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Modelling the scorpion stings using surveillance data in El Bayadh Province, Algeria

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ABSTRACT

Objective: To examine some epidemiological features of scorpion envenomations, analyse and interpret the recorded data, find any relationship between the incidence of scorpion stings and climatic factors, and finally develop a statistical model to estimate the variability among future cases in El Bayadh Province, Algeria.
Methods: To assess the effects of climate variability on the scorpion envenomations, we applied the count data regression models to the monthly recorded scorpion stings in El Bayadh Province from 2001 to 2012.
Results: The epidemiological analysis of data revealed that scorpion stings occured mainly in rural areas, round the clock, all year long with the highest seasonal incidence in summer, and the lowest in winter, all ages with male predominance. The ends of upper and lower limbs were the most affected parts of the human body. The majority of cases (95.7%) were classified as mild envenomations and systemic toxicity was observed in 4.3% of cases. The use of count data regression models showed that the negative binomial regression was appropriate to forecast cases and the fitted data agreed considerably with the actual data. Moreover, the model had predicted the monthly scorpion sting cases for the year of 2013, with satisfactory accuracy.
Conclusions: This study shows an optimism for forecasting scorpion stings by modelling and calibration with surveillance data and climate information. This knowledge could help to contain any unusual situation and assist health decision-makers to strengthen the prevention and control measures and to be in a state of readiness.

1. Introduction

Scorpionism is an actual public health problem, at various levels, in North-Saharan and South and East Africa, Middle-East, South India, Brazil, Mexico and Amazonian basin. The scorpions mainly predominate in arid, semi-arid or Saharan areas of the world in a band not exceeding 50° latitude, both south and north, and their distribution is dependent on a number of factors including climatic and environmental factors. Even though scorpionism is geographically limited, the world's population at risk of scorpion envenomations is almost two and a half billion people. It is noteworthy that epidemiological data remain scanty due to the under-reporting in many affected regions in the world. The human, scorpion, climate and environment are the main factors that determine the epidemiology of scorpion envenomations. Human have a great responsibility in scorpion accidents through negligence, ignorance or both. People offer to scorpion a supportive environment by building directly on top of scorpion shelters without land reclamation creating ideal habitats near houses. Moreover, human contributes to the reduction of cannibalism and to the proliferation of scorpions. Indeed, the detritus is littered in the streets and public spaces, thereby promoting cockroach outbreaks, flies and other arthropods, providing abundant preferred preys to scorpions. The risk exists in both urban and rural areas and is significantly higher in rural areas[1].

By its vast geographical scope and the diversity of its climate and its ecosystems, Algeria possesses a diverse fauna of scorpions and is seriously affected by scorpionism. More than 28 species are catalogued for the country. The four dangerous scorpion species to humans are *Androctonus australis* identified in the southern highlands and Saharan Atlas, *Buthus tunetanus* identified in septentrional edge of the Sahara, *Androctonus aeneas* identified in the highlands and Saharan Atlas, and *Androctonus crassicauda* identified in Tindouf. Regarding the north of the

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country, the scorpion fauna research is non-existent[2]. The scorpion envenomation was recognized in the mid-80s as a public health problem because of the morbidity and mortality it causes and the financial burden it imposes. Since the launch of the national committee against the scorpion envenomations in 1986, several initiatives were undertaken to address this issue. The recording of sting cases, therapeutic care and death investigations are the main undertaken actions. The epidemiological investigations in 2012 revealed that 81% of the provinces are concerned by the accidents of scorpion stings leading to an estimated at risk population of 74% of the country's population. The Sahara and Highlands are the most affected regions of the country and 90% of stung patients and all deaths occurred in these regions. For the period of 2001–2012, the mean incidence was 152 scorpion stings per 100 000 population and the mean mortality was 0.23 per 100 000 population. The incidence scorpion stings remains lowest in the Northern provinces with less than 7 scorpion stings per 100 000 population and highest in the Southern provinces with more than 1 000 scorpion stings per 100 000 population[3].

The identification of the scorpion fauna and the classification of the epidemiological features of scorpion stings have been undertaken in several endemic regions, such as Algeria, Brazil, Iran, Mali, Mexico, Morocco, Nigeria, Saudi Arabia, Turkey[4-15].

The present study aims to examine the epidemiological features of scorpion envenomations as well as the identification of any association between the incidence of scorpion stings and climatological variables, and ultimately to provide the best regression model to estimate the variability among future sting cases in El Bayadh, one of the endemic provinces in Algeria for the scorpion envenomations.

