

**Geographic Correlation between Nonmedical Exemption Rates in Arizona Kindergarten  
Classes and Rates of Community Pertussis Infection**

A thesis submitted to the University of Arizona College of Medicine – Phoenix  
in partial fulfillment of the requirements for the degree of Doctor of Medicine

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Class of 2018

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## *Acknowledgments*

I would first like to thank my mentor, Dr. Lisa Villarroel, at the Arizona Department of Health Services (AZDHS) for her support. I was very lucky to find someone with precisely the type of research project I had been asking for, but even more so, I have continued to be lucky in my work with her. It is rare to find a mentor with the knowledge, resources, and good humor that she brings, and I always look forward to all of our interactions. At AZDHS, I would also like to extend my gratitude to Bikash Bhattarai for all of his assistance in obtaining and analyzing our datasets and for his advice in developing our methods and to Shane Brady for his feedback during multiple stages of our project.

At the University of Arizona College of Medicine – Phoenix, I thank our scholarly project mentor, Dr. Michael McEchron. I cannot imagine how difficult it must be to juggle over three hundred research projects for all of our school's students, each of which is at a different stage of progress and with different complexities. That he continues to do so with such patience and passion has certainly been inspiring to see during my time here in medical school.

## *Abstract*

**Background:** Every state in the US mandates specific vaccinations for all children prior to school entry. However, many states, such as Arizona, are permit nonmedical exemptions (NMEs), and thus, communities with high levels of NMEs are potentially more vulnerable to outbreaks of vaccine preventable diseases.

**Objective:** The objective of this study was to detect spatial clusters of pertussis cases and kindergarten NMEs of DTaP vaccine in Arizona.

**Methods:** Data detailing kindergarten NMEs for each AZ school in the 2012-13 and 2013-14 school years and pertussis cases with report dates during those time periods were obtained from the Arizona Department of Health Services databases. Addresses for each school and pertussis case were geocoded, and the coordinates were obtained for each corresponding census tract. Using a purely spatial analysis with Poisson probability model, areas with high rates of pertussis or NMEs were identified with SaTScan. Clusters for both the number of NMEs and pertussis cases were detected and presented in maps. Extremely large (>50km radius) clusters extending beyond state boundaries were considered irrelevant and removed.

**Results:** Multiple clusters of NMEs and pertussis cases were identified in two school years. While the clusters were generally in highly populated regions, they were not located at the same region in both years. The NME clusters and case clusters did not always overlap.

**Conclusions:** The current analysis does not support an association between kindergarten NME frequency and pertussis outbreaks within these time periods. Clusters of both NMEs and pertussis cases were located in different regions each year. Since kindergarten NMEs vary from year to year, it is possible that these NME rates are not reflective of those in the community. Further studies with larger datasets will be important in elucidating the spatial distribution of pertussis cases and NMEs.

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## *Background and Significance*

With the elimination of highly infectious diseases such as smallpox, diphtheria, and polio, vaccines have proven to be one of the greatest public health achievements in the United States.<sup>1</sup> Advances in clinical research and drug development have produced many effective vaccines that are now standardly recommended for infants and children.<sup>2</sup> Some of the most crucial policies in managing vaccine-preventable diseases have been school immunization requirements.<sup>3</sup> Every state requires documentation of mandated vaccinations—including measles, mumps, rubella, tetanus, pertussis, diphtheria, and polio—from all children prior to school entry.<sup>2</sup> All 50 states allow for medical exemptions to immunization requirements, however, and 48 states will permit either religious or personal belief exemptions as well, collectively referred to as non-medical exemptions (NMEs). The policies guiding these exemptions vary greatly from state to state, with some requesting only a signed form from the child's parent and others requiring approval from a health official or annual renewal of the exemption. Previous studies have indicated that states with more lenient NME requirements also tended to have higher rates of exemption.<sup>3,4</sup> These rising exemption rates have been met with unease in the medical community as infectious diseases have begun to resurface.

The past decade has borne witness to outbreaks of several previously vaccine-controlled diseases, especially measles, mumps, and pertussis (also known as whooping cough).<sup>5-7</sup> While the national rate of childhood vaccine coverage has remained high during that time period,<sup>8</sup> geographic clusters have occurred with significantly lower vaccination rates, particularly in states with more lenient NME policies.<sup>9</sup> Parents often cited perceived risk of adverse effects, belief that vaccinations are unnecessary, and distrust of the medical community as reasons for refusing to vaccinate their children.<sup>10</sup> With the seemingly reduced threat from the diseases themselves, a growing minority of parents have expressed concerns over vaccine safety instead, leading to the trend in vaccine hesitancy and subsequently a resurgence of outbreaks.

