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The Correlation Between Snakebites And Meteorological Variations

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Climate and other risk factors for snakebite in New Mexico 1998-2012

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Abstract

Background: In the United States, approximately 45,000 snakebites occur annually and affect many people including veterinarians and farmers.[1] Snakebites can cause significant pain and morbidity such as severe bleeding and skin necrosis. Better predictive information on snakebite risk could help prevent snakebites by identifying high risk time periods, weather patterns, and locations.

Methods: This was a retrospective analysis of the New Mexico State Poison Control Center data between January 1998 and December 2012. Monthly average meteorological data were obtained from the Parameter-elevation Regressions on Independent Slopes Model climate group. Locations of the bites were categorized as urban or rural based on the National Center for Health Statistics urban-rural classification scheme for counties. Poison regression modeling was used to evaluate the influence of urban-rural locations and meteorological factors on snakebite incidence.

Results: A total of 928 snakebites was reported and the number per year appeared to be trending up in recent years. The groups most affected by snakebites were males and those aged 45 to 49 years. Most snakebite cases were of moderate medical severity and were reported in the late afternoon or evening. A trend of increasing incidence was noted. A Poisson regression model was constructed, which found a positive association between snakebite incidence and population density in rural areas as well as higher monthly average minimum temperature. Being in an urban location was negatively associated with snakebite incidences.

Discussion: In this study, the majority of the reported snakebites resulted in significant morbidity and males were disproportionately affected by snakebites. Snakebites were more common in rural areas, and during times of higher minimum temperature. These findings suggest that predictive models for snakebite risk may be helpful in shaping preventive strategies.

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Introduction

Even in today's modern world where many people live in settings that are far removed from nature, animal related injuries such as snakebites remain a serious source of injuries.[2] In the United States, approximately 45,000 snakebites occur annually and affect many people including veterinarians and farmers.[1] Many workers are affected by snakebite injuries in various occupations. Workers that have outdoor tasks may come in close contact with snakes and may be placed in harm's way.[3] These workers include agricultural workers, construction workers and wildlife workers such as forest rangers, Department of Fish and Wildlife and National Park employees, and biologists.[4] Other workers may come in close contact with snakes through their work with captive reptiles. These types of workers might include animal trainers, zoo workers, and veterinarians.

Snakebite injuries also pose potential harm for people who come in contact with animals away from work as well. Many people come into contact with snakes through pet ownership or through activities such as hiking or camping. When people own wild and exotic pets like snakes, such animals, even when handled with utmost care, can bite unexpectedly and cause serious harm.[5] Furthermore, there are groups that intentionally handle snakes for religious purposes. In 2014, for example, there was a highly publicized case of Jamie Coots, a pastor of a snake-handling church, who died after a fatal snakebite.[6]

Snakebite injuries are often preventable events that can be mitigated by certain safety precautions and public education about the potential hazard of snakes, whether as pets or wildlife. While fatal snakebites occur infrequently, snakebites can cause significant pain and morbidity.[7] Rattlesnakes, the predominant type of venomous snake in the American southwest, are widely distributed across the state of New Mexico. Rattlesnakes have hemotoxins in their venom that can cause tissue injury leading to skin necrosis and hematologic effects including severe bleeding. Their venom may also contain neurotoxins that can produce respiratory paralysis in their victims.[8] The medical outcomes of snakebites can be more severe among vulnerable populations such as children and the elderly.[9] Better predictive information on snakebite risk could help prevent snakebites in both the general public and exposed workers by identifying high risk time periods and areas. There are studies about snake activity that describe when the snakes are most active during the year and during the day.[10] However, there are limited studies regarding snakebite injury patterns in relation to geographical or meteorological variations or formal models to predict incidence.[11–14]

A snakebite incident results from a complex interplay between weather, geography, ecology and human activity. Understanding these factors could potentially help shape targeted preventive strategies and public health policies. Since people reside and work in both urban and rural settings, it is important to think about which population might be more vulnerable to snakebite injuries. Risk stratifying the various locations for the likelihood of snakebite incidences would be helpful in planning medical and public health resources to prevent snakebite injuries. This type of analysis is not readily available at present, as there is limited information regarding the population affected by snakebites in particular areas and how geographical and meteorological factors might differentially influence snakebite incidents.

The objective of this study was to obtain up-to-date information about epidemiological features of snakebites in the State of New Mexico, and to evaluate the correlation between snakebites and various potentially predictive factors. The first component of the study was an analysis of the snakebite data from the New Mexico Poison Control Center to establish a descriptive epidemiology of the snakebites in the state from 1998 to 2012. The second component of the study involved the design of a statistical model to explore the relationship between snakebite incidences and various potential predictive factors including geographical differences and weather.

Materials and Methods

Overall study design

This was a retrospective analysis of the data from the New Mexico State Poison Control Center between January 1998 and December 2012. With the cooperation of Dr. Steven Seifert and Dr. Blaine Benson from the New Mexico Poison Control Center (PCC), the PCC reports from across the entire state of New Mexico from January 1998 to December 2012 were obtained. The starting date of January 1998 was chosen because the availability of the computerized reports began at that time. The ending date of December 2012 was chosen because, at the time of the study, the complete collection of reports for 2013 was not yet finalized.

Any human subject recorded as having had exposure to snakebite and who reported the injury to the PCC was included. Two of the reports involved bites to non-human animals, and these cases were excluded. It was assumed that snakebite injuries stemmed from rattlesnake exposures, given that the rattlesnake is the predominant type of venomous snake in the region.

The snakebite reports consisted of information provided to the PCC at the time of the snakebite injury evaluation. These reports included information on the patient’s age, sex, location of the treatment center, the date and time of when the snakebites were reported to the PCC, and the medical severity of the case. Personal identifying information such as name, telephone number, address and dates of birth was not obtained from the PCC database. The anonymous, compiled list of snakebite case reports was then used to conduct an analysis of the seasonal variation of snakebites. Additional analysis was performed to evaluate whether variables such as sex, age or time of the day are associated with higher incidence of snakebites.

The data were surveyed for the age distribution in New Mexico based on the 2010 United Stated Census data. The 2010 Census dataset was chosen for being the most updated data available for the state at the time of the study. Then data were surveyed for the proportion of snakebites by age groups. Each proportion was calculated by total bites in each age group divided by the total in population in that age group. This was the cumulative incidence given that this was the number of new snakebite cases within the specified time period divided by the size of the population initially at risk.

The medical severity of the cases was determined based on the clinical information provided to the PCC.[2] Categorization of medical outcomes was in accordance with the PCC's predetermined criteria. The category of No Effect meant that the patient had no signs or symptoms after the snakebite exposure. The category of Minor Effect meant that the patient exhibited minimal signs or symptoms such as minor skin irritation, which resolved quickly with no residual morbidity. The category of Moderate Effect meant that the patient developed a more systemic sign or symptom that required treatment such as fevers, confusion, seizures or significant changes in blood pressure. The category of Major Effect meant that the patient developed life-threatening symptoms and/or significant residual morbidity such as status epilepticus, respiratory distress needing intubation, and cardiovascular collapse. The other categories such as Death, Not Followed, Unable to Follow, Unrelated Effect and Confirmed Nonexposure are self-explanatory. The 10 cases in the Confirmed Non-Exposed category were not included in the analysis.

