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Selected Topics: Toxicology

CrossMark

THE ASSOCIATION BETWEEN HEAT WAVES AND OTHER METEOROLOGICAL PARAMETERS AND SNAKEBITES: ISRAEL NATIONAL STUDY

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☐ **Abstract—Background: Published annual estimates report a global burden of 2.5 million snakebite cases and >100,000 deaths. In Israel, envenomations are the third most frequent cause of poisonings that are of moderate to major clinical severity. Most studies focus on the clinical descriptions of snakebites in tropical climates, and we sought to investigate the association between snakebite frequency and meteorological parameters. Objective: We sought to investigate the seasonality of snakebites and evaluate the association between increasingly common heat waves and other meteorological parameters and snakebite frequency in a semiarid nontropical climate. Methods: We obtained data for all medical evacuations (2008–2015) because of snakebites in Israel. Climate data included daily 24-hour average temperature (°C) and relative humidity (%). We used a time-stratified case crossover method, in which a conditional logistic regression was applied to estimate the association, and we also stratified our analysis by season and by region. Results: We identified 1234 snakebite cases over 8 years, of which most (74.2%) occurred in hot seasons and between 6 PM and 9 PM. The risk of snakebite was positively associated with temperature >23°C (odds ratio [OR] 1.24, 95% confidence interval [CI] 1.01–1.53) and inversely with humidity >40% (OR 0.74, 95% CI 0.57–0.97). We also found an association with heat waves both in cold (OR 1.62, 95% CI 1.01–2.60) and hot seasons (OR 1.50, 95% CI 1.18–1.92). Conclusions: In a semiarid nontropical climate, we observed an association between an increase in the number of snakebite cases and higher temperatures and lower humidity. Moreover, heat waves increased the frequency of snakebites in both cold and hot seasons.**

☐ **Keywords—heat waves; humidity; Israel; meteorological parameters; relative; season; snakebites; snakes; temperature**

INTRODUCTION

Published annual estimates report a global burden of 2.5 million snakebite cases and >100,000 deaths (1,2). Envenoming and deaths resulting from snakebites are particularly common in rural tropical areas, such as Africa, Asia, Latin America, and New Guinea, and pose a serious threat in the Middle East as well (1–3). In Israel, envenomations are the third most frequent cause of poisonings that are of moderate to major clinical severity (4).

The Israeli climate features long, hot, rainless summers and relatively short, cooler winters with rainfall, unlike tropical climates characterized by constant hot temperatures throughout the year (5). The genus *Vipera palastinae* is the sole genus of poisonous snake found in the Central and Northern regions of the country and the sole genus of snakes that have caused fatalities in Israel (3,6). The Southern region is inhabited by the remaining 7

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venomous species, including desert species, such as *Echis coloratus*, *Atractapis engaddenis*, and *Walterinnesia aegyptia* (Figure 1) (3,6). In Israel, 2 types of antivenoms are used, 1 against *V. palastinae* and the other against *E. coloratus*, with a typical dose of 50 mL. Antivenoms for other species, apart from Vipera or Echis, were neither used nor produced in Israel.

Most previous studies have focused on the clinical descriptions of snakebites in tropical climates and have demonstrated an increase in snakebite frequency during hot seasons, rainy seasons, and at evening or nighttime (1,6–15). However, studies have conflicting results regarding humidity, including both positive and negative correlation (13,15–17).

We sought to investigate the seasonality of snakebites and evaluate the association between snakebite frequency and meteorological parameters, including common heat waves, in the semiarid nontropical climate of Israel.

METHODS

Study Population

We obtained data for all medical evacuations caused by snakebites between 2008 and 2015 in Israel from Magen David Adom (MDA), the sole emergency medical service provider for the country. Nationwide, MDA responds to approximately 1000 emergency calls per day and uses paramedics, emergency medical technicians, and volunteers. The organization is currently divided into 11 operational regions that are geographically distinct and operates 119 stations, with a fleet of >700 ambulances nationwide (18).

This study was approved by the MDA Institutional Review Board, and snakebite data obtained from its database included the address, date and hour of the call, and the destination of the evacuation.