Compliance to immunization requirements is of particular importance with regards to the pertussis vaccines (a component of DTaP for children < 6 years old and Tdap for adolescents and

adults), which has been shown to be only 70-90% effective after the full 3 doses.<sup>11</sup> In comparison, the measles vaccine demonstrates 90-98% efficacy, mumps and rubella 90-97%, and polio 90-99%. Because of the lower efficacy of the pertussis vaccines, the threshold level of immunization required to achieve herd immunity is higher than for the other vaccines—at least 95% of the population.<sup>12,13</sup> Thus, as NME rates rise, herd immunity against pertussis would likely be amongst the first to wane, which has been reflected in the recent trend in pertussis outbreaks.<sup>7</sup> Retrospective analyses of NMEs in both Michigan and California have demonstrated that geographic clusters of high NME rates overlapped with clusters of pertussis cases.<sup>14,15</sup> An earlier study in Colorado similarly showed that frequency of measles and pertussis outbreaks in a county was associated with rates of exemption.<sup>16</sup> These studies are just part of a growing body of research suggesting that higher rates of NMEs put communities at higher risk for outbreaks of previously controlled infectious diseases.<sup>3,14-16</sup>

Pertussis-like symptoms are primarily caused by the highly contagious agent *Bordetella pertussis*.<sup>21</sup> First described in the 16<sup>th</sup> century, this illness is characterized by nonspecific rhinorrhea and severe coughing with a signature “whoop” for several weeks. Complications include pneumonia, broken ribs, and incontinence.<sup>22</sup> Prior to the advent of vaccinations, pertussis was particularly widespread amongst children 1-9 years of age. While pertussis symptoms in adults are relatively minor, current figures indicate that young infants constitute ~90% of pertussis-related fatalities in the United States.<sup>23</sup> It is important to emphasize the contribution of the pertussis vaccines in significantly reducing the morbidity and mortality of this disease since their introduction in the 1940s; in fact, pertussis was nearly eradicated from the developed world by the 1970s. However, concerns over vaccine safety led to a sudden decline in coverage, thus leading to a significant pertussis epidemic.<sup>21</sup> The current trends in vaccine refusal echo these past examples, demonstrating the impact of public opinion on community health.

Arizona is among the more lenient states regarding NME procedures, requiring only a form signed by a parent.<sup>17</sup> In the 2013-2014 school year, the DTaP exemption rate in kindergarten classes

was 5.7% with individual county exemption rates as high as 10.2% (Yavapai County). AZDHS registered 1440 reported cases of pertussis in 2013 and 519 in 2014.<sup>18</sup> However, incidences of pertussis have yet to be geographically correlated with NMEs in this state. In our original analysis, we performed a retrospective analysis of clusters of NMEs in Arizona kindergarten classes from the 2012-13 and 2013-14 school years as well as clusters of pertussis outbreaks within those timeframes, and we plan to expand through the year 2016. Through this study, we had hoped to determine whether geographic clusters with high NME rates overlap with pertussis clusters with high statistical significance.



## *Materials and Methods*

Data detailing NME rates in Arizona kindergarten classes from the 2012-13 and 2013-14 school years (starting August 1<sup>st</sup>) by school and by county are available through publicly accessible databases from AZDHS.<sup>17</sup> Regional data concerning probable and confirmed pertussis cases in Arizona from the same years are also available through AZDHS databases.<sup>18</sup>

In order to protect confidentiality under the Health Insurance Portability and Accountability Act (HIPAA), NME data from elementary schools with fewer than 20 students were excluded from the study. To obtain NMEs, parents or guardians have the option to complete a Religious Beliefs Exemption Form or a similarly formatted Personal Beliefs Exemption Form where they initial by each vaccine from which they wish to exempt their child, and this form is then submitted to the Arizona Department of Health Services (AZDHS).<sup>17</sup>

Pertussis is considered a nationally notifiable disease by the Centers for Disease Control and Prevention (CDC), and Arizona physicians are required to report suspect cases to their local health departments for surveillance and implementation of prophylactic control measures. The AZDHS abides by the CDC clinical criteria for pertussis, which included, in the absence of a more likely diagnosis, a cough illness lasting  $\geq 2$  weeks with at least one of the following additional symptoms: paroxysms of coughing OR inspiratory whoop OR post-tussive vomiting as described by the 2012 and 2013 definitions. In 2014, apnea was added as an alternative additional symptom for infants  $< 1$  year old. Laboratory criteria in all three years required either isolation of *B. pertussis* from a clinical specimen or a positive polymerase chain reaction (PCR) assay for pertussis. An epidemiologic linkage was defined as contact with a laboratory-confirmed pertussis case. Thus, a confirmed case of pertussis met the clinical case definition and was either confirmed by PCR or was epidemiologically linked directly to a case confirmed by culture or PCR. In 2012-14, a probable case met the clinical case definition but had neither laboratory confirmation nor an epidemiological link. However, in 2013 alone, a case with positive PCR assay but unknown symptoms was also classified as probable.<sup>19</sup>

Each case of pertussis was geocoded and aggregated to census tracts by staff at AZDHS prior to analysis by members of the primary research team. This included de-identified data on gender, age, and ethnicity. School addresses were geocoded to their geographic coordinates, and enrollment and NME data were aggregated to the census-tract level as well. Census tracts are often used in geographic cluster analysis as they are small subdivisions that change infrequently and can be easily compared from year to year with each including 2500-8000 individuals.