Snakebite cases were mapped onto a map of New Mexico using free software called GeoCommons (Redlands, CA).[15] The map was created as such that the size of the circle on the map reflected the corresponding number of the snakebite case occurrences at that location. Hence, an area that had more snakebite injury cases had a larger circle on the state map.

Statistical analysis

Using the geographical location and time of the snakebites, the corresponding historical weather information was obtained from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Datasets. The PRISM Climate Group has data on climate patterns, dating back to 1895. PRISM collects information on climate from thousands of weather stations across the United States, checks the information for quality, and uses sophisticated modeling techniques to interpolate data points taking into account the local geography such as mountains, deserts, and coastal proximity. The PRISM Climate Datasets were chosen because of their open and free access, and the climate datasets generated from modeling techniques provided meteorological information in times and locations, where there was a lack of actual measured information. A different source for climate data, which might provide actual measured climate data, was considered but the coverage for weather stations was minimal for most rural areas and hence, it was insufficient for the study. Large patches of the state of New Mexico are rural and rather sparsely inhabited and, in many such areas, there are no weather stations to collect meteorological data. Therefore, direct weather station data such as those from the National Weather Service and the Weather Underground were inadequate.[16,17]

Snakebite reports were mapped by zip code and converted into longitude and latitude. The geographical coordinates were then entered into the PRISM database website to obtain various monthly average meteorological data.[18] The meteorological data downloaded were the monthly average maximum temperatures, the monthly average minimum temperatures, and the monthly average precipitation. Once the meteorological data was obtained, it was added to a spreadsheet containing the PCC data on snakebite injury cases.

The locations of the bites were categorized as urban or rural based on the National Center for Health Statistics (NCHS) urban-rural classification scheme for counties.[19] The NCHS is a data system developed by Centers for Disease Control and Prevention (CDC) that provides a classification scheme for all counties and county-equivalents in the United States. The basis of this classification scheme was the utility in evaluating health status differences in different geographical areas in the country. This classification has been used to study health differences in the populations of urban versus rural areas in various studies.[20,21] Once the snakebite injury locations were classified as either urban or rural areas using the NCHS classification scheme, this information was linked to the PCC data on snakebite injury cases.

Corresponding raw population data at the county level was also obtained from the US Census with data sourced from the appropriate decades.[22–24] For example, a snakebite from 1998 was cross-referenced to Census data from 1990, and a snakebite from 2005 was cross referenced to Census data from 2000.

The final comprehensive database contained the details of snakebite injury cases along with the locations of the snakebites categorized as urban or rural, county population and meteorological information such as the monthly average maximum and minimum temperatures and precipitation. A Poisson regression model was then constructed using SAS 9.3 (Cary, NC) to model the relationship between snakebites per month, population, temperature, precipitation, and urban/rural counties.

Results

Characteristics of snakebite cases

During the study period of 1998 to 2012, a total of 928 human snakebites were reported to the New Mexico PCC. The majority of the cases were males (714, 77%). Most snakebite cases were of moderate medical severity (Table 1). Those in the extremes of age group suffered more cases of major medical severity as compared to other age groups (Figure 10).

The 45 to 49 age group had the highest number of snakebite cases (Figure 1). Adjusting for population using the US Census data, this age group also demonstrated the highest estimated cumulative incidence (6.28 snakebites / 10,000) (Figure 2).[24]

The number of snakebite cases ranged from 35 cases in 1998 to 81 cases in 2010 (Figure 3). The mean number of annual snakebite cases was 59.5 snakebite cases/year, with a median of 61, during the study period. A linear regression line was fitted for the number of snakebite cases over the study period. The number of reported snakebite cases appeared to be trending up in the recent years with R^2 value of 0.44414 (Figure 3).

The geographical distribution of snakebite cases was mapped onto the state map. There were more snakebites reported from more populated areas such as Albuquerque, the state capitol, and the other large towns such as Las Cruces, Roswell and Carlsbad (Figure 4).

Snakebite cases were the most prevalent during the summer months (Figure 5). There was a correlation between the monthly average minimum temperature and snakebites ($p<0.0001$) (Figure 9). The number of snakebites reported was the highest during late afternoon to evening hours (Figure 6), the pattern of which was similar for every month (Figure 7). The time of day also did not appear to be predictive of the age of the victim (Figure 8).

Predictive Model of Snakebite Risk

$$\log(snakebites) = -16.5781 + \log(population) + 0.0692(T_{min}) - 0.9261(urban)$$

Modeling snakebites as probabilistic events, a Poisson regression was constructed (Table 2). The regression model was optimized by minimizing Akaike information criterion (AIC) and number of explanatory variables. The model was offset by log(population) since it was expected that more snakebites would occur in a more populated area with more people in the risk pool. The urban area variable showed a negative correlation, meaning that being in an urban environment was protective against snakebite injuries. The monthly average minimum temperature (T_{min}) was a better predictor than the monthly average maximum temperatures. The Poisson regression model demonstrated that snakebite frequency increases with rising population and increasing minimum temperatures, but is relatively less common in urban areas (Figure 9). Precipitation was not a useful predictor of snakebites in this model.

Discussion

Descriptive epidemiology of snakebite cases

Analysis of the cumulative incidence shows that the risk for snakebite injuries in New Mexico is the highest in people in the 30 to 50 year old age group (Figure 2). This was in contrast to the Parrish study, which showed that the group at the highest risk were teenagers.[1] Wingert and Chan had also found in California that the highest risk appeared to be those in the age group of 17 to 27 years.[14] The groups most affected by snakebites were males, which was consistent with the previous studies that showed male patients outnumbering female patients.

Results from this study indicate that snakebites resulted in numerous injuries causing significant pain and morbidity. The majority of those bitten had moderate medical severity as a result of the snakebites.

Because there were more snakebite cases reported during late afternoon and evenings, there was a question of whether more adults, rather than children or the elderly, who are outdoors during those times might be the victims of snakebites during those times of the day. However, the time of day did not appear to be predictive of the age of the victim (Figure 8).

The total number of snakebite cases varied from year to year but the reason for the variability remains unclear. The seasonal variation in temperature and precipitation appeared to be similar from year to year (Figures 11 and 12). Based on the regression line fitted onto the annual number of snakebite cases from 1998 to 2012, it appears that there is an upward trend in snakebite cases over the years (Figure 3). However, it is unclear why the number of snakebite cases might be on the rise. The number of years analyzed for this study is too small to consider the potential effect of global warming as a cause, as the slow rise in global temperatures would be minute over the study period. The temperatures in New Mexico on average were not on an upward trend during the study period (Figure 11). It is possible that the increase in the total number of snakebite cases was attributable to a significant increase in the total population of the state given that the total population in New Mexico in 2000 was 1.8 million and increased only slightly to 2 million in 2010.[23,24] Other potential possibilities are if there was an increasing detection of snakebite incidences over the years due to improved reporting to the PCC. Another possibility would be whether there was increasing human encroachment into wildlife areas that resulted in more intimate human animal contact. Finally, it is also possible that public awareness of the hazards of snakebites have been falling off in more recent years.

