization of rates or risk involves taking a weighted average of the underlying stratum-specific rates or risks. The standard is the set of weights that is used in taking the weighted average (Rothman, Greenland, & Lash, 2008). The importance of using standardized rates is if any differences are observed between compared rates, they cannot be attributed to differences in population distribution of the standardized variables (ie., age and gender).

Age standardized death rates by year using the direct method were calculated as a way of minimizing the effect of differences in age groups, thus allowing rates to be compared with other populations (ex., other countries, the United States). The 95% confidence intervals were calculated for each of the standardized rates and used for comparison between different years. US 2010 population estimates by age group were used as the standard population for this calculation. As a means of comparison, age adjusted mortality rates for the year 2015 were calculated for both the US and Puerto Rico, using the 2010 US population estimates by age group as the standard population for each of the respective rates.

Analysis of proportions

Analyses of differences in proportions were conducted for the following variables: Manner of Death, Place of Death and Month of Death. Six years of death information (from 2010 to 2015) was aggregated to conduct comparisons between categories. The analysis evaluated whether at least one of the categories within a specific variable (ex., Manner of Death) was significantly different from the other categories within the same variable. As differences in proportions are assumed to have a Chi-Square distribution, a test for differences in proportions based on this distribution was used (Dalgaard, 2008). Death rates for these variables were not calculated due to lack of available population estimates.

Multiple regression analysis

Multiple regression analysis was conducted to estimate the risk of dying from asthma by covariates (sex and age groups), controlling for possible confounding effects of the other covariates. This confounding effect, as explained by Porta et al. (2014), "occurs when all or part of an apparent association between the exposure and outcome is in fact accounted for by other variables that affect the outcome, and are not themselves affected by the exposure." In other words, if there is confounding and it is not taken into account in the analysis, the estimates will be biased.

To conduct a regression analysis, the distribution of the outcome (dependent variable) needs to be known in order to select an appropriate function for the model. The outcome, number of deaths, can be referred as count data of rare events, leading to a Poisson distribution. As expressed by Kleinbaum, Kupper, Nizam, & Rosenberg (2013), Poisson regression is a technique available for modeling dependent variables which is able to describe count data and is often used to model the occurrence of rare events. Diagnostic statistics indicates whether over-dispersion of the data has occurred. An approach developed to deal with over-dispersed Poisson data is to model it as a Negative binomial distribution (Rothman et al., 2008). Both Poisson and Negative Binomial regression analyses were conducted using the present data. Neither the estimates nor the standard error were different between these types of analysis. The resulting coefficients of the regression model were exponentiated to obtain the risk estimate, known as the Risk Ratio (RR). If the RR=1 then the comparison group has the same risk as the reference group. If the RR>1 then the comparison group has a higher risk than the reference group. Finally, if the RR<1 then the comparison group has a lower risk than the reference group. The Wald test statistic was used to test whether the reference group estimates were statistically different from the comparison group estimates accounting for the inclusion of other variables in the model (Rosner, 2015).

Disease mapping

"Spatial epidemiology concerns the analysis of the spatial/geographical distribution of the incidence of a disease or the study of the occurrence of disease in spatial location and its explanatory factors. In its simplest form, the subject concerns the use and interpretation of maps of the locations of disease cases, and the associated issues relating to map production and the statistical analysis of mapped data must apply within this subject" (Lawson, 2013). The present work applies disease mapping to describe the overall geographical distribution of asthma in Puerto Rico.

The purpose of this technique is to produce maps which take into account the spatial variation of disease occurrence in order to identify areas of unusually high risk. This type of mapping can then lead to etiological hypothesis formulation. The spatial resolution or scale used to observe the geographical distribution of asthma related deaths in Puerto Rico was by municipalities.

Cases by municipality are aggregated count data that represent the occurrence of the disease in each of the 78 municipalities of Puerto Rico.

Three maps will be presented as a result of this spatial analysis: 1. Observed cases (to plan for resources allocation); 2. Age standardized rates which were smoothed by a local empirical Bayes estimator to know the number of cases in relation to the population size as an estimate of risk; and 3. Age adjusted Standardized Mortality Ratio (SMR) smoothed by a local empirical Bayes estimator to compare the risk of each municipality against a standard, the risk of Puerto Rico as a whole. Rates were adjusted to reduce the likelihood that any differences in mortality proportions between regions are due to differences in age distributions within the regions rather than to differences in the underlying age-specific risk of disease (Waller & Gotway, 2004).

The explanation for why map smoothing was employed is beyond the scope of this work. However, it is important to point out that although the SMR is an unbiased estimator of relative risk of each municipality it has several limitations. These limitations include the fact that that crude SMR's cannot be used for comparing regions with zero incidence counts, and can yield large changes in estimates with relative small changes in expected values. Another difficulty associated with the use of SMR's for inference is that areas that are geographically close induce spatial correlation, which if not taken into account could introduce errors in the models used for inference (Pascutto et al., 2000). Ignoring this effect, the over-dispersion can create the impression of artificial geographic variation in disease rates. (Leyland, 2005) Statistical approaches have been developed to overcome those limitations. It can be argued that the Bayesian hierarchical modeling and the Empirical Bayes approach are the most appropriate to use for spatial analysis. The local Marshall Empirical Bayes estimator (EB) with parameters estimated by the moments smoothing technique was chosen to study the geographical distribution of asthma related deaths. The purpose of the local Marshall EB is to shrink the rate towards a local spatial neighborhood (Marshall, 1991).

Software

The R language for statistical computing and its associated packages were used as the computational tools to conduct our data management and analysis procedures (R Core Team, 2017).

Results

This section is organized into the same sub-sections as the statistical analysis section. Each sub-section explains the results of the statistical analysis used.

Death count

There was a total of 415 asthma deaths recorded during the 2010 to 2015 period. When asthma related deaths were analyzed by year, a non-monotonic trend was observed from 2010 to 2015. A decrease of 89 asthma related deaths in 2011 to 37 deaths in 2013 was observed. Subsequently, an increase of 100 asthma related deaths was recorded in the year 2014, decreasing to 89 deaths in 2015. Refer to table 1 for these observations.