A Poisson probability model was used to determine statistically significant census tract clusters of high NME rates and clusters of pertussis infection with “high rates.”<sup>20</sup> Through comparison between the experimental dataset and controls generated through SaTScan, candidate spatial clusters of events were identified, and a likelihood ratio statistic was calculated for each. A parameter was set to 50% or more of the population being at risk without restricting the radius of the cluster circle. Afterwards, the output files of the clusters were examined for extremely large (> 50-kilometer radius) and clusters extending beyond state borders were considered irrelevant. Simple and multiple logistic regression models were developed to determine the odds ratio of a census tract being in both a pertussis cluster and a NME cluster versus a tract being in a pertussis cluster but not a NME cluster, thus estimating the overlap between pertussis clusters and NME clusters. Identified clusters and associations were considered significant with reference to  $\alpha = 0.05$ . Logistic regression was used to assess variables such as population density, socioeconomic distribution (ethnicity, income level), and proportion of children < 5 years old.

## *Results*

First, multiple clusters were determined for NMEs and pertussis during the 2012-13 and 2013-14 school years in Arizona through spatial scan statistics using SaTScan, which identifies census tracts with higher rates in comparison to background rates for that school year. Although these tended to occur in larger metropolitan areas, they were not located within the same region during the same year (Figure 1). Clusters extending beyond state boundaries and those with over a 50-kilometer radius were excluded from the final analysis. The geographic overlap between clusters was not significant in either year.

The relative risk (RR) of each census tract occurring within a cluster was calculated (Tables S1 and S2). Census tracts with  $RR > 1$  were identified as high-risk and those with  $RR \leq 1$  were considered low-risk. Tracts with a value of zero were excluded from the study, whether the risk was truly zero or data were not reported. These risks were also stratified using parameters such as race, household size, education, and income. We compared the number of census tracts with high versus low risk of occurring within NME and pertussis clusters (Table 1). In 2012-13, the overall probability for a census tract of having a higher pertussis risk was 0.81 and of having a higher NME risk was 0.57. In 2013-14, the probability was 1 for pertussis and 0.55 for NME. The correlation between NME and pertussis risks was not significant in either year.

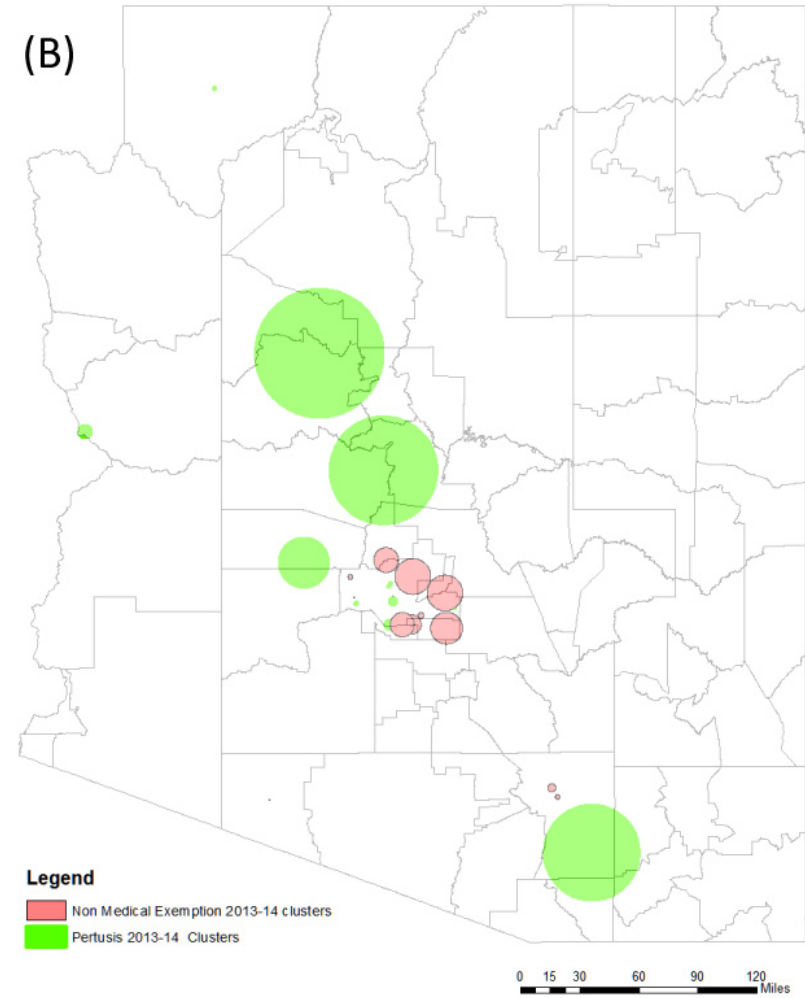
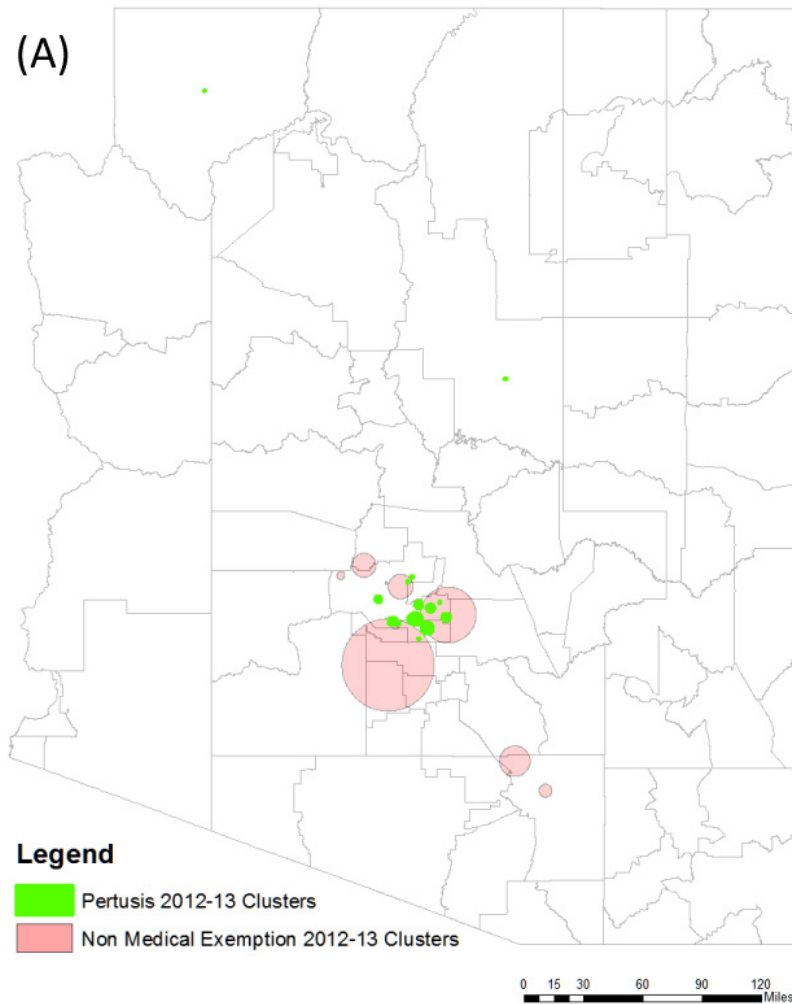