Correlation between climate factors, geography, and snakebite cases

To evaluate the potential predictive variables for snakebite injuries, a statistical model was selected to carry out the analysis. Initially a linear regression model was considered but ultimately rejected because this model would predict invalid negative numbers of snakebites at realistic temperature ranges. It also did not easily take into account the data points of zero snakebite, e.g. months of high temperatures, which did not have any snakebite due to chance alone. A Poisson model was chosen ultimately because it was well suited for count data that is based on probability. There were many people at potential risk for snakebites, yet there was ultimately a relatively low probability of snakebite.

Based on the statistical model, more cases were reported from the more populated areas, which are accounted for by the larger number of people at risk. On the other hand, according to the Poisson regression model, the risk for snakebites was relatively increased in rural areas when taking into account population and temperature ($p<0.001$). This is likely due to the proximity of human habitation to snake habitats in rural areas.

More snakebite injuries occurred during the summer months when snakes are generally more active. Interestingly, it was not the monthly average maximum temperatures but the monthly average minimum temperatures that had a more statistically significant correlation to snakebites ($p<0.0001$). This might be because the monthly maximum temperatures might represent more transient spikes in temperatures while a more generalized rise in temperature allows for more snake activity.

Precipitation appeared to offer no further predictive information, during the process of optimizing our regression model, than the average minimum temperature (Figure 12). The implication for this might be that as New Mexico approaches summer, the rise in minimum temperatures may be a good predictor to use in planning medical and public health resources in regards to snakebites. High-risk months can be flagged to be the period of targeted public education campaigns about snakebite hazard, first aid information and improving access to medical care by ensuring adequate staffing and anti-venom in healthcare facilities

The number of snakebite cases appeared to be highest in late afternoon and evenings, which may be a result of when snakes are the most active during the day. Rattlesnakes are more active during the early morning and dusk hours, avoiding the hot mid-day.[10] The snakes avoid being active in very hot temperatures, given that they are cold blooded and cannot readily control their internal temperatures.[10] However, there may be a time delay from when the snakebite occurs to when the call reporting the snakebite might be made to the PCC.[10]

In conclusion, the estimated number of snakebites was significantly related to the population, monthly average minimum temperatures and being in a rural area. The results of this study would be useful for many in the public. The results can help guide public health and health care professionals in New Mexico in identifying potential trends in snakebite occurrences and risk factors that can be targeted with preventive strategies. Furthermore, this study may also guide those in other regions with rattlesnakes and similar weather patterns.

Limitations

The PCC database only had the time when someone, such as a healthcare provider, called the PCC with reports of snakebite injuries. The database did not have the actual time that the patients suffered the snakebites. Hence, there was most likely a time delay in reporting the snakebite injuries to the PCC. This would affect the analyses regarding the time of the snakebite injury.

The PCC database did not always have complete information on each of the snakebite injury cases. Many of the cases had adequate follow-up such that the ultimate disposition of the patient was able to be determined in terms of medical severity. However, there were some cases where there was not any information on the ultimate medical outcome of the patient.

There was no actual meteorological data available for analysis. The climate data was obtained from the PRISM Climate Group, which is a database that provides spatial meteorological information for research from various modeling technologies that takes into account the local geography. The use of PRISM climate data was necessary because the study area had inadequate coverage by weather stations in many rural areas and the historical climate data was often incomplete. While the climate information provided by PRISM is invaluable in a situation where there are no actual weather data available, it is ultimately ideal to have raw climate data so this is a potential limitation. Also, using the PRISM database that was freely accessible on the website meant that the data available only provided the monthly averages for various meteorological variables such as temperatures and precipitation, rather than daily temperature or precipitation data points. It might be possible to do a more sophisticated analysis of the data if more fine-grained daily climate data were available.

Future Studies

One important future direction for this study would be to expand on the study to investigate the interaction of all the involved populations: humans, snakes, and domestic animals and wildlife. The PCC data on snakebites could potentially be correlated with the data on animals affected by snakebites. The Epidemiology Department of the National Park Service is currently interested in conducting a survey of veterinarians near various National Parks, in order to assess the number of animals that are injured by snakebites.[25] The idea behind the study is that any clustering of the animal snakebite injuries is likely an early signal of impending increases in risk for human snakebite injuries. Injuries and illnesses in domestic animals and humans often occur during similar time periods and locations since animals and humans live in close proximity. There are numerous existing cases of animals serving as sentinels for human illnesses such as the classic story of the canary in the coal mine.[26] Presumably, a dog or a cat might be the sentinels for snakebites, since these animals are closer to the ground and are likely to be more susceptible to attacks by snakes.

It is likely that a large section of the population affected by snakebites is coming into contact with wildlife while performing their jobs. To date, there do not appear to be published studies describing the burden of snakebite injuries for various occupations. A future study might be able to determine such an impact on workers by looking at certain data such as workers' compensation claims or the health insurance claims. While not all workers that come in contact with snakes would have health insurance (e.g. a construction worker might not have health insurance while a wildlife government biologist likely does have health insurance), the workers' compensation claims might catch more work related snakebite injuries and the two databases linked together might render a more complete picture.

Summary

Snakebite injuries are a hazard to the general public, as well as an occupational hazard to those workers who come into contact with snakes through veterinary or outdoor work. While snakebites are infrequent events, the patients who suffer snakebites can have high morbidity including hematological derangement and skin necrosis. Hence, better predictive information such as weather and location that increase snakebite hazard may assist in better protecting the public and the workers. Previous studies had reported on the biological activity patterns of snakes but there have been very limited studies done on the descriptive epidemiology of the snakebite patients and the potential predictive factors of geography and climate.

To this end, this study was done to establish the descriptive epidemiology of snakebites in New Mexico and to evaluate the correlation between meteorological and geographical factors and snakebites. The study resulted in a comprehensive retrospective survey of the snakebite cases from the New Mexico PCC database from January 1998 to December 2012. The snakebites were modeled as probabilistic events with the total number of snakebites as a distribution using a Poisson regression model.

Living in an urban area decreased the likelihood of snakebite injuries while the rising monthly average minimum temperatures increased the likelihood of snakebite injuries. Hence, monitoring where the public resides and observing the rises in the minimum temperature may be a good strategy when the community health resource planners want to target the appropriate time to start preparing public service messages to the general public and workers to be more vigilant about snakebite hazard, and to ensure there is adequate healthcare resources such as anti-venom and healthcare personnel to take care of snakebite patients.