2. Materials and methods

2.1. Scorpions

Scorpions are venomous arthropod animals affiliated to the class Arachnida. They sting, usually when they are disturbed inadvertently, yet their natural tendencies are to hide and escape[2]. They use their venom for both prey capture and defence. The scorpion has the ability to control the venom flow and the existence of scorpion sting with mild envenomation, or even, without the inoculation of venom has been established in several studies. The stings by a dangerous scorpion species can be life-threatening, especially for children and older individuals[1].

2.2. The study region

El Bayadh Province is located west of Algeria, at 33°40′49″ N and 1°01′13″ E. As 2012, the province accommodated an estimated population of 291 600. The province consists of three distinct zones: high plains, near Saharan and Saharan Atlas. Climatologically, the province is characterised by two main periods, a harsh winter with frequent snowfalls and a hot and dry summer.

2.3. Data

The study data included the epidemiological data and meteorological data. The climate variables possessed great influence on the scorpion distribution and activity[16].

The monthly recorded scorpion sting cases between January 2001 and December 2013 in El Bayadh's Province were used in statistical modelling, the breakdown by gender, by anatomical sting site, by age group, by place, and by time slot used in the epidemiological survey for the year of 2012, as well as the monthly recorded scorpion sting cases for the 22 municipalities that maked up the province were provided by El Bayadh's Department of Public Health.

Monthly mean, maximum, and minimum temperature, monthly mean relative humidity (RH), the monthly precipitation amount and monthly mean wind speed (km/h) were gained from the website (http://en.tutiempo.net/climate/ws-605500.html) which compiles and stores data from meteorological stations around the world[17].

2.4. Modelling method

Count data are common in many fields, particularly, in health and in epidemiology. The number of disease cases ranks among common examples. Poisson and negative binomial regression models is amongst the mathematical models intended to analyse these kinds of data. The Poisson model is the most commonly used model when it comes to count events arising within a specific period. One of the key features of the Poisson model is that the variance equals the mean. However, with real life data, the equality between the mean and the variance does not always occur. In most cases, the observed variance is larger than the assumed one, which is known as overdispersion. If the overdispersion is ignored, statistical inference results in an inaccurate conclusion by underestimating the variability of the data. Poisson regression can be adjusted to correct for a modest overdispersion of data, leading to a scaled Poisson model. An alternative method and often preferred solution is the negative binomial regression and such method adjusts the overdispersion[18-20].

2.4.1. Poisson model

The basic count model used to associate a count variable with one or more explanatory predictors is the Poisson regression model. The counts in the response variable are to be understood by virtue of one or more predictors. In Poisson regression, we suppose that the number of occurrences of an event (Y) had a Poisson distribution given the independent variables $X_1, X_2, \ldots, X_m$:

$$P(Y = a \mid X_1, X_2, \ldots, X_m) = \frac{e^{-\mu}\mu^a}{a!}, \qquad a = 0,1,2,\ldots$$

where the log of the mean (μ) is supposed to be a linear function of the independent variables

$$\log(\mu) = \alpha + \beta_1 X_1 + \ldots + \beta_m X_m$$

The parameters are estimated using the maximum likelihood method[18,20].

2.4.2. Scaled Poisson model

A dispersion parameter is added to the Poisson variance to correct for overdispersion, thus scalling the Poisson model. This technique provides an appropriate inference only for modest overdispersion. The dispersion parameter is estimated by deviance or Pearson's χ^2 test statistic divided by its degree of freedom from the fitted model. The variance in a scaled Poisson model is of the form:

$$Var(Y) = k\mu$$

The model was fitted as in Poisson model and the estimated variance was inflated to adjust for overdispersion, while the parameter estimates were not affected by the value of k[18,20].

2.4.3. Negative binomial model

Another count data model to correct for overdispersion in the data is negative binomial model. A multiplicative random effect is added to the Poisson regression model to represent unobserved heterogeneity. The relationship between the mean and the variance is of the form:

$$Var(Y) = \mu + k\mu^2$$

where the negative binomial dispersion parameter k is estimated by maximum likelihood[18,19].