Environmental Data

Data for the study period included daily 24-hour average temperature (°C) and relative humidity (%), obtained from 28 monitor stations in Israel, operated by the Ministry of Environmental Protection, which sample the air in 5-min intervals. The data are available on the National Air Monitoring Network website. Meteorological parameters were linked to each snakebite case based on the proximity of the location of the call to the monitor station using ArcInfo 10.2 software (ESRI, Redlands, CA). Heat waves were defined with a threshold above the 80th or 85th percentile temperature that lasted 2 consecutive days.

Seasons were defined according to Alpert et al.: "winter" (December 7–March 30) and "summer" (May 31–September 22) seasons each lasted about 16 weeks, and "autumn" (September 23–December 6) and "spring" (March 31–May 30) seasons were markedly shorter, at 75 and 61 days, respectively (19). These designations reflect the duration of various seasonal climates in Israel.

Geographic Distribution

We divided Israel into 3 regions according to the snakes' species distribution, based on the MDA's operational and geographically distinct regions (3,6). The Southern region extends south to Beer Sheva, the Northern region from the north to Umm al Fahem-Beit Shean line, and the Central in between both regions.

Statistical Analysis

Data were summarized using frequency tables for categorical variables and mean with standard deviation

Figure 1. Venomous snake species found in Israel.

Table 1. Summary Statistics of Snakebite Frequency and Daily Average of Meteorology Factors, by Season and Region

	Season			
	Summer (May 31–Sep 22)	Autumn (Sep 23–Dec 6)	Winter (Dec 7–Mar 30)	Spring (Mar 31–May 30)
Temperature (°C)				
Mean ± SD	26.7 ± 2.6	21.5 ± 4.1	14.7 ± 3.4	20.6 ± 3.7
Maximum	42	37.2	33	38.9
Relative humidity (%)				
Mean ± SD	67.9 ± 13.7	62.3 ± 17.6	65.2 ± 18.5	62.7 ± 17.4
Maximum	100	100	100	100
Snakebite cases, N = 1234				
n (%)	684 (55.4)	229 (18.6)	89 (7.2)	232 (18.8)

	Region		
	Center	North	South
Temperature (°C)			
Mean ± SD	20.8 ± 5.7	20.5 ± 5.7	22.5 ± 6.8
Maximum	35.6	34.5	42
Relative humidity (%)			
Mean ± SD	67.4 ± 14	63.1 ± 18.8	58.5 ± 21.7
Maximum	100	100	99
Snakebite cases, N = 1234			
n (%)	585 (47)	515 (42)	134 (11)

SD = standard deviation.

(SD) for continuous variables. We used a time-stratified case crossover method, in which cases act as their own controls on a set of predefined control days proximate to the snakebite time. This method avoids confounding by individual characteristics and longer time-varying covariates, such as seasonal effects, by design. The control periods were defined as the same days of week within the same month and year as the day of snakebite (20).

Conditional logistic regression was applied to estimate the association between meteorological parameters and snakebites. In addition, we stratified our analysis by regions and by seasons (hot seasons [summer and spring] vs. cold seasons [winter and autumn]). Analyses were performed using SPSS 23.0 software (IBM, Armonk, NY). A p value < 0.05 was considered statistically significant, and results are reported as odds ratios (ORs) and 95% confidence intervals (CIs), associated with heat waves, daily average temperatures >23°C or >20°C, and daily average relative humidity >40%.

RESULTS

Seasonality

We identified 1234 snakebite cases over the course of 8 years (2008–2015). Of these, 55.4% occurred in summer, 18.8% occurred in the 61-day spring, 18.6% occurred in the 75-day autumn, and 7.2% occurred during the 16 weeks of winter. The interquartile range of daily mean temperature ranged between 25.3°C and 27.9°C in the summer and between 14.5°C and 21.7°C during the rest of the year. Relative humidity was higher in the summer, with an interquartile range of 64% to 76%, compared to 54% to 76% in other seasons (Table 1).

Figure 2 shows the monthly rate of snakebites and the monthly average values of both temperature and relative humidity. Snakebites were mostly frequent between June (15%) and September (14%) and were relatively rare in January (1%) and February (1.2%) (Figure 3).