Figure 1. Geographic clusters of increased relative risk of pertussis and of NMEs in (A) 2012-13 and (B) 2013-14 school years. Lines in gray represent county divisions. Cluster sizes calculated from SaTScan.

Table 1. Comparison of high versus low relative risk of a census tract occurring within a pertussis or NME cluster in (A) 2012-13 and (B) 2013-14

(A)

		Pertussis risk		
		High	Low	
NME risk	High	105	27	132
	Low	83	17	100
		188	44	232

(B)

		Pertussis risk		
		High	Low	
NME risk	High	89	0	89
	Low	73	0	73
		162	0	162

## *Discussion*

We were unable to determine a significant correlation between high-risk clusters of pertussis and high-risk clusters of NMEs. Due to the lower efficacy of pertussis vaccines and their potentially waning effects relative to the other pediatric vaccines, some of these outbreaks may have been unavoidable even with higher vaccination rates.<sup>24</sup> Since kindergarten NMEs vary from year to year, it is possible that these NME rates are not reflective of those in the community. Additionally, several known outbreaks occurred near the northern border overlapping with other states, and these were excluded from this analysis because the calculated areas of the clusters were too large or crossed state boundaries. It is reasonable to assume that maintaining the areas occurring within some of these clusters could have had a significant impact on the final results. In our follow-up study analyzing data from 2012-2016, we will explore different methodologies to include more of the clusters that affect the state of Arizona.

It has previously been shown that states that require more difficult procedures to obtain NMEs generally have lower rates of exemption as well as lower incidence of pertussis.<sup>3</sup> Demonstrating a correlation between NME rates and pertussis within Arizona would have supported a change in the state's policies regarding NMEs, to protect against not only pertussis but also other vaccine-preventable diseases. Furthermore, it could have encouraged the state to increase trust and improve communication between the medical community and the general public regarding vaccine and overall health education.

### *Conclusions and Future Directions*

The current analyses do not support an association between kindergarten NME frequency and pertussis outbreaks within these time periods. Clusters of both NMEs and pertussis cases were located in different regions each year. Since the results of this study have thus far been non-significant, Arizona-specific evidence on the relationship between NMEs and pertussis is still not conclusive. However, the pertussis vaccines have been demonstrated to offer protection against *B. pertussis* in clinical trials, which still suggests that higher vaccination rates would confer greater protection to a population overall.<sup>25</sup> Further studies with larger datasets will be important in elucidating the spatial distribution of pertussis cases and NMEs, and we will also attempt analysis that includes key clusters that were previously excluded.

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Supplemental Information

Table S1. Relative risk of pertussis and NMEs for each Arizona census tract in 2012-13