2.4.4. Incidence and relative risk

We applied the estimated coefficients to compute the increase in the number of scorpion sting cases, the relative risk with the confidence interval (*CI*) and the probability using the following equations:

Incidence (%) = 100 × (*exp* (*βX*) – 1) (1)

Relative risk = *exp* (*βX*) (2)

$Cl_{95\%} = exp(\beta \pm 1.96\ se(\beta))$ (3)

where *se*(*β*) is the SE of *β*

$$\text{Probability (\%)} = \frac{1}{1 + exp(-(\alpha + \beta X))} \quad (4)$$

All analyses were performed using SPSS 17 software.

3. Results

For the period of 2001–2012, a total of 18 565 scorpion sting accidents, including 51 deaths, have been recorded from El Bayadh Province. The estimated incidence of scorpion stings in this province was 709 per 100 000 population. The yearly data were plotted in Figure 1. The lethality is the ratio between the number of deaths attributed to scorpion envenomations and the number scorpion stings during the same period and expressed in percentage. The highest yearly number of scorpion stings occurred in 2001 (1 933 cases), in 2009 (1 799 cases), and in 2012 (1 795 cases) and the highest number of deaths by envenomation was also reported for those years with 14 deaths in 2001, 10 deaths in 2009, and 6 deaths in 2012. Among the 51 recorded deaths, 32 occurred in August, and 9 in July, and 5 in June, which accountted for 90.2% of deaths that occurred in the summer.

3.1. Geographical distribution of scorpion envenomations

The population data for each municipality were provided by National Office of Statistics. The geographical distribution of scorpion sting incidence per 100 000 population for the year of 2012 was mapped using MapInfo version 8.6 (Figure 2). Half of the cases occurred in four municipalities, namely, El Abiodh Sidi Cheikh (18.5%), El Bayadh (11.3%), Bougtoub (11.3%) and El Kheither (9.5%). The number of scorpion stings by municipality was seen to be highly correlated with the size of the population of 21 of the 22 municipalities (r = 0.914) and El Bayadh municipality was considered as an outlier due to high population density (235 hab./km^2) while for the other municipalities, it varied between 0.2 and 26.5 hab./km^2.

3.2. Epidemiological analysis

The breakdown of the scorpion sting cases by the gender, by anatomical sting site, by age group, by place and by the time slot were established from the analysis of designed questionnaires for stung patients for the year of 2012 supplied by El Bayadh's Department of Public Health. The analysis revealed that the most affected human body areas were the ends of upper limbs with 51.9% of cases followed by the ends of lower limbs with 39.8% of cases (Figure 3A). The 15–49 years age group was the most affected with 62% of stung people followed by less than 14 years old children with 24% of cases (Figure 3B). Of the 1 795 recorded scorpion stings, 970 (54%) were males and 825 (46%) were females, namely, a male-female ratio of 1.2. In 2012, 65% of sting cases occurred within the dwellings of which 54% were women while outside the dwellings, men were most exposed with 62% of stung cases (Figure 3C). More than half of recorded scorpion sting cases (54.7%) occurred between 6 pm and 6 am, and roughly the same percentage of cases for the two other time slots, more precisely, 22.8% occurred between 6 am and 12 pm and 22.5% occurred between 12 pm and 6 pm (Figure 3D). Clinical manifestations of scorpion envenomation fell into three grades, namely, Grade I for local pains, Grade II for mild systemic symptoms and Grade III