Timing and Geography

When mapping the cases by time of the event, we found that most snakebites occurred between 6 and 9 PM (Figure 3). Considering the geographic distribution of all snakebites, most snakebites occurred in the Central (47%) and Northern (42%) regions, followed by the Southern region (11%) (Table 1, Figure 4).

Climate

We conducted a case crossover analysis to evaluate the association between snakebites and meteorological parameters. In the multivariate analysis, the risk of snakebite was positively associated with daily average temperature >23°C (OR 1.24, 95% CI 1.00–1.53) and heat waves (OR 1.24, 95% CI 1.00–1.54) and negatively associated with daily average humidity >40% (OR 0.74, 95% CI 0.57–0.97) (Table 2, Figure 2).

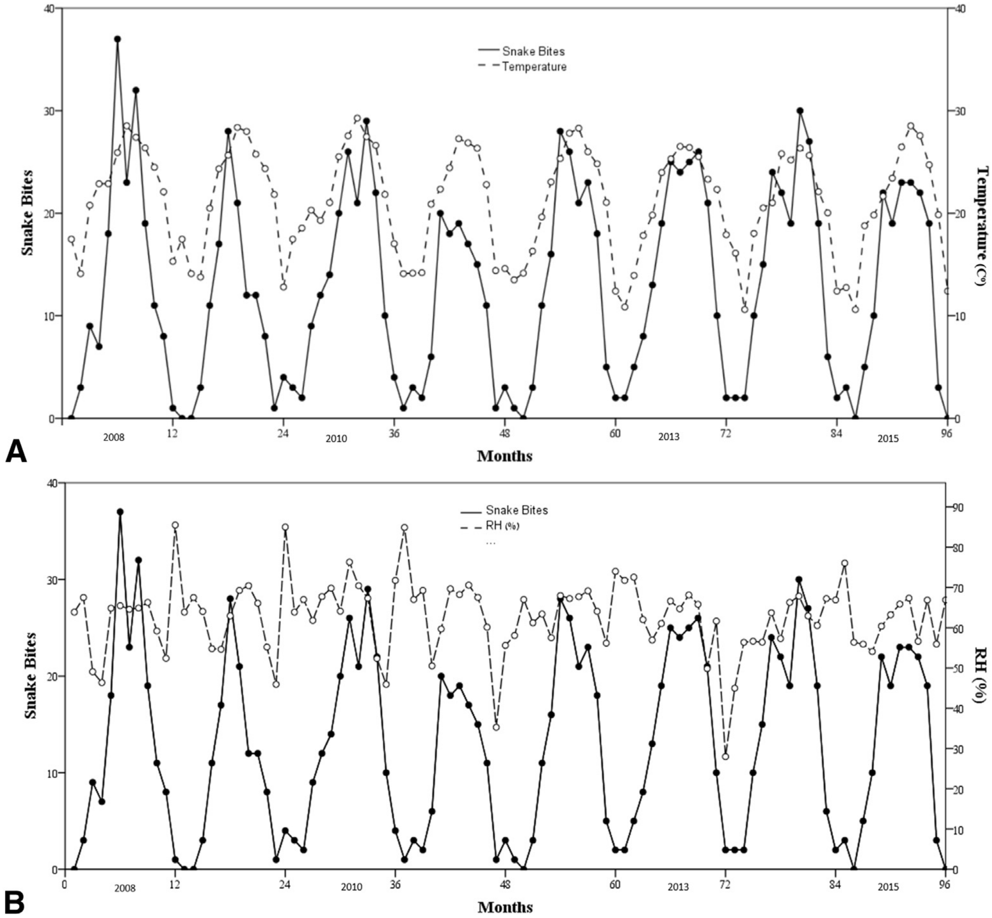

Figure 2. Monthly snakebite rate and monthly temperature/relative humidity (RH) average. The association between snakebite cases and average concentrations of (A) temperature and (B) RH per month during the 8 years of study. The solid line represents the total snakebite cases per month and the dashed line represents the temperature/RH.