Census tract	RR pertussis	RR NME	Latitude	Longitude
4005000300	0.79	0.37	35.21	-111.62
4013050608	0.79	1.05	33.43	-112.56
4013061009	0.68	0.76	33.46	-112.4
4013082002	0.98	0.4	33.5	-112.28
4013082026	0.95	0.4	33.44	-112.32
4013103502	0.96	1.79	33.61	-112.03
4013104802	1	2.72	33.59	-112.02
4013105800	0.9	0.24	33.55	-112.14
4013109400	0.68	0.081	33.5	-112.18
4013116603	0.99	0.75	33.38	-112.21
4013116613	0.87	0.73	33.37	-112.11
4013116713	0.93	3.04	33.3	-112
4013318900	0.91	0.45	33.41	-111.95
4013319903	1	0.29	33.37	-111.92
4013420501	0.9	0.65	33.44	-111.83
4013422104	0.98	0.42	33.4	-111.88
4013422641	0.89	5.47	33.36	-111.66
4013422642	0.99	2	33.37	-111.63
4013422646	0.73	1.81	33.34	-111.59
4013523103	0.97	3.43	33.3	-111.87
4013611800	0.87	2.4	33.71	-112.14
4013614100	0.99	2.18	33.67	-112.21
4013619900	0.95	1.38	33.65	-111.96
4013810600	0.87	0.77	33.32	-111.92
4013810700	0.84	1.58	33.31	-111.9
4013812200	0.91	0.89	33.27	-111.88
4013812700	0.98	1.48	33.25	-111.85
4013815400	0.9	3.06	33.29	-111.75
4013816100	0.78	1.45	33.27	-111.71
4013816400	0.83	1.37	33.23	-111.71
4013817200	0.92	2.55	33.22	-111.64
4015950704	0.95	1.01	35.37	-113.97
4015953601	0.64	1.63	35.19	-113.99
4015953800	0.89	1.89	35.21	-114.04
4019003702	0.74	0.2	32.14	-110.96
4019004064	0.74	1.48	32.11	-110.72
4019004322	0.86	0.89	32.12	-111.03

4019004425	0.92	1.76	32.38	-111.46
4019004427	0.7	1.85	32.38	-111.13
4019004429	0.77	1.15	32.34	-111.12
4021000204	0.86	4.01	33.27	-111.57
4021000205	0.72	0.82	33.23	-111.55
4021000801	0.65	1.1	33.07	-111.45
4025001900	0.81	1.5	34.74	-112.15
4003001100	3.15	0.78	31.38	-109.84
4003002100	2.2	0.25	31.39	-110.26
4005000900	2.47	4.72	35.16	-111.63
4005001301	1.11	1.27	35.27	-111.54
4005001302	1.02	0.45	35.31	-111.38
4005001700	1.66	2.73	35.23	-112.2
4005002200	2.64	1.99	35.58	-111.76
4009961500	2.55	0.93	32.59	-109.43
4011960200	1.91	0.41	32.99	-109.33
4013040518	3.4	2.34	33.9	-112.51
4013061016	1.23	0.2	33.5	-112.44
4013061024	5.21	2.64	33.42	-112.4
4013061033	1.89	0.89	33.61	-112.38
4013061037	1.43	1.7	33.6	-112.39
4013061038	1.25	1.83	33.59	-112.39
4013061043	2.31	0.5	33.57	-112.33
4013071903	2.7	0.35	33.59	-112.21
4013071913	1.12	0.89	33.59	-112.24
4013071914	1.81	0.45	33.57	-112.22
4013082203	2.27	0.58	33.42	-112.28
4013082210	1.22	0.29	33.42	-112.3
4013083000	1.73	0.82	33.45	-112.26
4013092307	1.94	0.25	33.56	-112.18
4013092309	1.09	0.31	33.56	-112.16
4013092713	2.26	0.6	33.52	-112.23
4013103206	2.25	3.4	33.6	-111.95
4013103211	2.58	2.34	33.62	-111.99
4013103212	1.34	1.78	33.62	-111.97
4013103214	1.47	3.35	33.62	-111.95
4013103304	1.21	0.12	33.63	-112.02
4013103614	1.89	0.95	33.61	-112.09
4013104204	1.76	0.4	33.59	-112.16
4013104702	1.28	6.49	33.57	-112.05
4013104801	3.14	0.59	33.58	-112.03

4013105003	1.25	3.38	33.57	-111.95
4013107202	3.46	1.13	33.52	-112.13
4013108000	1.64	1.02	33.5	-111.96
4013108301	6.68	1.68	33.51	-112
4013108502	1.61	1.62	33.5	-112.03
4013109300	1.21	0.54	33.5	-112.16
4013109500	1.16	0.17	33.5	-112.19
4013110901	1.84	0.25	33.49	-112.01
4013111201	1.08	0.7	33.47	-111.97
4013111202	2.89	1.13	33.46	-111.97
4013112509	2.46	0.15	33.47	-112.23
4013112510	1.36	0.32	33.44	-112.22
4013112513	1.39	0.25	33.42	-112.19
4013113502	4.3	0.16	33.45	-112.02
4013113602	3.34	0.31	33.46	-112.01
4013114800	3.45	0.42	33.42	-112.09
4013116100	1.43	0.7	33.4	-112.02
4013116610	3.84	0.75	33.37	-112.15
4013116708	5.65	1.31	33.34	-111.98
4013116710	4.9	1.83	33.33	-112.01
4013116714	1.72	1.5	33.3	-112.02
4013116719	1.77	2.78	33.31	-111.98
4013116720	4.51	1.99	33.32	-112
4013116728	4.93	1.76	33.31	-112.06
4013116732	1.64	0.41	33.35	-112.1
4013116800	8.56	0.16	33.47	-112.11
4013216807	6.95	2.02	33.57	-111.9
4013216816	3.08	1.62	33.61	-111.91
4013216831	1.96	3.07	33.59	-111.93
4013216839	7.2	0.55	33.6	-111.86
4013216847	1.95	1.34	33.66	-111.88
4013216851	2.74	3.24	33.68	-111.84
4013216852	1.98	0.66	33.62	-111.88
4013218000	2.11	0.32	33.47	-111.93
4013319401	3.11	0.55	33.39	-111.92
4013319402	1.39	1.62	33.39	-111.9
4013319600	1.04	1.67	33.4	-111.93
4013319904	2.33	1.15	33.37	-111.9
4013420110	2.33	2.18	33.46	-111.61
4013420111	1.44	2.02	33.43	-111.62
4013420112	1.73	2.05	33.43	-111.59