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Appendix A: TABLES

Appendix A-1

Table 1: Medical outcome of the 928 snakebite cases reported to New Mexico Poison Control Center between 1998 and 2012

Medical Outcome	Number
Death	1
Major Effect	44
Moderate Effect	516
Minor Effect	132
No effect	11
Confirmed, non-exposed	10
Unable to follow, judged as a potentially toxic exposure	128
Not followed, minimal clinical effects possible	64
Not followed, judged as nontoxic exposure	7
Unrelated effect	15

Appendix A-2

Table 2: Predictive Model of Snakebite Risk

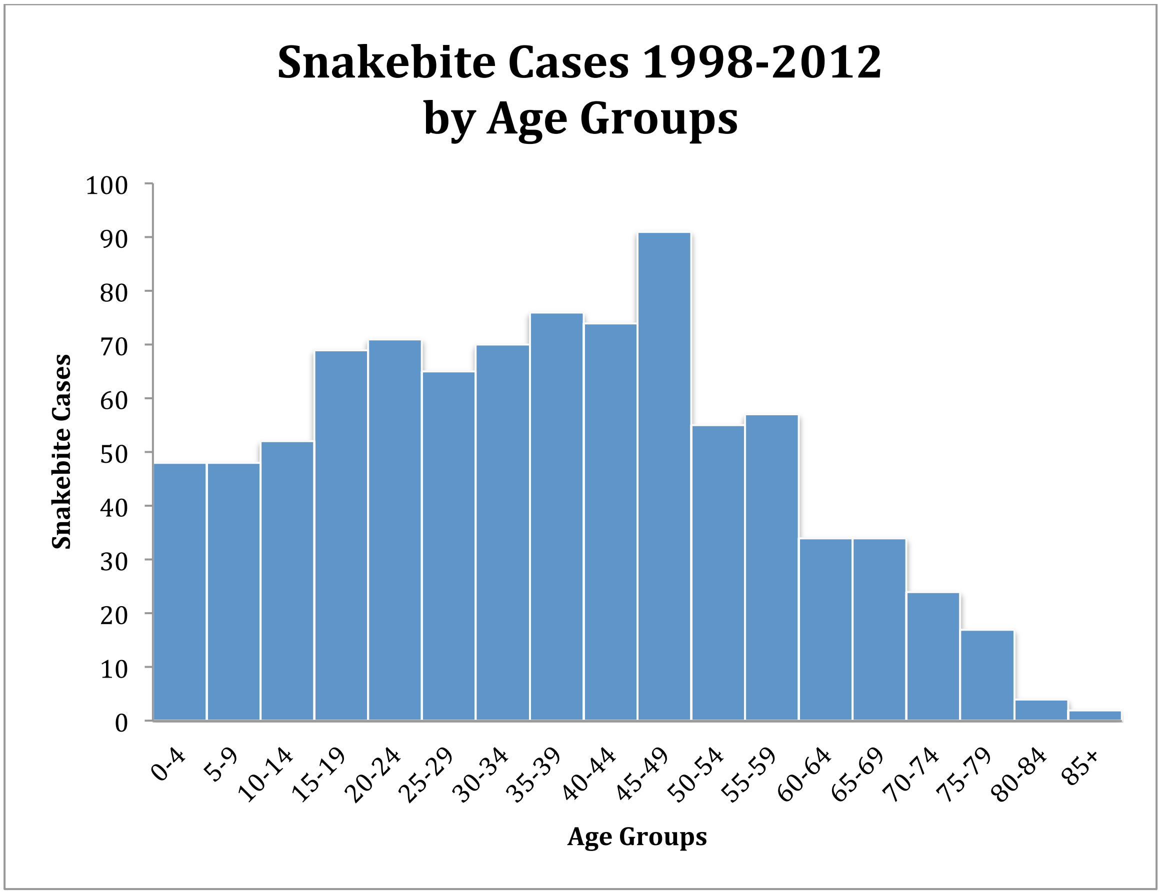
$$\log(snakebites) = -16.5781 + \log(population) + 0.0692(T_{min}) - 0.9261(urban)$$