When asthma related deaths were evaluated by age group, several observations stood out. The 0 to 24 age group had only 4 asthma deaths recorded during the period of observation. There were no asthma deaths in the 0 to 24 age group between the years 2012 to 2014. In 2015, one asthma related death in this age group was recorded. A smooth upward trend of cases of asthma death was observed within the 25 to 64 age groups between the years 2013 to 2015. The year-to-year fluctuation of asthma deaths was pronounced among the 65 plus age groups.

The aforementioned downward trend through the year 2013 was also observed among both sexes. Females maintained a higher number of asthma deaths than males across the whole observation period. In addition, the 2013 increase in asthma deaths occurred in both sex groups. When marital status was evaluated, a notable difference between deaths in the married group compared to those in the divorced group was seen. This observation needs to be confirmed with the rate calculations. No other distinguishable observations were made with regard to marital status. Among education groups, the graduate or professional degree group and the bachelor's degree group experienced a monotonic trend during the observation period. The other three groups presented a similar decrease in asthma related cases from 2011 to 2013 and an increase in the year 2014. Refer to table 2.

Regarding the variable manner of death, the majority of asthma deaths were classified as natural deaths. From 2006 to 2009, three asthma deaths were classified as accidents. In 2004 and 2015, two asthma deaths were classified as could not be determined. Refer to figure 6. Evaluating the variable place of death, as shown in figure 7, asthma related deaths classified as inpatient and having occurred in the decedent's home accounted for the majority of cases, and followed the same general trend mentioned above. The other place of death groups presented an overall monotonic trend. Finally, when evaluating month of death, no specific month appeared to stand out. Refer to figure 8.

Crude death rates

Figure 1 and table 1 shows asthma death rates by year from 2010 to 2015. The asthma death rate was lower in the year 2013 with a rate of 1.03 per 100,000 individuals. The highest asthma death rate was recorded in the year 2014, with a rate of 2.83 per 100,000 individuals. Evaluating the confidence intervals between these two points, a statistically significant difference in rates was seen.

Table 2 shows the results of the bi-variate analysis. Regarding sex groups, females had a death rate of 2.11 per 100,000 and males had a death rate of 1.71 per 100,000. Evaluating the confidence intervals between females and males, the differences in rates were not statistically significant. A visualization of this analysis can be found in figure 2.

Likewise, we evaluated death rates by age groups. We found that the lowest death rate among all age groups was in the 0-24 age group, with a rate of 0.06 per 100,000 individuals. The highest asthma death rate was recorded in the age group 65+, with a rate of 7.77 per 100,000 individuals. The difference in rates between the two aforementioned age groups was statistically significant. Figure 3 shows a visualization of this analysis.

Among individuals grouped by marital status, widowed had the highest asthma death rates at 9.25 per 100,000 individuals. On the other hand, the never married group had the lowest asthma death rates at 1.23 per 100,000 individuals. The differences in rates between the two aforementioned marital status groups were statistically significant. Figure 4 shows a visualization of this analysis.

Regarding education levels, less than high school graduate had the highest asthma death rates at 4.64 per 100,000 individuals. The bachelor degree group had the lowest asthma death rates at 0.5 per 100,000 individuals. The differences in rates between the two aforementioned education levels were statistically significant. Figure 5 shows a visualization of this analysis.

Age standardized death rates

Table 3 shows the age standardized rates for this population. When the yearly crude rates were compared with the yearly standardized rates, a small difference between compared rates by year was observed. The 2015 US age adjusted mortality rate using the 2010 US reference population was 1.06 per 100,000 individuals. This compared to a rate of 2.18 in Puerto Rico during that same year, 1.12 times higher than the US mortality rate.

Analysis of Proportions

The variables manner of death, place of death and month of death as presented in figures 6, 7 and 8 were evaluated using analysis of proportions. The resulting p-value of the variables manner of death and place of death was less than 0.001, thus finding that at least one of the groups was statistically different than the other groups. Based on the graph, we can deduce that an asthma related death is significantly more likely to be classified as a natural death than any other category. Likewise, we can deduce that dying from asthma at home or as an inpatient is a more likely event than dying at any other place. However, when month of death was evaluated, no statistical differences existed between deaths occurring at different times of the year.

Regression Modeling

The Poisson regression results shows that females had an 8 percent higher risk than males of dying from asthma as the underlying cause of death after controlling for age group during the 2010-2015 period. When observing the results of age group, and after taking into account sex, we observed an increase in risk with increasing age group. The reference age group in this analysis was the 0 to 24 age group, which had the lowest risk. The 65+ age group had the highest risk of all age groups, with a 137 times higher risk of having an asthma related death than the 0 to 24 age group.

Disease mapping

The top five municipalities with the highest observed asthma related deaths during the observation period were San Juan, Bayamón, Ponce, Mayagüez, and Arecibo with 36, 25, 22, 18, and 17 deaths, respectively. Refer to figure 9 for a map of observed cases by municipalities. The municipalities of Ceiba, Culebra, Luquillo, Maunabo, and Rincón did not report any asthma related death during the observed period. When analyzing asthma related death rates during the observation period, it was observed that the top five municipalities with the highest age adjusted rates were Las Marías, Mayagüez, Hormigueros, Añasco, and Lajas with 3.53, 3.33, 3.24, 3.19, and 3.13 deaths per 100,000 individuals, respectively. Refer to figure 10 for a map of age adjusted asthma death rates by municipality. Lastly, the top five municipalities with the highest age adjusted SMR during the observation period were Las Marías, Añasco, Moca, San Sebastían, and Mayagüez with 1.72, 1.67, 1.61, 1.59, and 1.56 respectively. Refer to figure 11 for a map of SMR's by municipalities. Overall, it appears that the north-center, north west and west portion of Puerto Rico had higher risk of asthma related death than other areas.