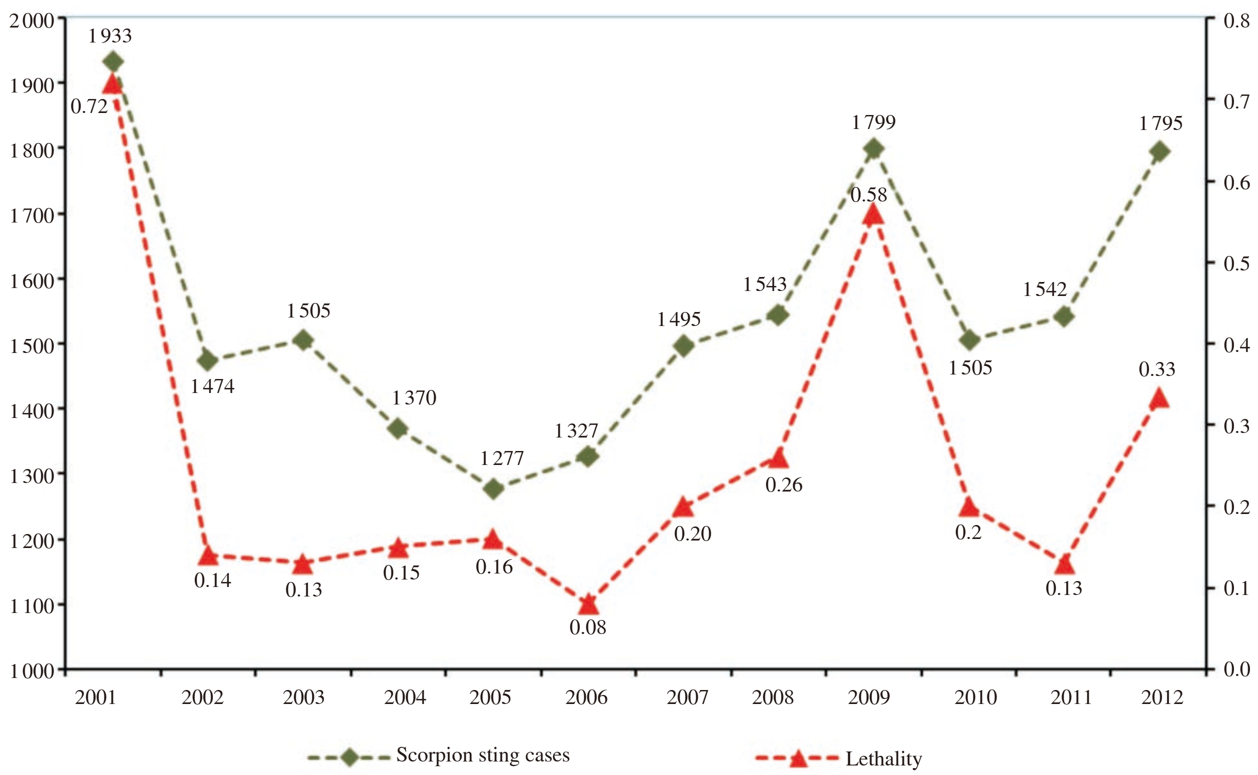

Figure 1. Yearly evolution of recorded scorpion sting cases and lethality in El Bayadh Province.

for life-threatening envenoming. For the year of 2012, the majority of cases (95.7%) were classified as mild, 3.2% of cases were classified as moderate and 1.1% of cases were classified as severe. A total number of 1 504 antivenom vials were used and a stung patient who visited the health facility 6 h after the accident and showed no clinical symptoms, did not receive neither the antivenom vial, nor care.

3.3. Statistical analysis

3.3.1. Descriptive statistics and time series analysis

The scorpion sting cases were strongly positively correlated with temperature (r = 0.908 Pearson product-moment correlation coefficient). Moreover, the scatter plot between the sting cases and temperature showed a quadratic relationship (Figure 4). The scorpion