Stratified Analysis

We repeated our model in stratification by season and region to assess possible effect modification. In both seasons, the risk of snakebite was significantly associated with heat waves. However, in cold seasons snakebites were also associated with temperatures >20°C (OR 2.11, 95% CI 1.54–3.29) and in hot seasons with humidity >40% (OR 0.66, 95% CI 0.48–0.91) (Table 3).

In stratification by region, in the South region snakebites were associated with temperatures >23°C (OR 1.91, 95% CI 1.03–3.52) compared with humidity >40% and heat waves in the Central and Northern regions ([OR 0.75, 95% CI 0.56–1.00] and [OR 1.26, 95% CI 1.01–1.58] respectively) (Table 3).

DISCUSSION

In this case-crossover study, we have shown a higher risk of snakebites associated with daily average temperatures >23°C on the day of the event and inversely associated with daily average humidity >40%. In addition, we found a positive association with heat waves in all seasons and with humidity in hot seasons. Moreover, we demonstrated differences between geographic regions regarding the meteorological parameters affecting snakebites—temperature in the Southern region vs. humidity and heatwaves in the Central and Northern regions.

In the current analysis, we found that the peak of the snakebites occurred at evening to nighttime (6–9 PM) and during hot and dry seasons (May–October). A majority of the cases occurred in the Northern and Central regions (89%) and a minority occurred in the Southern semiarid region (11%).

Seasonality and Snakebites

An early attempt to review the worldwide epidemiology of snakebites was reported in 1954 (21). Since then, epidemiologic studies worldwide have demonstrated that most snakebites occur in high temperatures and hot seasons, rainy seasons, and at evening to

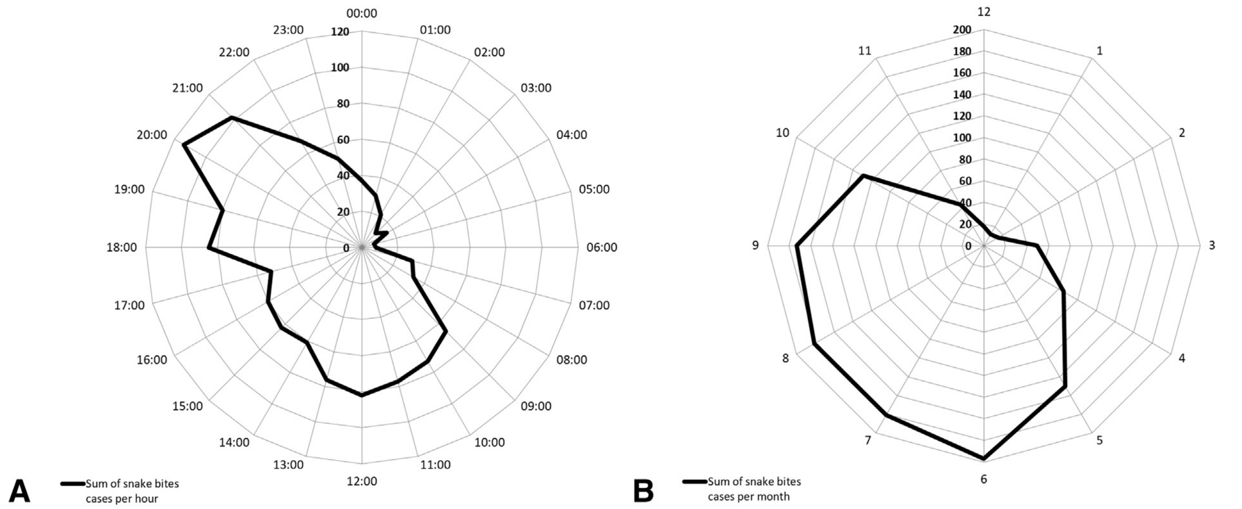

Figure 3. (A) Hourly and (B) monthly distribution of snakebites. The line represents the total of snakebite cases per month or hour during the 8 years of study.

nighttime (1,6–15,22). These results show that snakebites follow meteorological changes with a predilection for hot temperatures. Snakes are poikilothermic (“cold-blooded”), and their body temperature changes according to the animal’s surroundings. Therefore, snakes are almost completely inactive during the winter months and the hot summer days, while seeking their prey during the cooler summer nights (6).