Discussion

Asthma is a common chronic condition that is associated with high levels of morbidity worldwide. It is estimated that approximately 300 million individuals suffer from the disease globally (Masoli, Fabian, Holt, & Beasley, 2004). Fortunately, the condition can be controlled through successful management by properly following disease control guidelines and ensuring adequate treatment access and adherence. These management techniques have been associated with a reduction in disability-adjusted life years and mortality in countries where asthma management plans have been implemented (J. Bousquet, Bousquet, Godard, & Daures, 2005). Asthma morbidity and mortality can take a large toll on health systems as well. In the United States, asthma is responsible for more than 10 million outpatient visits and 500,000 hospitalizations (NCHS, 2001). In addition, the annual cost of asthma in the United States is estimated to be nearly $18 billion. In Puerto Rico, asthma death rates are estimated to be even higher than in the United States (Bartolomei-Díaz et al., 2011). The objective of this surveillance activity was to explore asthma related deaths distribution between 2010-2015 among residents of Puerto Rico according to key time and demographic variables to identify any patterns, trends, or at-risk population groups that may exist.

Fortunately, many of the asthma deaths that occur are avoidable, and countries that have implemented disease control strategies have experienced decreasing or stable death rates in recent years (World Health Organization, 2007). These disease control strategies include early diagnosis of the disease, greater focus on asthma treatment in primary care settings and implementation of clinical practice guidelines (Masoli, Fabian, Holt, Beasley, & Program, 2004), greater access to specialists, improved access to health care services, greater use of low-dose inhaled corticosteroids (Suissa, Ernst, Benayoun, Baltzan, & Cai, 2000), developing educational programs aimed at asthma control, and providing appropriate training for healthcare professionals. Surveillance of asthma deaths can identify any patterns or changes in trends in asthma deaths, thus informing public health authorities of appropriate actions that can be taken to lessen the burden of the disease. Further, monitoring these trends by specific risk factors helps public health priorities to be appropriately set and interventions to be more effectively targeted, resulting in more actionable and effective asthma control. The trends presented in this report could provide important information as to the best manner to implement these control measures in the Puerto Rican population, in terms of noteworthy person, time, and place variables.

We found an overall statistically-significant non-monotonic trend in the rate of mortality deaths in Puerto Rico between the years 2010 and 2015, with the lowest death rate occurring in 2013 and the highest rate occurring in the following year, 2014. Based on previous reports where the rate of asthma mortality was seen to decrease between the years 1980 and 2007 in Puerto Rico (Bartolomei-Díaz et al., 2011), and based on evidence of overall decreasing asthma mortality rates in other countries G. D'Amato et al. (2016); Haahtela et al. (2001); Casado et al. (2006); Sánchez-Bahíllo, García-Marcos, Pérez- Fernández, Martínez-Torres, & Sánchez-Solís (2009), one would expect a similar decrease in the rate of asthma deaths across the years 2010-2015 in Puerto Rico. Several hypotheses could explain this non-monotonic trend between 2010-2015. First, this trend may be partially explained by natural fluctuations in the rate of asthma deaths by year, although these natural fluctuations are not expected to completely explain observed statistically significant changes across years. It is also possible that this non-monotonic trend is partially a result of inconsistencies or changes in the methodology of recording or reporting asthma deaths via death certificates in Puerto Rico. For example, changes in the way asthma deaths were attributed as being the underlying cause of death, recorded, or reported from year to year could affect rates. Future investigations could focus on evaluating the comparability of death certificates to hospital and other patient records in terms of identifying underlying cause of death and other reporting features.

Geographical spatial analyses were also conducted to identify whether any trends in asthma rates could be observed across the island. We found that, after adjusting for age, asthma rates were higher in the north, north-west, and western areas of Puerto Rico. These differences in asthma rates may indicate differences in asthma risk factors across the island, and warrant further study.

The present surveillance effort was able to track trends in asthma rates by key demographic variables including age, marital status, education, place of death, and time of death. We found that females had higher asthma mortality rates compared to males, although this difference was not statistically significant. This finding is consistent with data from other sources, with reports that women account for almost 65% of asthma deaths (NCHS, 2001). It is hypothesized that these sex differences are due to differences in airway caliber and hormones between men and women (De Marco, Locatelli, Sunyer, Burney, & Group, 2000). Among individuals analyzed, we also found a trend of increasing asthma death rates with increasing age. This is a well-documented trend, with many studies having shown that increasing age is associated with increasingly severe clinical asthma outcomes and mortality (Tsai, Lee, Hanania, & Camargo, 2012). Looking at the effect of age across time, there were strong year-to-year fluctuations. We also found that widowed persons were more likely to die from asthma compared to never married, married, and divorced persons. It has indeed been postulated that widowed persons are more likely to have worse health outcomes, including mortality, than married persons (Goldman, Korenman, & Weinstein (1995); Manzoli, Villari, M Pirone, & Boccia (2007); Hughes & Waite (2009)). The association between being widowed and increased likelihood of dying from asthma is an interesting trend that may merit further research and could inform efforts to improve access to asthma care and asthma treatment adherence rates. When evaluating asthma deaths by educational groups, those with less than a high school education were found to have the highest rates of asthma deaths followed by those with a high school education, highlighting a trend of lower asthma deaths with higher levels of education. However, after the year 2015 the NCHS changed the manner by which they stratified education status. For this reason, educations groupings using 2015 and more recent years did not match with the educational groups used by the Census Bureau, and asthma death rates could not be calculated due to lack of matching numerators and denominators. Future efforts could advocate for consistent use of educational group classification across data platforms. Finally, we observed that individuals who died from asthma were most likely to do so as an inpatient or in their own homes. Deaths from asthma at home could imply that certain individuals with asthma may be experiencing a life-threatening delay in obtaining help during an asthma attack. Further investigation into the profile of persons who die from asthma at home may help to inform appropriate population sub-groups to target in terms of fostering improved access to emergency care for asthma as well as overall asthma treatment and care.