Variable	***p***
Intercept	*<0.0001*
Tmin	*<0.0001*
urban	*<0.0001*

Appendix B- FIGURES

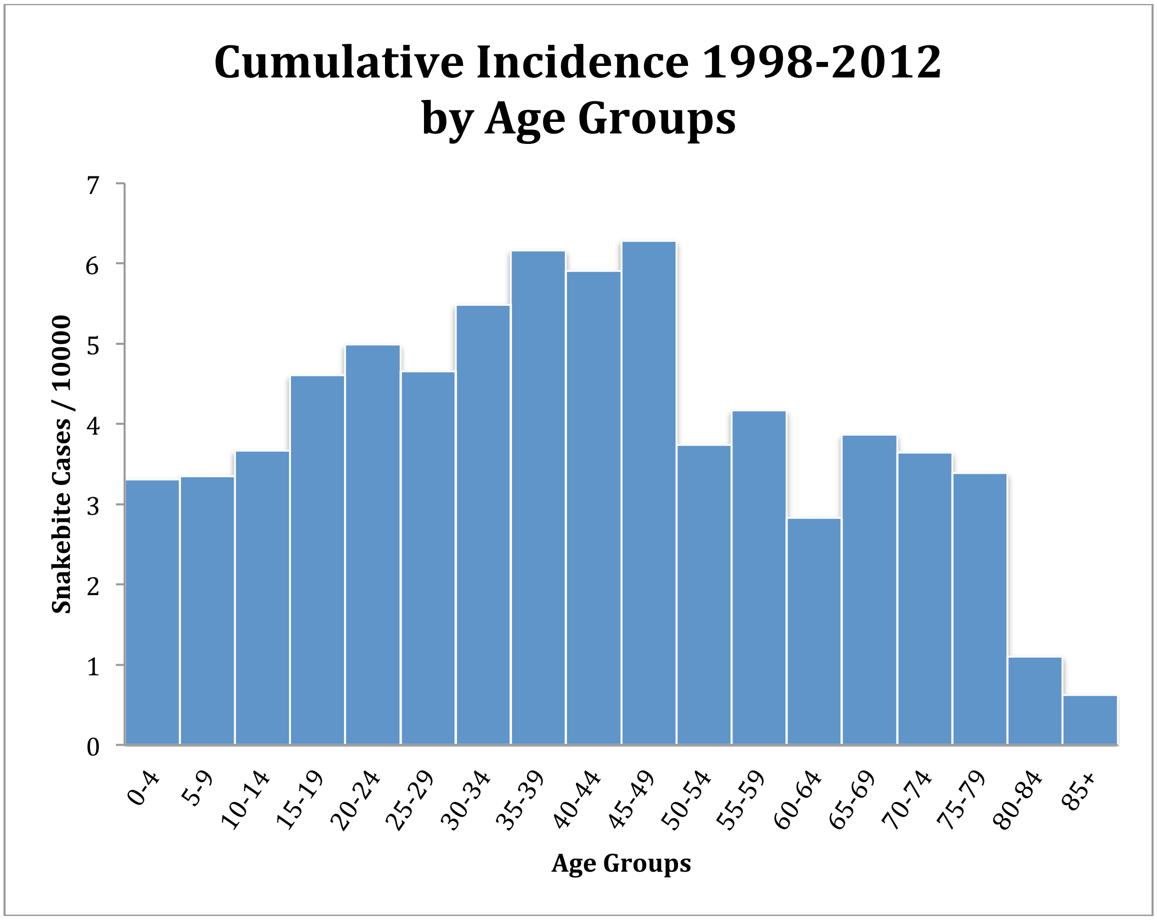
Appendix B-1

Figure 1:Snakebite cases 1998-2012 by age groups



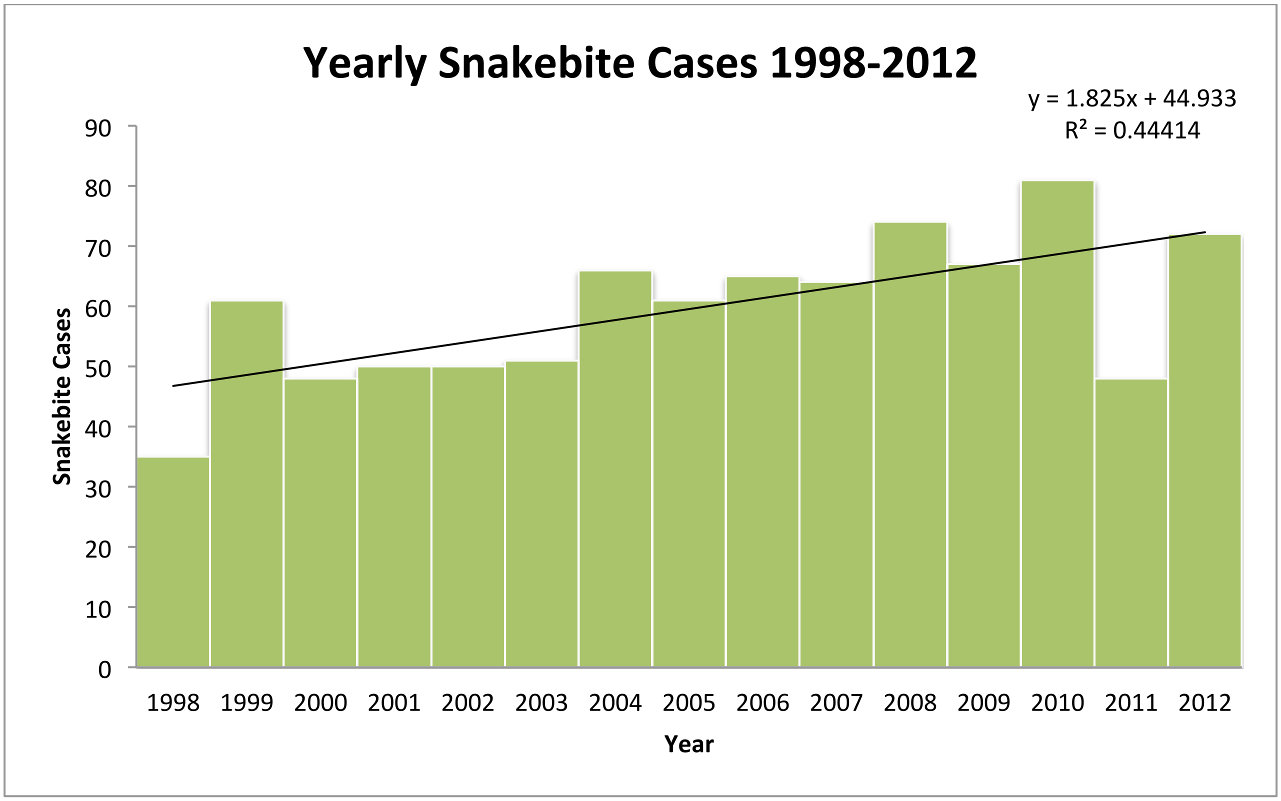
Appendix B-2