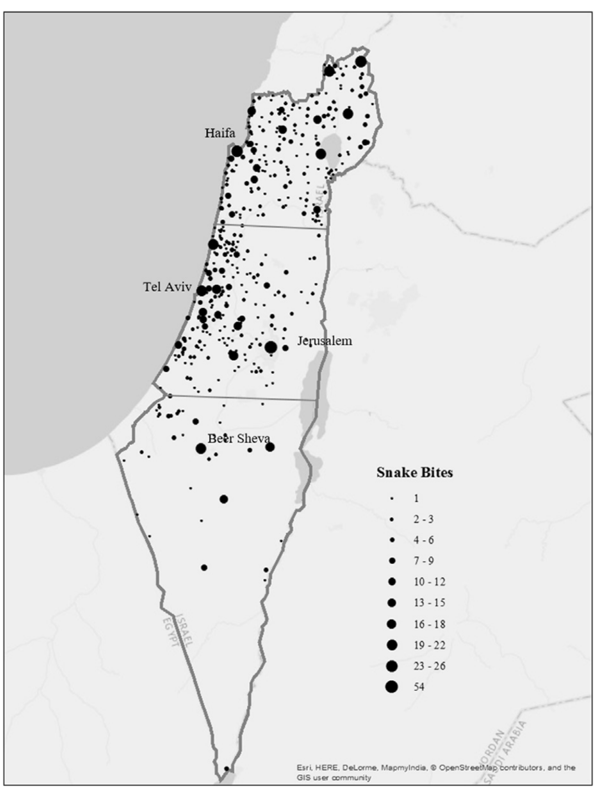

Figure 4. Geographical map of snakebites in Israel during the 8 years of study in 3 areas of Israel: Northern, Southern, and Central. Each dot size shows the corresponding number of snakebites.

Unlike the majority of studies, we found a minority of snakebites in rainy seasons. This difference in findings can be explained by the difference in climate; in tropical climates, characterized by hot constant temperatures, snakes’ activity is enabled despite the rain. However, in Israel, characterized with temperature variability of the Mediterranean climate, snakes’ activity is not possible in rainy seasons characterized by relatively low temperatures.

Similar to the current study, a recent study in Costa Rica, a country with a tropical climate, showed a negative association between snakebite frequency and rainfall (5). Costa Rica is characterized with a unique climate of hot and cold phases caused by the El Niño phenomenon, and therefore it can be considered distinct from other tropical climates. The similarity with our Mediterranean climate findings is plausible.

Meteorological Parameter Effects on Snakebites

Similar to the Costa Rica study, snakebites were associated with higher temperatures (5). However, in addition, we investigated an association between humidity and heat waves. We found a positive association of snakebites with heat waves in all seasons and a negative association with humidity in hot seasons. These findings strengthen the understanding that temperature is the principal meteorological parameter influencing snakebites in all seasons, and that humidity may also play a role in hot seasons.

Table 2. Association Between Meteorological Parameters and Snakebite Rate: Case-Crossover Results

Multivariate Model		Univariate Models		
OR (CI)	*p* Value	OR (CI)	*p* Value	
1.24 (1.003–1.53)	0.05	1.88 (1.05–3.37)	0.03	Temperature >23°C
0.74 (0.57–0.97)	0.03	0.72 (0.35–1.49)	0.38	Relative humidity >40%
1.24 (1.00–1.54)	0.05	1.36 (0.71–2.6)	0.35	Heat wave*

CI = confidence interval; OR = odds ratio.
* A threshold above the 80th percentile temperature for 2 consecutive days.

Snakebites in Israel

The distribution of snakebites mostly in the Northern and Central regions (89%) is compatible with the portion of the Israeli population living there (86%) (23). However, a study of poisonous animal bites in the Israel Defense Forces between 1993 and 1997 demonstrated more cases southern to Beer Sheva (33% vs. 11%) (6). The small portion of cases in the South in our study can be explained either by differences in the populations (civilians vs. army), or by the length of the analysis period (8 years vs. 1 year). Yet it appears that there is an increase of *V. palastinae* bites in Israel.