Several limitations associated with the analysis of this data for surveillance purposes exist. First, the present evaluation of asthma deaths relied on the classification of asthma deaths as per the cause of deaths listed on death certificates housed by the Demographic Registry in Puerto Rico. Several limitations exist with regard to the use of death certificates to classify death due to asthma. First, it is possible that a bias exists with regard to the type or severity of asthma cases represented by death certificate data. Specifically, it is possible that more severe cases of asthma were attributed to the underlying cause of the individual’s death as opposed to moderate or less severe cases. Further, if the deceased individual suffered from other comorbidities in addition to asthma, it is possible that the underlying cause of death was attributed to another comorbidity apart from asthma. It is well documented that individuals with asthma tend to have a variety of other risk factors, including cardiovascular disease, which is the most frequent cause of death among hospitalized asthma patients. (Soto-Campos et al. (2013); Papaiwannou et al. (2014)) The possibility of comorbidities is even more relevant as asthma sufferers are experiencing greater longevity in recent years, thus increasing the likelihood of comorbidities. (R. J. Adams et al., 2006) In this case, asthma death rates could represent either an over- or underestimate of the true rate of asthma deaths. However, death certificate data is nonetheless useful in providing surveillance of asthma deaths as this bias would not be expected to change from year to year. Further, information on risk factors for asthma deaths captured via death certificates would still be a useful tool for informing disease control measures. Studies aimed at evaluating differences in hospital records versus death certificate information, for example, might help to elucidate the possibility of this bias. Another limitation of this data for surveillance purposes is the absence of information regarding known asthma comorbidities, including obesity, family history, viral respiratory infections, allergies, occupational exposures smoking, and air pollution, several of which have been positively correlated with increased asthma severity. (Huang, Zhang, Qiu, & Chung, 2015; Manion, 2013; Tarlo, 2017) In addition, although the different types of analysis conducted in this work are appropriate tools to study the epidemiology of a disease, the vital statistic data set was limited in terms of diversity of covariates. Among the small amount of available variables for analysis, not all of them had the required population estimates to included them in the modeling analysis. Furthermore, this limits the hypothesis we can test to investigate mortality with this data set.

Conclusion

Asthma is a common and important chronic health condition worldwide, and its prevalence is predicted to increase from 45% to 59% by 2025 (Masoli et al., 2004). Currently it is estimated that asthma is responsible for 250,000 deaths per year (Masoli et al., 2004). The morbidity and mortality associated with this disease places an extreme burden on national health systems and results in a loss in the quality of life of countless individuals, including in Puerto Rico. Fortunately, effective prevention and control measures exist for this disease. The present analysis showed that several time trends and differences by key risk factors exist with regard to asthma mortality rates in Puerto Rico, indicating that through public health surveillance appropriate public health control measures may be effectively implemented. Effective public health control measures may include improving support of treatment plans for patients and improving access to care among the overall and key populations in Puerto Rico. (Peters et al., 2007)

Tables

Table 1: Crude asthma mortality rate per 100,000 by Year, Puerto Rico 2010-2015					
Year	Deaths	Population	Rate	LL*	UL**
2010	53	3721526	1.42	1.07	1.86
2011	89	3678736	2.42	1.94	2.98
2012	47	3634487	1.29	0.95	1.72
2013	37	3593079	1.03	0.73	1.42
2014	100	3534888	2.83	2.3	3.44
2015	89	3474182	2.56	2.06	3.15

Data sources: US National Center for Vital Statistics and US Census
LL* = 95% confidence interval lower limit
UL** = 95% confidence interval upper limit

Table 2: Asthma mortality rates per 100,000 by demographics, Puerto Rico 2010-2015					
Category	Deaths	Population	Rate	LL*	UL**
Sex					
Male	177	10350641	1.71	1.47	1.98
Female	238	11286257	2.11	1.85	2.39
Age					
0-24	4	7113912	0.06	0.02	0.14
25-34	10	2762776	0.36	0.17	0.67
35-44	21	2769499	0.76	0.47	1.16
45-54	42	2845426	1.48	1.06	2
55-64	64	2616996	2.45	1.88	3.12
65+	274	3528289	7.77	6.87	8.74
Marital Status					
Divorced	59	2349333	2.51	1.91	3.24
Married	154	7502130	2.05	1.74	2.4
Never married	83	6724889	1.23	0.98	1.53
Widowed	117	1265066	9.25	7.65	11.08
Education					
Less than high school graduate	171	3685258	4.64	3.97	5.39
High school graduate	85	3154479	2.69	2.15	3.33
Some college or associate's degree	23	2597129	0.89	0.56	1.33
Bachelor degree	10	2000446	0.5	0.24	0.92
Graduate or professional degree	5	741855	0.67	0.22	1.57
Data sources: US National Center for Vital Statistics and US Census LL* = 95% confidence interval lower limit UL** = 95% confidence interval upper limit					

Table 3: Age adjusted asthma mortality rate per 100,000 by year, Puerto Rico 2010-2015

Year	Deaths	Population	Adj Rate	Adj LL*	Adj UL**
2010	53	3721526	1.34	1.01	1.77
2011	89	3678736	2.18	1.75	2.7
2012	47	3634487	1.14	0.83	1.52
2013	37	3593079	0.93	0.65	1.29
2014	100	3534888	2.39	1.94	2.92
2015	89	3474182	2.18	1.74	2.7

Data sources: US National Center for Vital Statistics and US Census
LL* = 95% confidence interval lower limit
UL** = 95% confidence interval upper limit

Table 4: Poisson regression modeling results of asthma mortality in Puerto Rico, 2010-2015

	Estimates	Relative Risks	Std. Errors	Z-values	P-values
Intercept	-14.43	1	0.5	-28.71	0
sex_Female	0.08	1.08	0.1	0.77	0.44
age_25-34	1.86	6.42	0.59	3.14	0
age_35-44	2.6	13.45	0.55	4.76	0
age_45-54	3.26	26.16	0.52	6.24	0
age_55-64	3.77	43.31	0.52	7.31	0
age_65+	4.92	137.31	0.5	9.77	0