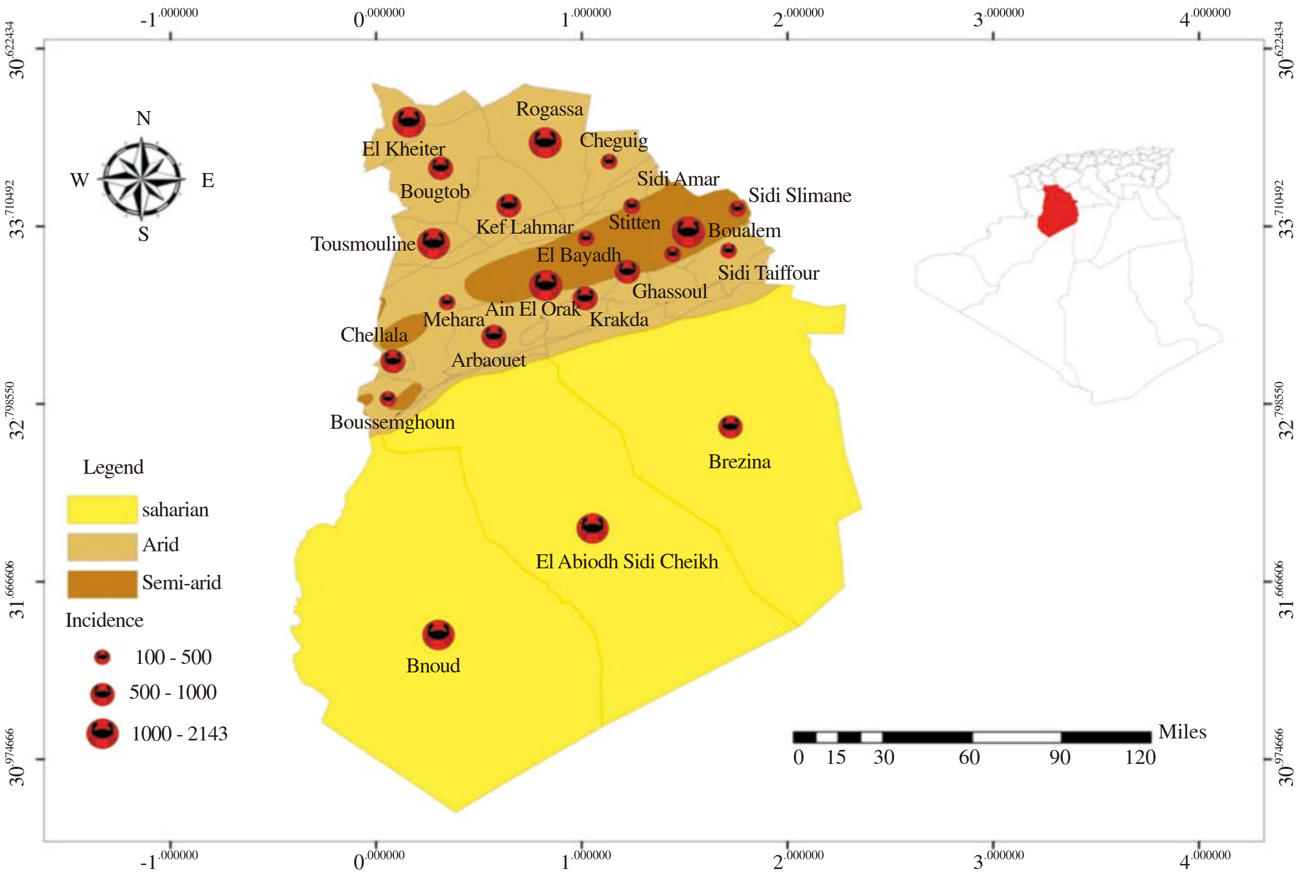

Figure 2. Geographical distribution of the incidence of scorpion stings in El Bayadh Province.

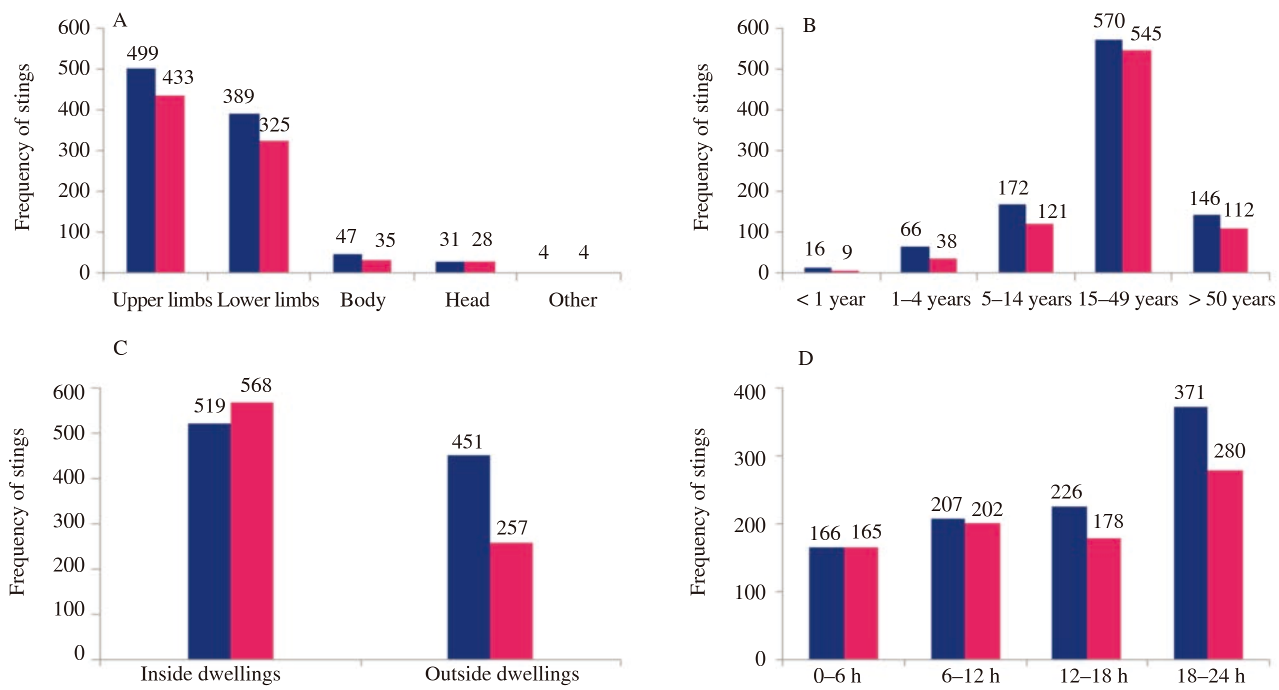

Figure 3. Envenomed patients classified by sex.