Figure 2: Cumulative incidence by age groups, normalized using Census 2010 data



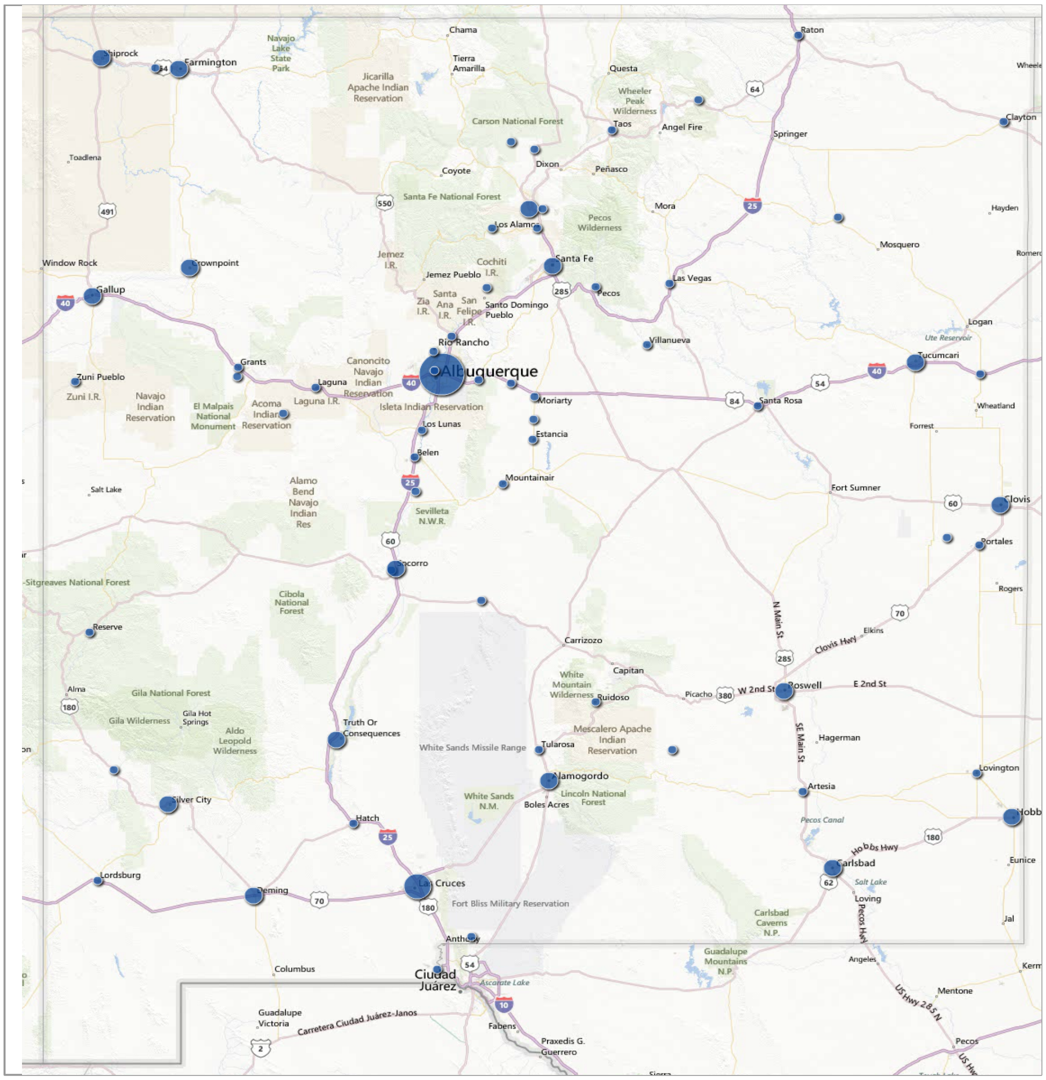
Appendix B-3

Figure 3: Yearly snakebite cases from 1998 to 2012



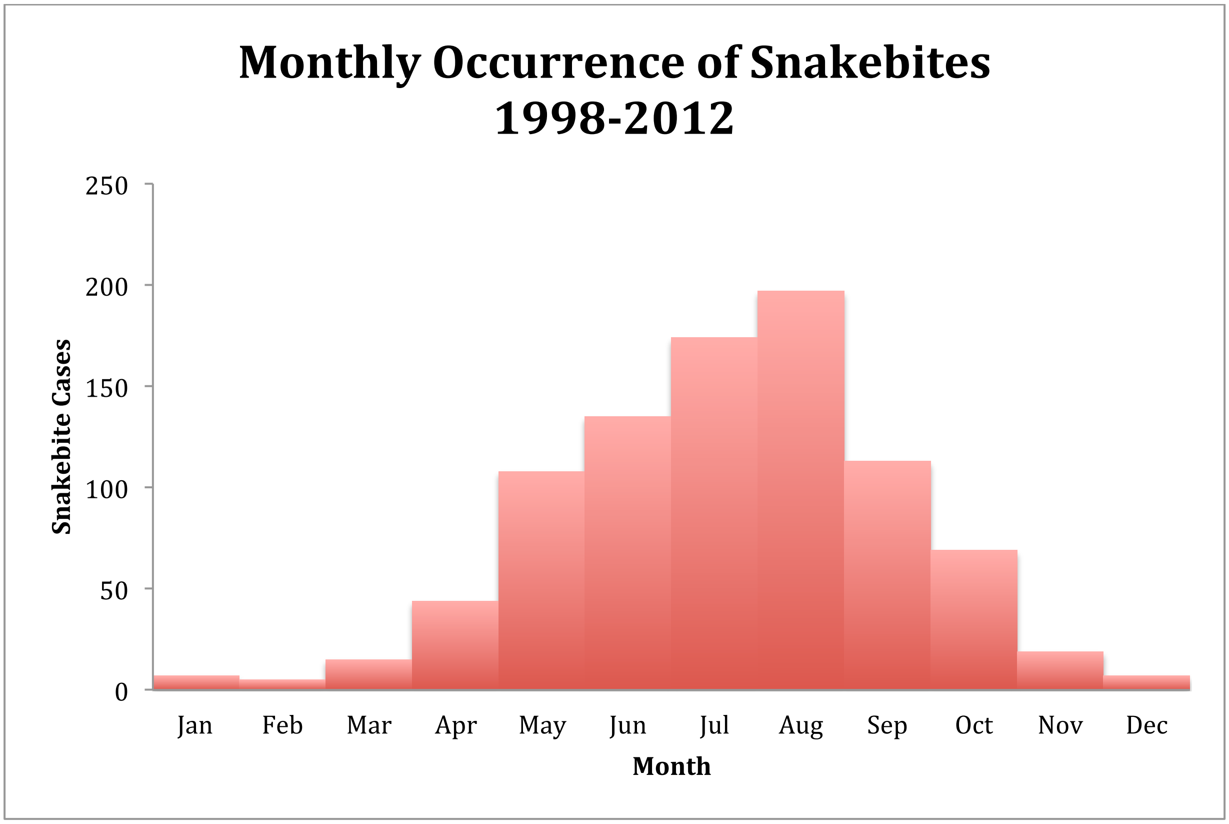
Appendix B-4

Figure 4: Snakebite Cases by Location: Larger circle represents more cases.