Data sources: US National Center for Vital Statistics and US Census

Figures

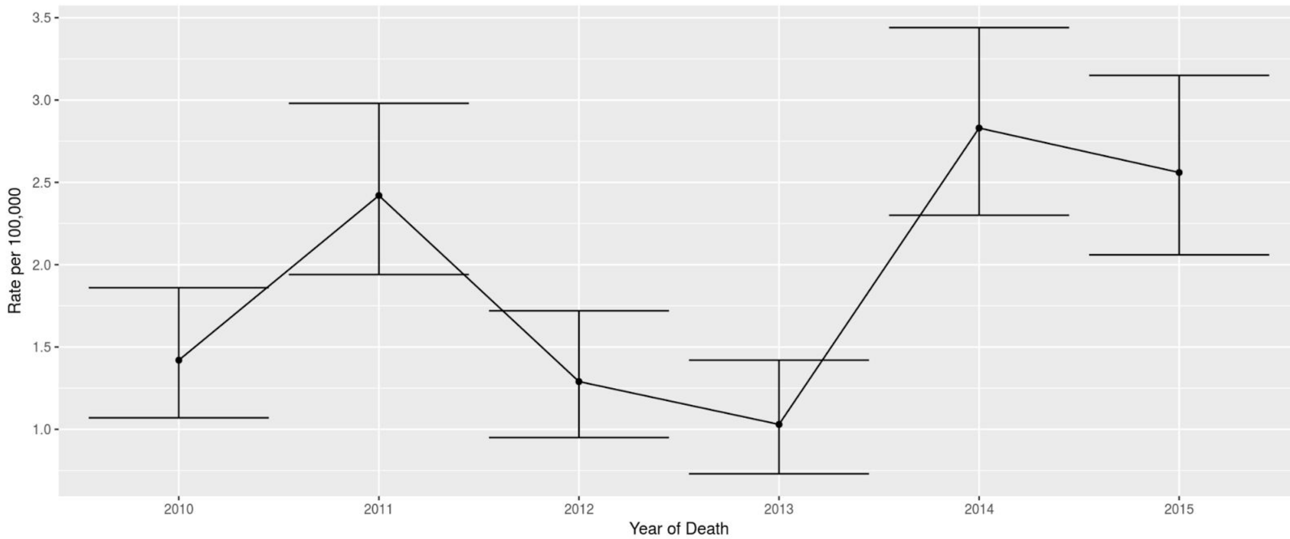

Figure 1: Asthma mortality rate by year, Puerto Rico 2010-2015

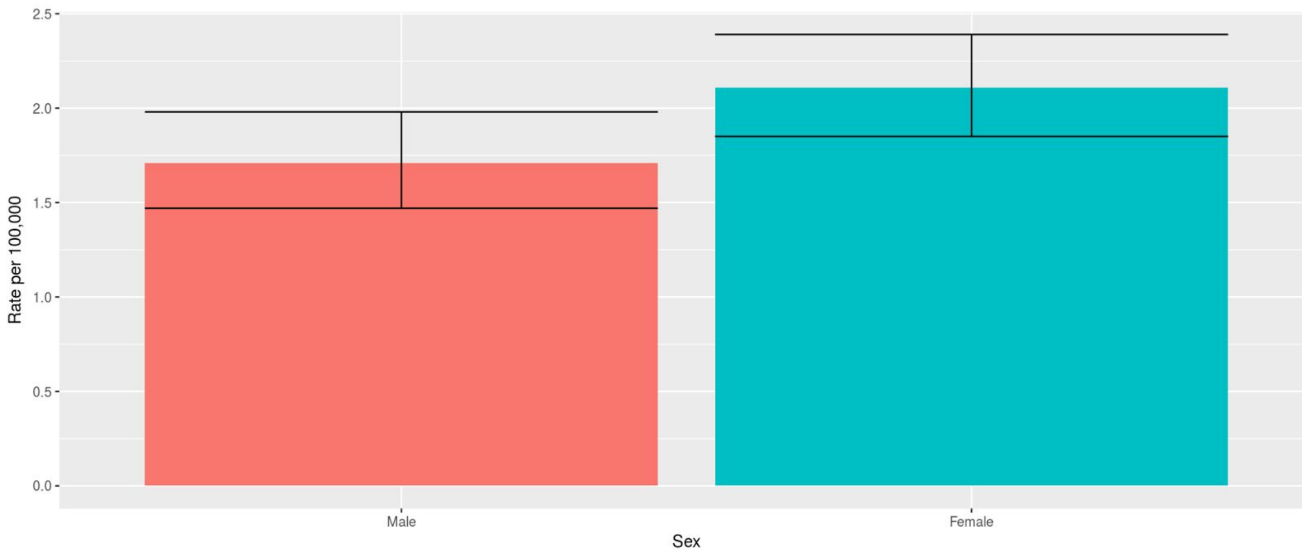

Figure 2: Asthma mortality rate by sex, Puerto Rico 2010-2015

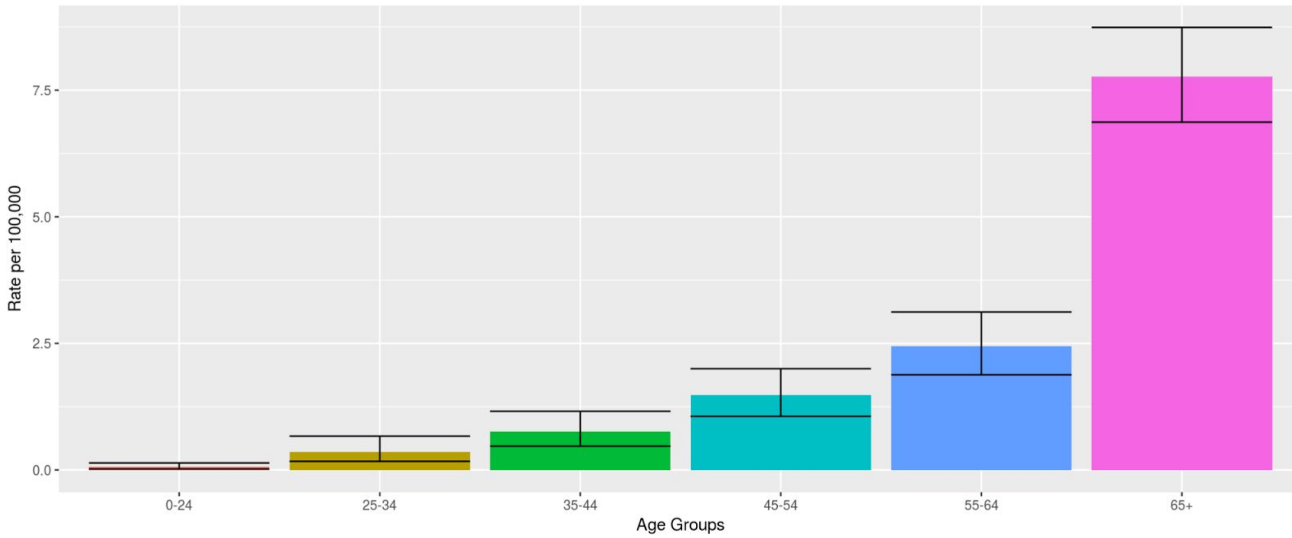