Blue bars: The number of stung men; Pink bars: The number of stung women; A: Anatomical site sting; B: Age group; C: Locations; D: sting hours.

sting cases were highly negatively correlated with RH (r = 0.797) while the correlation with precipitation was weak (r = 0.227) and non-significant with wind speed (r = 0.091).

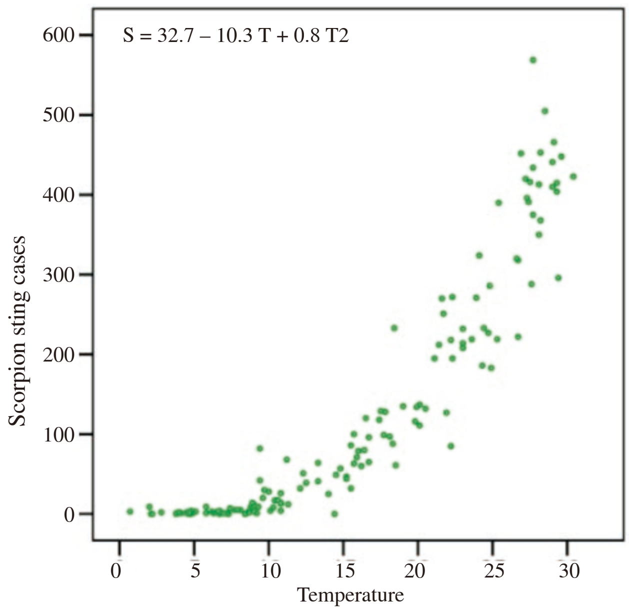

Figure 4. Scatter plot of monthly scorpion sting cases and temperature from 2001 to 2012.

The stings were observed throughout the year and 67.9% of cases occurred in the summer (Figure 5B). The box and whisker plot (Figure 5A) showed the total monthly average number of recorded scorpion sting cases. The monthly peaks were observed in the summer months, more precisely, in August with 26.8% of cases and in July with 25.7%, which represented more than half of sting cases. A similar percentage was observed in June (15.2%) and in September (14.7%). The monthly maximum reported scorpion sting cases occurred in 2009 in August (569 cases) and in July (466 cases), and in 2001 in June (415 cases) and in September (324 cases) and in November (82 cases), and in 2012 in February (9 cases) and in March (42 cases) and in October (120 cases) and in December (9 cases). The scorpion stings were spread between April and October, matching the dry period of the province, and picks were observed in July and August the driest months in the year, corroborating thus the conclusions made about the relationship between the scorpion sting incidence and dry and hot climate in other affected parts of the world.

Figure 6 shows the time series of the monthly scorpion sting cases and climatological variables. Scorpion sting cases followed the same trend as temperature and the reverse trend with the RH. The highest monthly accumulated precipitation were recorded in October 2003 with 179 mm and in October 2008 with 175 mm and the recorded scorpion sting cases were respectively 96 and 25 cases (average number being 81 cases in October). Hence, the scorpion sting incidence was independent of precipitation amount.

3.3.2. Regression models

We used generalized linear models in SPSS to fit a Poisson, scaled Poisson, and negative binomial regression model respectively, to scorpion sting cases as the dependent variable and the maxT, RH and trend as the independent variables. The trend variable was incorporated into the model to account for other factors that could influence the scorpion stings such as human behaviour and degradation of the environment. Precipitation and wind speed variables were excluded from the final model. They were firstly incorporated into the model and showed an insignificant contribution. Besides they did not improve the statistical model output. We used the Pearson *Chi*-squared method to estimate the scale parameter for the scaled Poisson model by specifying the scale χ^2 of Pearson option in SPSS. Tables 1 and 2 summarise the outputs of the Poisson, scaled Poisson and negative binomial regression models. The output interpretations were similar across for the three mentioned count regression models. Model parameters revealed the same information for the three regression models. Consequently, the discussions that followed will relate to the findings of the three regression models. The influence of the independent variables on the dependent variable was ascertained by the regression coefficients, displayed in Table 2. The statistical significance of the coefficients was indicated by the P value and was below the standard threshold of 0.05 for at least half of the coefficients for the three models, meaning that the findings were statistically significant.