4013420208	7.55	1.25	33.43	-111.73
4013420209	1.42	1.52	33.43	-111.71
4013420604	5.32	2.24	33.44	-111.8
4013420704	1.15	2.5	33.43	-111.76
4013420902	1.69	0.24	33.43	-111.81
4013421002	2.14	0.24	33.43	-111.83
4013421501	1.66	0.66	33.41	-111.81
4013422002	4.38	0.4	33.4	-111.83
4013422105	1.78	0.26	33.4	-111.85
4013422209	2.61	0.25	33.34	-111.85
4013422210	4.28	1.26	33.34	-111.87
4013422216	1.1	0.71	33.37	-111.85
4013422218	1.83	0.94	33.35	-111.89
4013422219	7.78	1.5	33.35	-111.87
4013422301	1.01	1.25	33.39	-111.83
4013422302	1.19	0.17	33.39	-111.8
4013422402	1.14	1.39	33.36	-111.78
4013422403	2.19	1.47	33.34	-111.8
4013422502	1.86	0.25	33.4	-111.78
4013422508	1.54	1.92	33.37	-111.78
4013422511	1.86	0.3	33.34	-111.76
4013422513	1.32	1.25	33.4	-111.74
4013422606	1.24	1.86	33.35	-111.72
4013422615	1.69	1.44	33.39	-111.61
4013422621	2.64	1.44	33.37	-111.71
4013422631	1.46	2.98	33.39	-111.62
4013422637	8.55	0.74	33.4	-111.71
4013422638	2.77	1.31	33.39	-111.71
4013422643	2.94	1.55	33.36	-111.61
4013523005	4.68	3.39	33.33	-111.87
4013610300	1.9	1.95	33.85	-112.13
4013610400	1.1	2.83	33.85	-112.11
4013611200	1.92	2.04	33.71	-112.21
4013612200	1.68	1.53	33.75	-112.09
4013612400	3.32	1.94	33.76	-112.03
4013612600	2.42	2.43	33.76	-111.99
4013613000	1.92	1.94	33.78	-111.96
4013613300	1.6	1.52	33.72	-111.97
4013613700	2.12	1.06	33.67	-112.25
4013615100	1.68	1.83	33.69	-111.98
4013615200	1.05	2.13	33.68	-111.94

4013615900	1.3	0.98	33.66	-112.19
4013616100	4.77	0.84	33.67	-112.16
4013616300	2.77	1.09	33.66	-112.15
4013616600	2.99	0.47	33.66	-112.09
4013616800	2.03	0.88	33.66	-112.06
4013618000	1.24	2.27	33.64	-112.18
4013618100	3.92	1.23	33.65	-112.16
4013618200	1.47	1.99	33.65	-112.14
4013618400	1.47	1.51	33.65	-112.12
4013618900	3.66	0.62	33.65	-112.08
4013619500	1.11	0.39	33.65	-112.02
4013723308	3.02	1.91	33.33	-112.43
4013810300	1.02	1.06	33.33	-111.88
4013810500	1.1	0.89	33.31	-111.94
4013811400	3.26	0.44	33.31	-111.82
4013811500	2.27	0.84	33.31	-111.8
4013811600	1.36	0.26	33.3	-111.82
4013812900	1.91	1.46	33.24	-111.87
4013813000	2.1	0.89	33.23	-111.85
4013813100	4.64	1.06	33.24	-111.83
4013813900	1.09	1.01	33.21	-111.8
4013814700	1.37	5.41	33.33	-111.73
4013814800	5.2	10.91	33.33	-111.7
4013815000	1.33	1.27	33.31	-111.76
4013815900	5.71	3.27	33.26	-111.76
4013816000	1.39	1.26	33.24	-111.74
4013816900	1.67	4.77	33.26	-111.61
4013817100	3.01	1.81	33.24	-111.62
4015950705	2.75	0.47	35.25	-114
4015952700	1.16	0.79	34.51	-114.32
4015953401	2.09	0.26	34.46	-114.29
4015953900	1.69	0.74	35.24	-113.97
4017960200	1.51	0.92	34.85	-110.04
4017961300	3.01	3.24	34.16	-109.99
4017961700	1.79	1.69	34.21	-110.03
4019000600	2.3	0.16	32.23	-110.94
4019001304	1.06	0.35	32.26	-110.97
4019002702	2.23	0.66	32.27	-110.94
4019002802	1.38	5.5	32.26	-110.92
4019004008	1.26	0.3	32.2	-110.85
4019004026	1.01	1.48	32.2	-110.76