Figure 3: Asthma mortality rate by age group, Puerto Rico 2010-2015

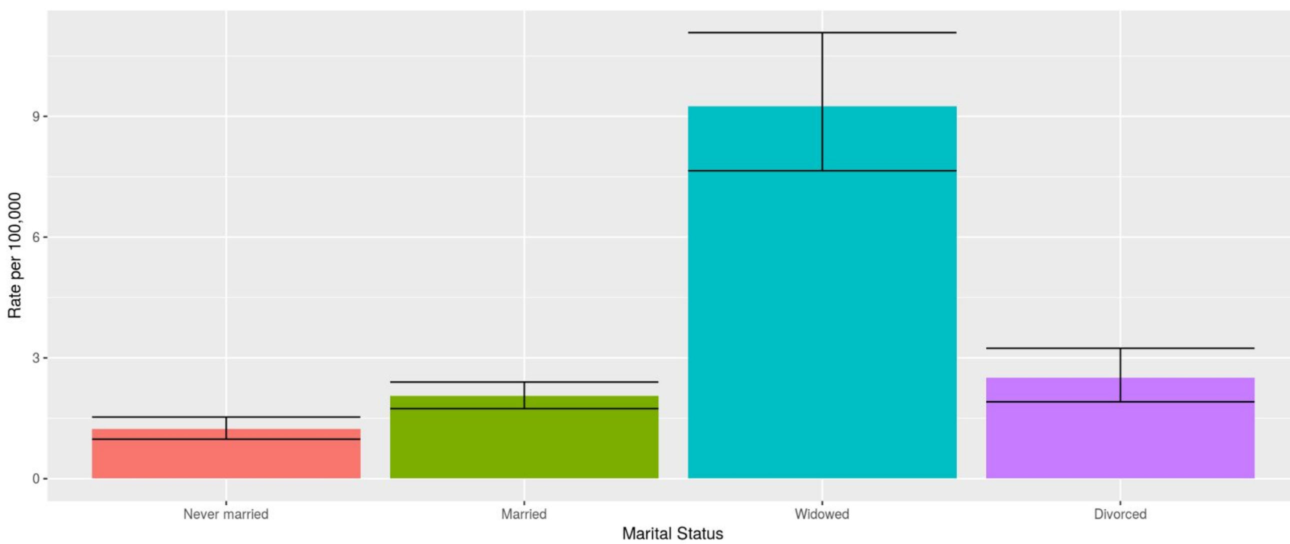

Figure 4: Asthma mortality rate by marital status, Puerto Rico 2010-2015

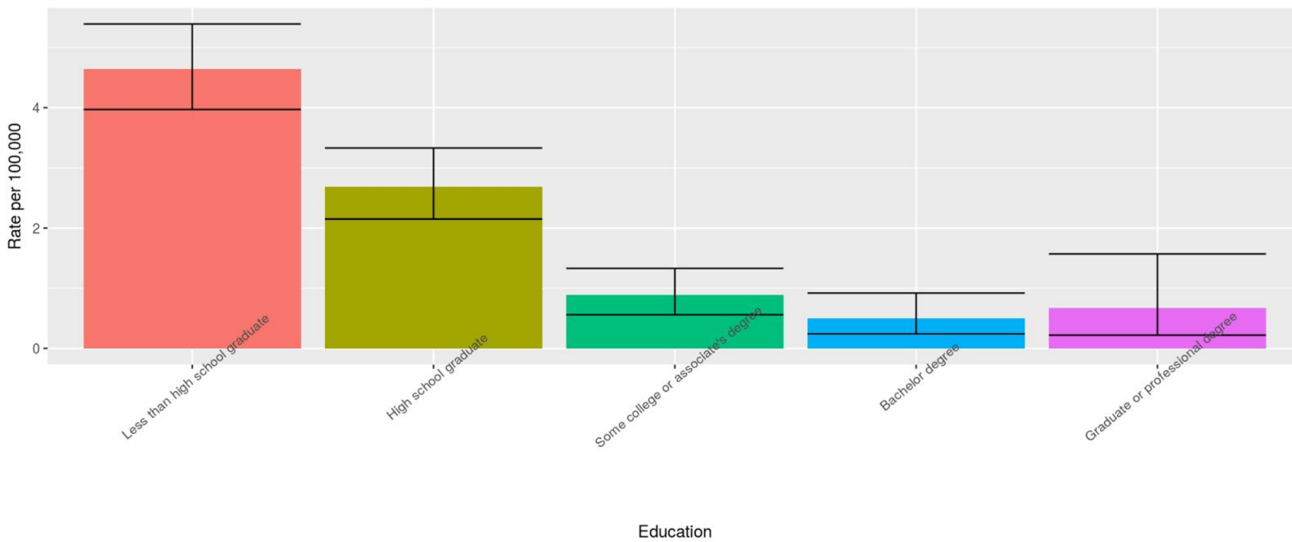

Figure 5: Asthma mortality rate by education, Puerto Rico 2010-2014

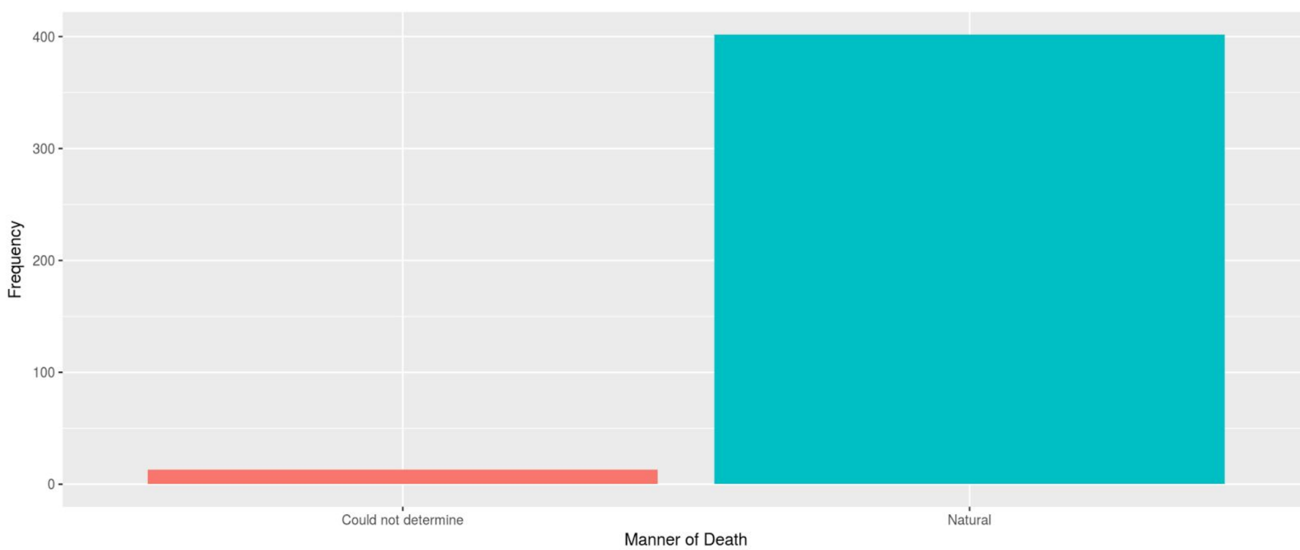

Figure 6: Asthma mortality frequency by manner of death, Puerto Rico 2010-2015