The associations between scorpion sting cases, MaxT, and RH were significant. The estimated dispersion parameter in the Poisson model implied overdispersion with 13.75. For the scaled Poisson model, the parameter estimates did not change, but their standard errors were inflated by the value of the scale parameter and the resulting P values for MaxT and RH were still significant. The dispersion parameter (0.973) for the negative binomial model was close to 1 and the result showed that only the intercept, MaxT and $MaxT^2$ were significantly

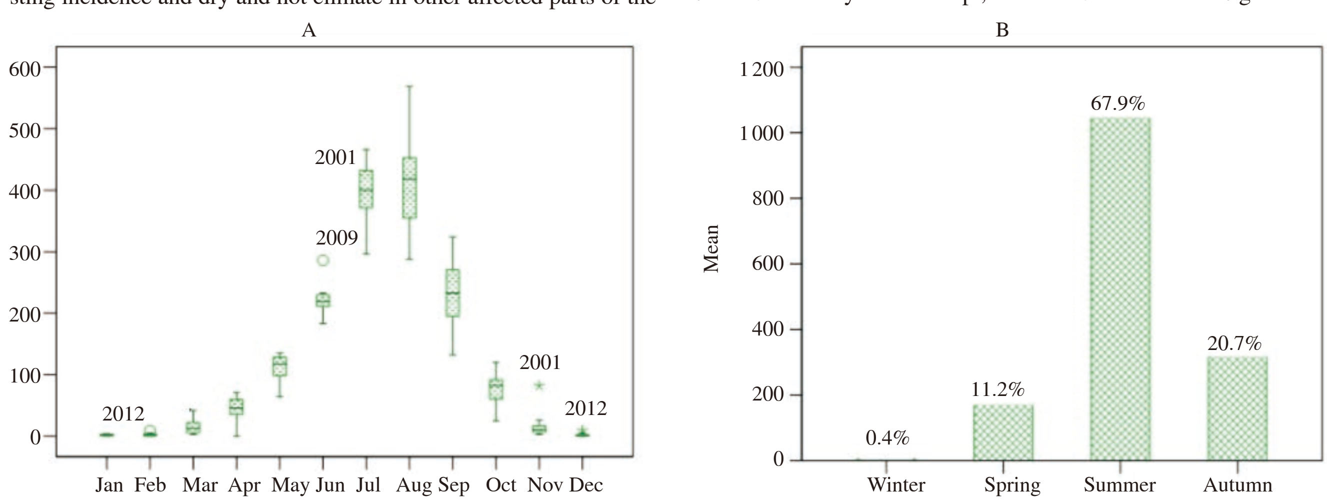

Figure 5. Monthly and seasonal evolution of recorded scorpion sting cases in El Bayadh Province from January 2001 to December 2012.
A: Box and whisker plot of monthly scorpion stings; B: Seasonal distribution of scorpion stings. The box represented the 25th and 75th percentiles. The median was represented by a solid horizontal line. The whiskers showed the 1st percentile to 99th percentile. Values lower than the first and greater than the 99th percentile were displayed in the graph in years.