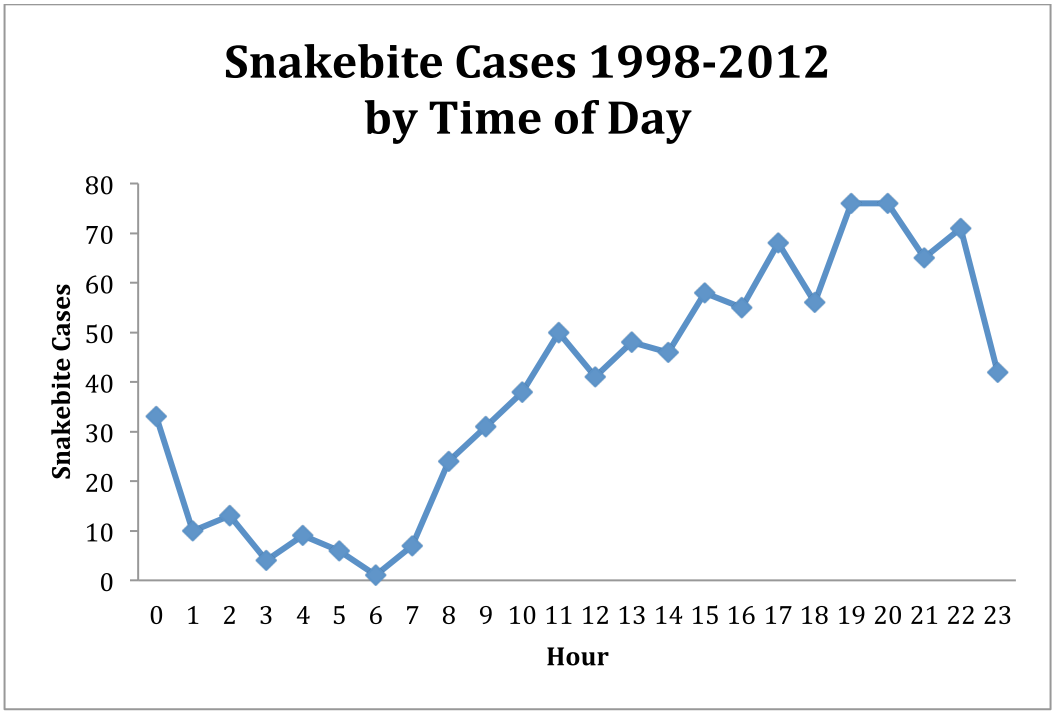
Appendix B-5

Figure 5: Monthly occurrence of snakebites



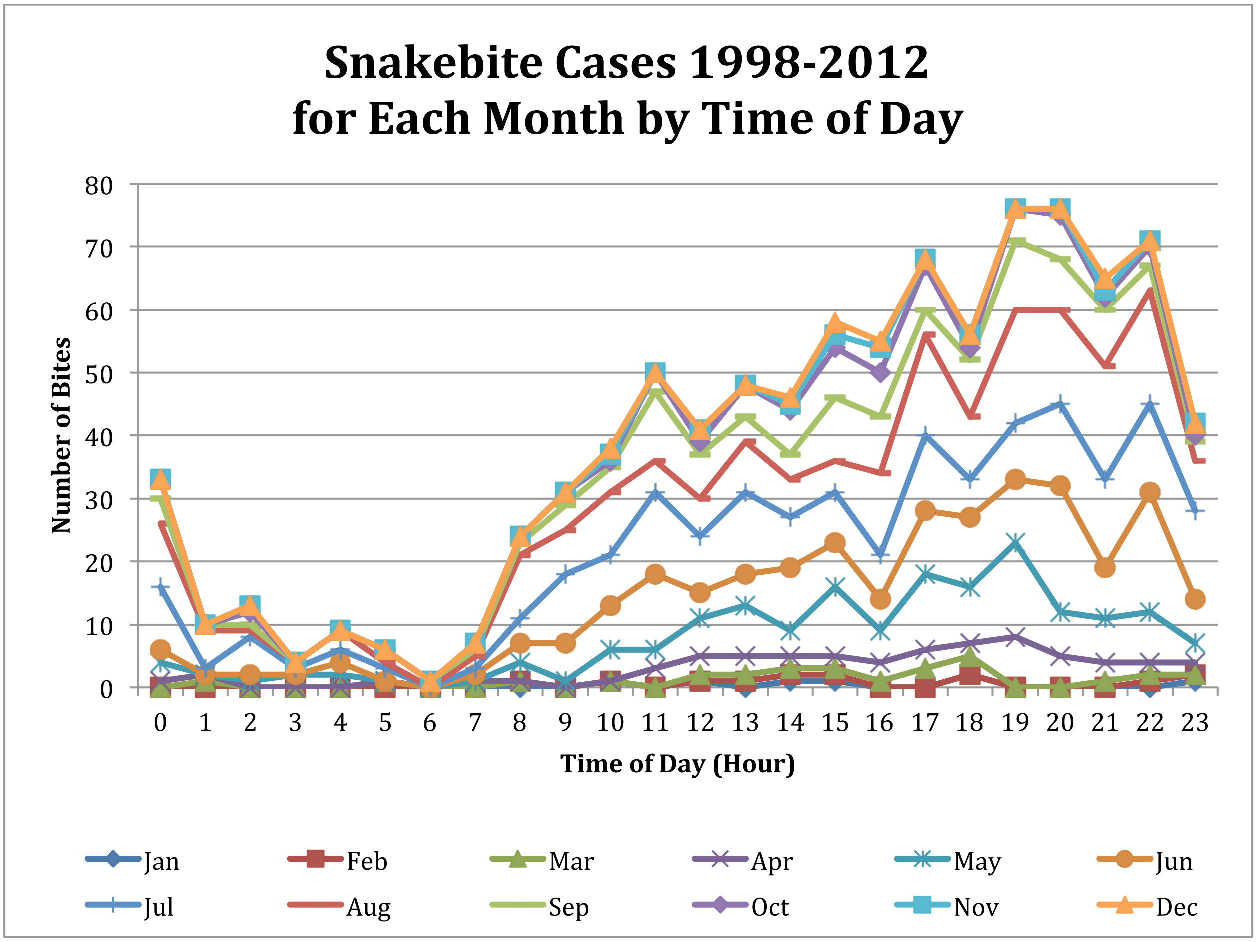
Appendix B-6

Figure 6: Snakebite cases by time of day



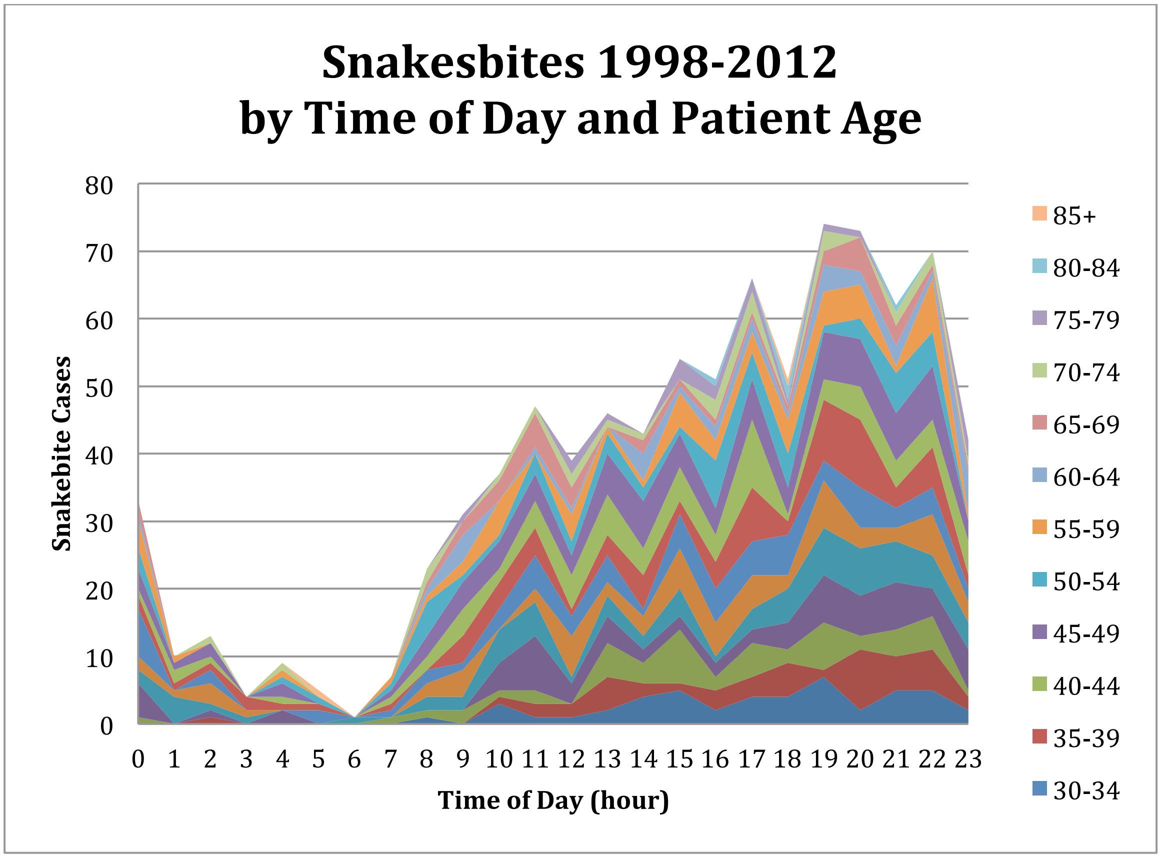
Appendix B-7

Figure 7: Snakebite cases for each month by time of day



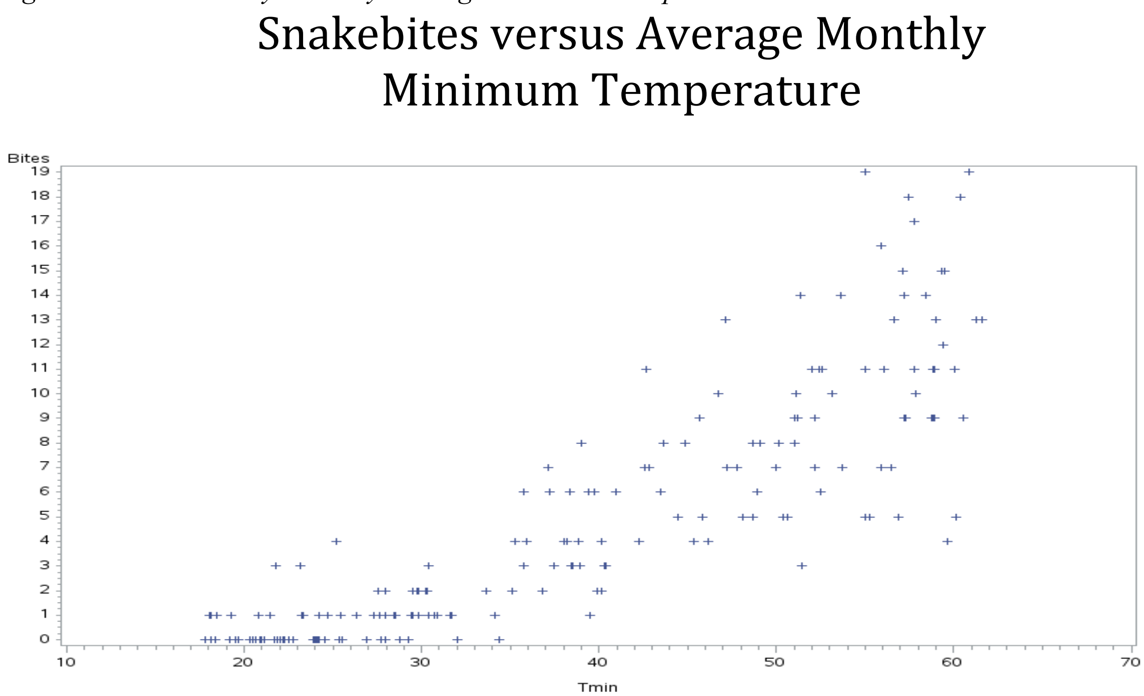
Appendix B-8

Figure 8: Snakebites by time of day and patient age