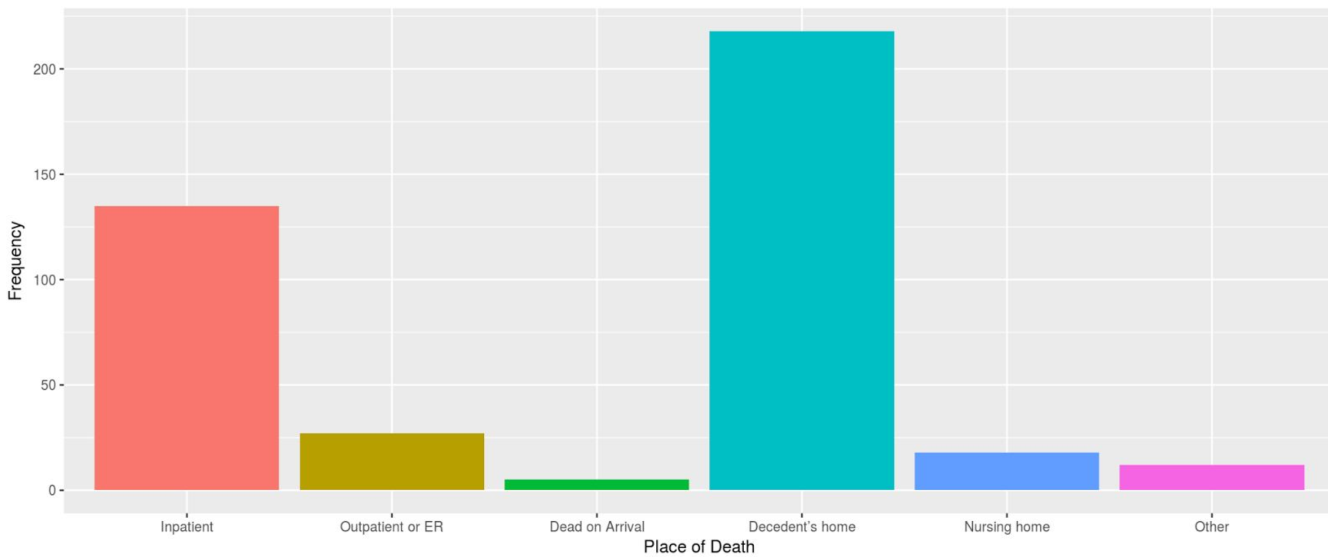

Figure 7: Asthma mortality frequency by place of death, Puerto Rico 2010-2015

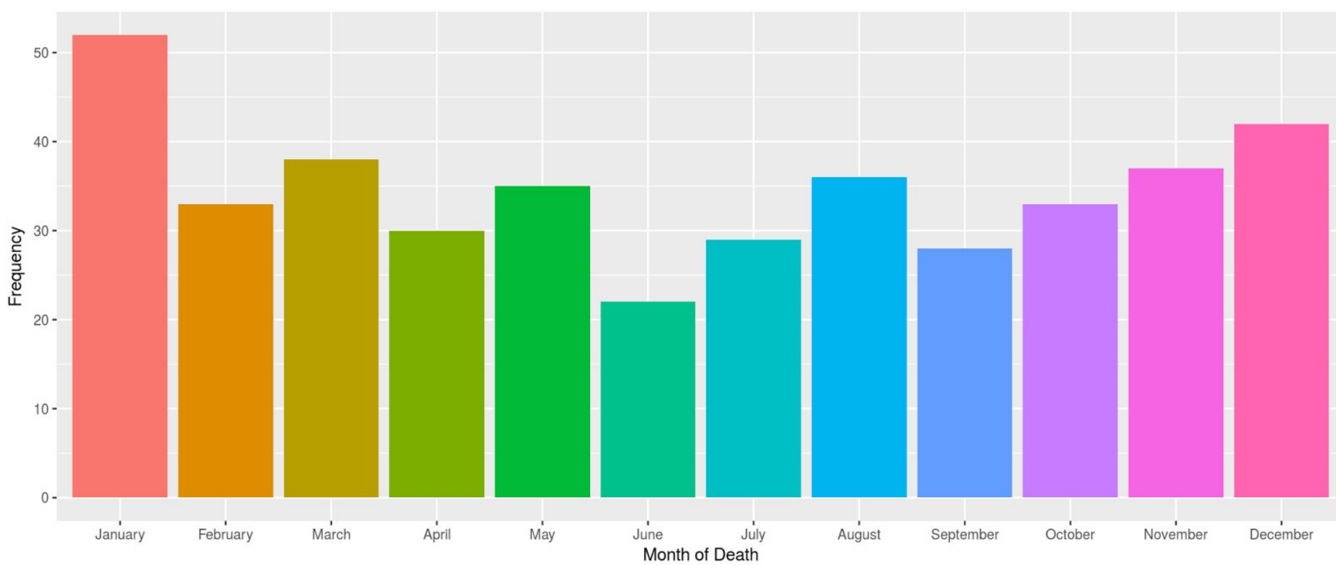

Figure 8: Asthma mortality frequency by month of death, Puerto Rico 2010-2015

Maps

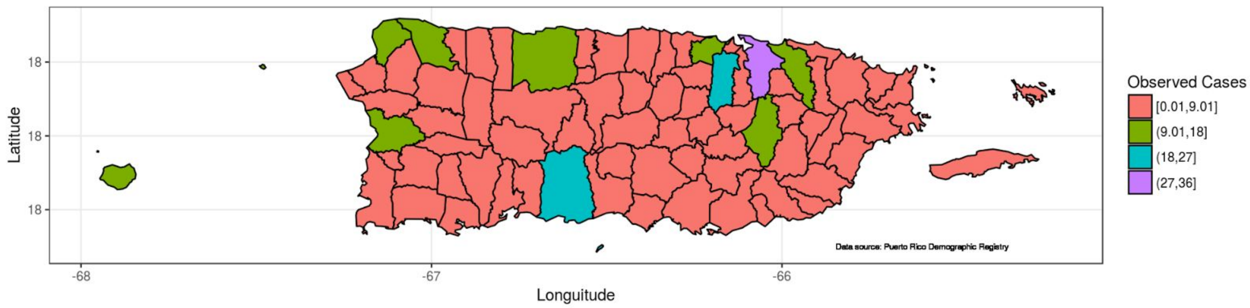

Figure 9: Observed asthma deaths by municipalities, Puerto Rico 2010-2015