4019004051	1.11	1.13	32.27	-110.72
4019004063	1.21	0.58	32.14	-110.77
4019004114	1.04	0.55	32.02	-110.91
4019004326	1.73	0.9	31.93	-110.97
4019004419	1.8	0.76	32.44	-111.32
4019004430	4.62	1.39	32.43	-111.26
4019004431	1.45	8.64	32.41	-111.18
4019004511	1.28	1.62	32.28	-110.97
4019004647	1.44	0.63	32.34	-111.05
4019004712	1.86	5.57	32.29	-110.91
4021000201	1.04	0.27	33.36	-111.24
4021000207	1.03	1.9	33.23	-111.44
4021000314	1.08	2.94	33.4	-111.55
4021001705	1.57	1.94	33.08	-112.03
4021001706	1.16	2.01	33.06	-112.04
4021001710	1.31	1.94	33.05	-111.97
4021941400	1.33	0.72	32.74	-112.01
4023966200	1.14	0.87	31.36	-110.96
4025000402	2.3	1.31	34.58	-112.45
4025000700	4.29	1.5	34.48	-112.39
4025000801	1.53	4.55	34.52	-112.47
4025001500	1.73	3.05	34.27	-111.85
4025001603	1.94	0.59	34.63	-111.8
4025001702	2.51	5.51	34.77	-111.84
4025001802	1.2	6.21	34.9	-111.92
4025002001	1.18	2.16	34.74	-112.02
4025002003	1.36	4.86	34.72	-111.99
4025002004	1.38	0.79	34.7	-112.05
4027000907	1.73	0.21	32.68	-114.65
4027011106	1.13	1.18	32.65	-114.52
4027011403	1.39	0.059	32.49	-114.78

Table S2. Relative risk of pertussis and NMEs for each Arizona census tract in 2013-14

Census tract	RR pertussis	RR NME	Latitude	Longitude
4003000700	2.03	0.32	31.36	-109.49
4003000901	2.93	0.15	31.34	-109.55
4005001301	2.06	1.34	35.27	-111.54
4005942201	5.18	0.5	36.55	-111.33
4005945100	5.73	0.23	35.74	-111.03
4009961400	4.26	0.55	32.81	-109.72
4011960200	3.55	0.3	32.99	-109.33
4013040516	7.38	3.58	33.68	-112.73
4013040518	3.16	1.52	33.9	-112.51
4013050605	9.09	1.37	33.55	-112.65
4013050608	1.47	0.26	33.43	-112.56
4013050610	1.33	0.83	33.43	-112.49
4013050701	2.07	0.98	33.39	-112.58
4013061010	2.27	0.58	33.5	-112.35
4013061021	6.01	1.18	33.48	-112.35
4013061023	2.29	0.32	33.43	-112.42
4013061025	1.41	4.72	33.63	-112.44
4013061026	3.86	1.31	33.63	-112.42
4013061030	1.45	1.17	33.62	-112.44
4013082012	1.84	0.7	33.5	-112.3
4013082024	2.58	0.81	33.47	-112.28
4013082207	4.4	0.48	33.4	-112.29
4013103212	2.48	1.07	33.62	-111.97
4013104221	1.79	0.28	33.59	-112.18
4013104226	7.24	3.79	33.63	-112.14
4013104802	1.85	1.95	33.59	-112.02
4013104900	2.63	21.46	33.59	-112
4013105800	1.67	0.56	33.55	-112.14
4013106802	16.31	0.37	33.53	-112.11
4013107000	1.48	1	33.53	-112.14
4013107500	3.15	1.07	33.52	-112.07
4013108000	3.04	1.35	33.5	-111.96
4013111700	1.86	0.23	33.47	-112.06
4013112505	5.05	0.19	33.46	-112.19
4013116202	2.09	0.15	33.39	-111.99
4013116712	4.95	1.4	33.3	-111.98
4013116714	3.19	2.08	33.3	-112.02
4013216807	6.45	1.44	33.57	-111.9
4013216816	1.9	1.99	33.61	-111.91



4013216846	3.2	1.81	33.63	-111.87
4013216847	1.81	1.95	33.66	-111.88
4013216851	2.54	3.79	33.68	-111.84
4013217101	4.27	3.46	33.5	-111.91
4013218200	2	2.21	33.46	-111.92
4013319705	3.08	2.68	33.4	-111.95
4013319902	8.53	0.71	33.37	-111.94
4013319905	2.2	1.05	33.36	-111.92
4013420105	2.03	0.98	33.45	-111.66
4013420110	4.33	2.26	33.46	-111.61
4013420115	4.08	1.07	33.42	-111.62
4013420501	3.36	0.57	33.44	-111.83
4013420602	4.44	1.18	33.43	-111.78
4013420704	4.29	1.89	33.43	-111.76
4013420800	2.22	0.82	33.43	-111.8
4013421303	4.42	0.28	33.42	-111.87
4013421901	2.63	0.76	33.4	-111.81
4013422001	2.55	2.68	33.4	-111.83
4013422105	3.31	0.5	33.4	-111.85
4013422402	4.24	1.41	33.36	-111.78
4013422503	3.33	1.06	33.39	-111.78
4013422606	8.14	1.82	33.35	-111.72
4013422615	1.57	0.73	33.39	-111.61
4013422616	7.02	0.6	33.39	-111.59
4013422621	2.45	1.26	33.37	-111.71
4013422630	10.93	1.11	33.4	-111.63
4013422641	1.66	4.15	33.36	-111.66
4013523102	5.95	0.9	33.3	-111.83
4013523103	1.8	2.09	33.3	-111.87
4013523104	1.75	0.26	33.3	-111.85
4013610000	2.99	2.66	33.92	-112.17
4013610500	1.62	2.96	33.84	-112.09
4013611200	1.78	1.91	33.71	-112.21
4013612400	1.54	0.91	33.76	-112.03
4013613900	1.71	1.15	33.68	-112.23
4013614000	2.39	1.94	33.69	-112.21
4013615000	4.78	1.97	33.68	-112
4013617600	1.72	0.16	33.65	-112.24
4013618200	5.47	2	33.65	-112.14
4013723308	1.4	1.03	33.33	-112.43
4013810700	6.24	0.29	33.31	-111.9