In addition to the seasonal distribution analysis, we investigated the association of snakebites with meteorological parameters stratified by region: humidity and heat waves in the Central and Northern regions compared with temperature in the Southern region. The difference between regions can be explained either by the variation in climate characteristics between the regions (hot, dry climate in the south), or by the unique characteristics of the snake species located in it, which influences their activity pattern.

Limitations

Our study has 2 main limitations. First, MDA is not evacuating 100% of the affected individuals—MDA treated 154 snakebite cases in 2012 compared to the 184 cases reported by the Israel Poison Information Center (4). Evacuation can be conducted independently by the patient or by the Israel Defense Forces. Thus, from these data we can estimate that non-MDA–evacuated cases constitute approximately one-fifth of all snakebites. Yet, because MDA is the sole emergency medical service provider in Israel and because our study covers a long period of time, we believe that we have described a representative data of the Israel population. Second, we do not have individual-level data pertaining to each patient's unique individual characteristics, their individual clinical presentation, or the identity of the species that caused each of the individual envenomations. Nevertheless, from the previous reports we can conclude that most of the bites are by *V. palastinae* and of mild to moderate severity.

This study also has 2 main strengths. First, it is based on accurate timing and geographic locations of

Table 3. Association Between Temperature, Relative Humidity, Heat Waves, and Snakebite Rate Stratified by Seasons and Regions: Case-Crossover Results, Multivariate Models

Seasons					
Cold Seasons			Hot Seasons		
OR (CI)	*p* Value		OR (CI)	*p* Value	
2.11 (1.36–3.29)	0.001	Temperature >20°C	1.15 (0.90–1.47)	0.28	Temperature >23°C
1.06 (0.65–1.74)	0.82	Relative humidity >40%	0.66 (0.48–0.91)	0.01	Relative humidity >40%
1.62 (1.01–2.60)	0.05	Heat wave (>80th percentile)	1.50 (1.18–1.92)	0.001	Heat wave (>85th percentile)*
Regions					
South			Center and North		
OR (CI)	*p* Value		OR (CI)	*p* Value	
1.91 (1.03–3.52)	0.039	Temperature >23°C	1.17 (0.93–1.47)	0.17	Temperature >23°C
0.66 (0.31–1.41)	0.283	Relative humidity >40%	0.75 (0.56–1.00)	0.05	Relative humidity >40%
1.02 (0.51–2.0)	0.96	Heat wave (>80th percentile)	1.26 (1.01–1.58)	0.05	Heat wave (>80th percentile)

CI = confidence interval; OR = odds ratio.
* A threshold above the 80th or 85th percentile temperature for 2 consecutive days.

snakebites. Second, our study includes a large national sample over a period of 8 years.

CONCLUSION

In a semiarid nontropical climate, we observed an association between an increase in snakebite cases and higher temperatures and lower humidity. Moreover, heat waves increase snakebites frequency both in cold and hot seasons.

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ARTICLE SUMMARY

1. Why is this topic important?

This topic is important because the worldwide human death toll caused by snakebites exceeds 100,000 annually. Many of these patients never reach medical treatment, but for those who do, it is useful for emergency physicians to understand the circumstances under which snakebites are more likely. In addition, there exists a demonstrable association of snakebites in our arid, generally warm environment with certain meteorological conditions. From public health and emergency readiness perspectives, nations and their health organizations can use data such as ours guide their citizens and medical caregivers toward attempts to minimize or prevent exposures to snake envenomations and their consequences.

2. What does this study attempt to show?

In the current study, we sought to investigate the seasonality of snakebites and evaluate the association between snakebite frequency and meteorological parameters, including common heat waves, in the semiarid nontropical climate of Israel.

3. What are the key findings?

In a semiarid nontropical climate, we observed an association between an increase in snakebite cases and higher temperatures and lower humidity. Moreover, heat waves increase snakebites frequency both in cold and hot seasons.

4. How is patient care impacted?

In countries with nontropical climates, health organizations and individuals can prepare themselves for an increased risk of snakebites during heat waves (days with an average daily temperature >80th percentile temperature during 2 consecutive days), during days of higher daily average temperatures (days with average temperature >23°C), and during days of low humidity (daily average humidity <40%).