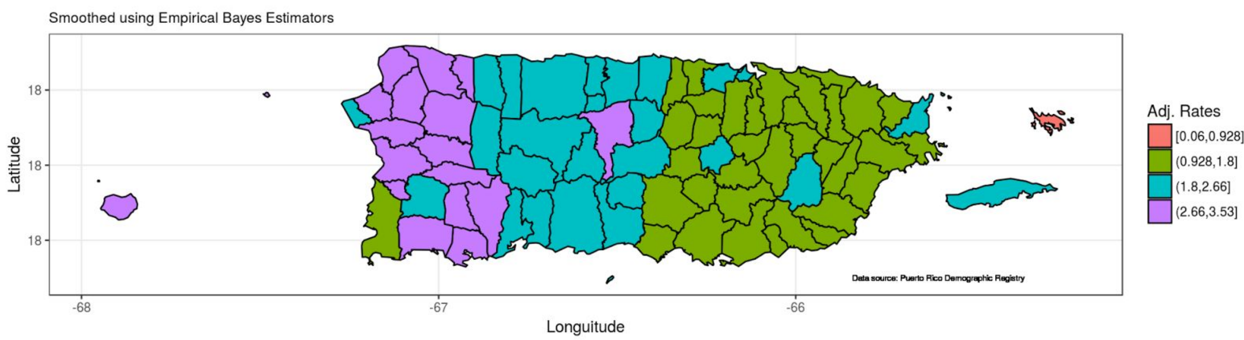

Figure 10: Age adj. asthma death rates per 100,000 by municipalities, Puerto Rico 2010-2015

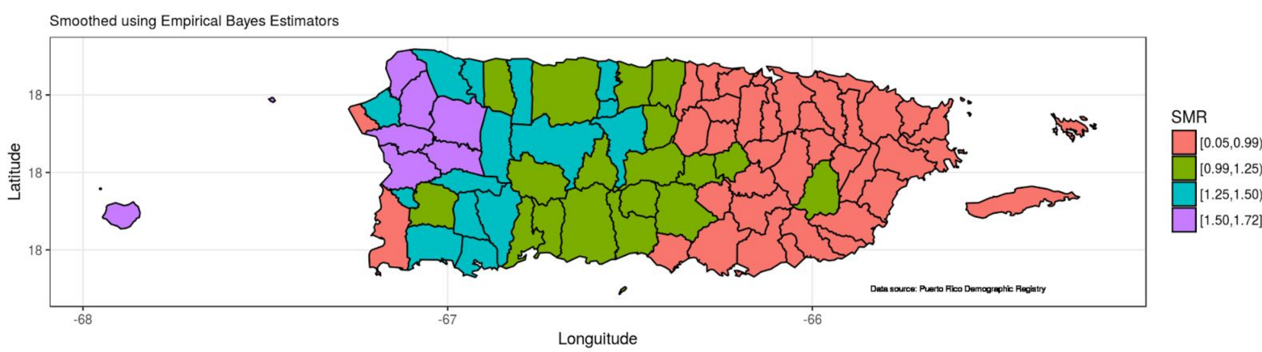

Figure 11: Age adj. standardized mortality ratio of asthma deaths by municipalities, Puerto Rico 2010-2015

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