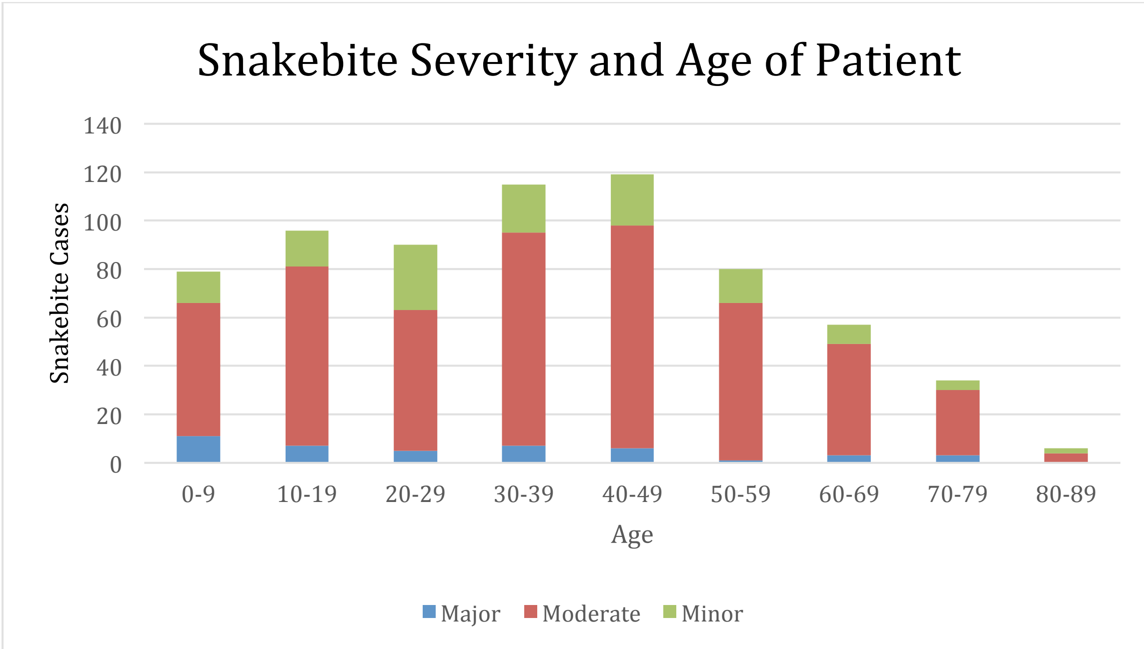
Appendix B-9

Figure 9: Snakebites by Monthly Average Minimum Temperature



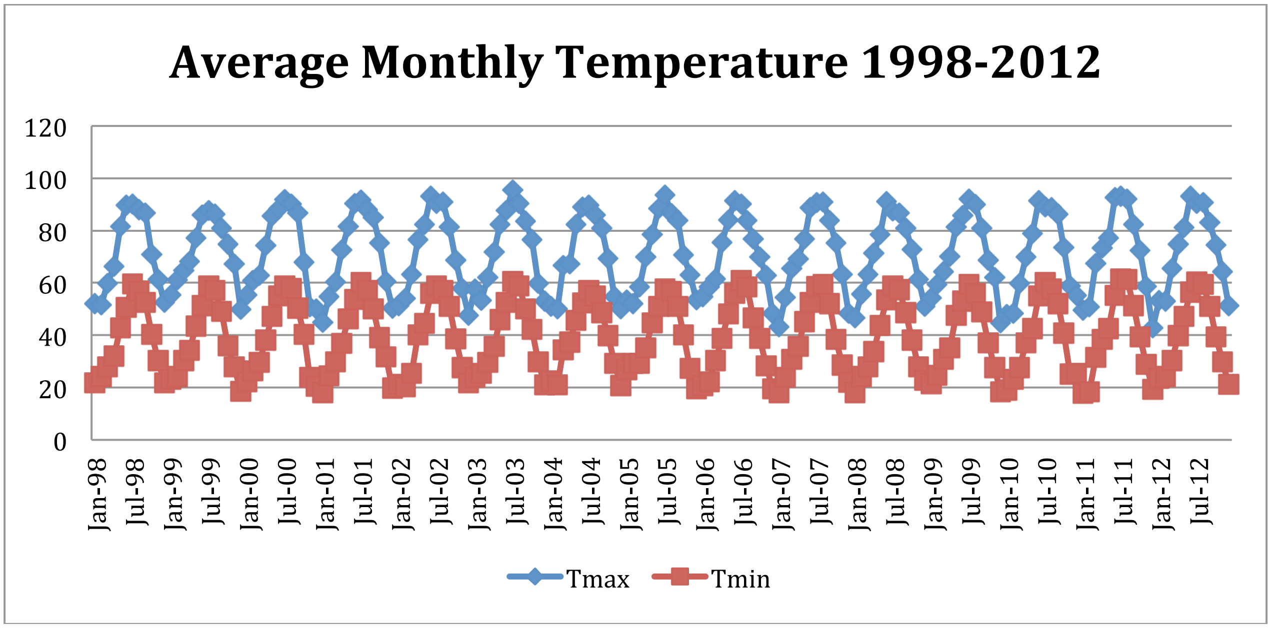
Appendix B-10

Figure 10: Snakebite severity and age of patient



Appendix B-11

Figure 11: Average temperature over time from 1998 to 2012



Appendix B-12

Figure 12: Average precipitation over time from 1998 to 2012