4013810900	3.74	0.68	33.3	-111.94
4013811700	4.7	1.72	33.3	-111.8
4013812300	2.33	0.82	33.27	-111.85
4013812700	1.82	1.45	33.25	-111.85
4013812900	3.55	1.17	33.24	-111.87
4013813000	7.81	1.21	33.23	-111.85
4013813300	2.18	5.56	33.24	-111.79
4013813900	2.02	0.9	33.21	-111.8
4013814600	4.73	6.35	33.32	-111.75
4013815000	4.95	1.23	33.31	-111.76
4013815200	1.57	2.14	33.31	-111.7
4013815400	3.35	1.19	33.29	-111.75
4013816000	2.57	2.16	33.24	-111.74
4013816400	1.54	1.41	33.23	-111.71
4013816600	2.46	1.51	33.28	-111.68
4013817200	1.71	2.83	33.22	-111.64
4015950705	2.55	21.46	35.25	-114
4015951700	1.79	0.32	35.1	-114.63
4015952002	2.83	1.39	34.87	-114.48
4015952900	8.1	1.07	34.48	-114.31
4015953000	1.99	0.42	34.49	-114.32
4015953601	3.58	0.82	35.19	-113.99
4015953800	1.66	1.02	35.21	-114.04
4015954800	3.01	1.95	34.84	-113.76
4015954900	2.77	1.53	35.24	-114.06
4017960500	5.09	2.75	34.89	-110.45
4017963700	5.96	1.91	34.41	-110.55
4017964800	2.52	3.17	34.28	-110.16
4019000600	2.13	0.96	32.23	-110.94
4019000900	3.73	0.41	32.21	-110.97
4019002504	1.81	0.21	32.17	-111
4019002604	2.71	0.55	32.27	-110.98
4019002904	2.73	1.46	32.25	-110.88
4019002905	2.43	0.41	32.26	-110.9
4019003101	3.5	1.19	32.24	-110.9
4019003303	2.92	0.26	32.22	-110.87
4019003501	1.3	0.2	32.2	-110.9
4019003600	4.63	0.19	32.16	-110.85
4019004022	1.67	1.45	32.2	-110.8
4019004034	3.07	0.4	32.18	-110.85
4019004044	2.66	0.29	32.22	-110.75

4019004048	2.31	0.78	32.23	-110.8
4019004053	3.55	0.46	32.28	-110.8
4019004062	9.81	0.8	32.08	-110.74
4019004063	13.61	1.52	32.14	-110.77
4019004064	2.74	0.41	32.11	-110.72
4019004065	13.9	0.43	32.11	-110.79
4019004068	6.95	0.68	32.23	-110.84
4019004069	2.86	0.92	32.21	-110.82
4019004073	6.61	0.4	32.12	-110.82
4019004074	5.16	0.93	32.09	-110.79
4019004107	13.8	0.8	31.85	-110.78
4019004312	1.85	0.16	32.14	-111.03
4019004329	1.08	0.37	31.98	-110.98
4019004425	1.71	1.63	32.38	-111.46
4019004504	1.48	0.38	32.27	-111.01
4019004610	1.75	0.32	32.31	-111.02
4019004613	2.95	0.15	32.33	-111.05
4019004623	2.06	1.37	32.36	-111.03
4019004624	1.72	0.68	32.35	-111.04
4019004644	4.2	0.42	32.37	-111.06
4019004712	3.46	6.5	32.29	-110.91
4019470400	2.99	18.52	32.22	-112.98
4021000201	1.92	0.44	33.36	-111.24
4021000214	1.16	1.24	33.18	-111.6
4021000307	4.34	0.22	33.45	-111.54
4023966000	3.28	2.68	31.57	-110.64
4025000202	6.57	1.97	34.85	-112.37
4025000204	13.18	5.12	34.94	-112.61
4025000401	3.64	6.78	34.59	-112.46
4025000402	2.14	3.91	34.58	-112.45
4025000605	2.34	1.95	34.61	-112.35
4025000606	1.62	3.17	34.59	-112.33
4025000608	3.12	0.69	34.63	-112.31
4025000700	13.34	0.46	34.48	-112.39
4025000801	2.84	4.97	34.52	-112.47
4025001001	2.43	1.79	34.57	-112.49
4025001500	9.72	2.43	34.27	-111.85
4025001603	1.8	2.93	34.63	-111.8
4025001802	2.22	3.41	34.9	-111.92
4025002100	4.48	2.01	35.15	-112.98
4027000908	3.75	0.29	32.65	-114.66