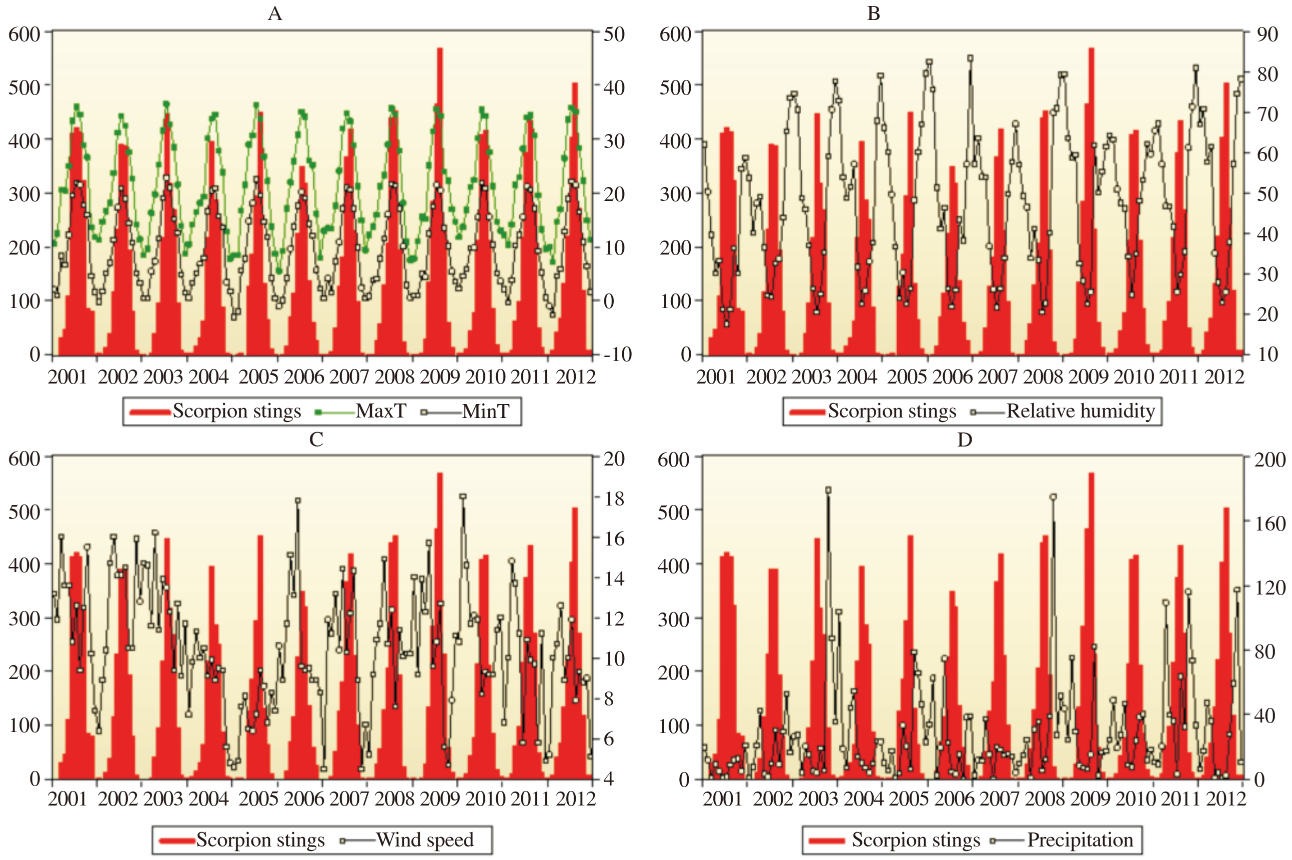

Figure 6. Time series of the monthly recorded scorpion sting cases in El Bayadh's Province in the period of 2001–2012.
A: With the monthly average of the maximum (solid line) and minimum (dotted line) temperature; B: With monthly average RH (solid line); C: With monthly mean wind speed (solid line); D: With monthly accumulated precipitation (solid line).

Table 1

The outputs of the Poisson, scaled Poisson and negative binomial regression models.

Indicators	Poisson			Scaled Poisson			Negative binomial		
	Value	*df*	Disp	Value	*df*	Disp	Value	*df*	Disp
Deviance	1594.86	139	11.47	1594.86	139	15.42	78.67	139	0.56
Scaled deviance				115.99	139	0.83			
Pearson χ^2	1911.31	139	13.75	1911.31	139	13.75	135.25	139	0.97
Scaled Pearson χ^2				139.00	139	1.00			
Log-likelihood	-1174.58			-1174.58			-685.62		
Adjusted log-likelihood				-85.42					
AIC	2359.15			2359.15			1381.24		

Disp = Value/*df*; AIC: Akaike's information criterion (smaller was better).

associated with the dependent variable. The comparison between the log-likelihood for the negative binomial regression and for the Poisson regression indicated that the negative binomial regression offered an improvement over the Poisson regression. Moreover, the AIC value was lower than the AIC values estimated in Poisson model and scaled Poisson model, allowing us to conclude that the negative binomial was the best model.

The estimated coefficients by the Negative Binomial model and displayed in Table 2, were applied to equations (1–4) to compute the number of scorpion stings, the relative risk with *CI*. Because it is the log of the mean that was modelled by the count regression techniques, the coefficients had the following interpretation: for one unit change in an independent variable, the log of the dependent variable was expected to change by the value of the regression coefficient. The relative risk

Table 2

Estimated coefficients by the Poisson, scaled Poisson and negative binomial regression models.

Indicators	Poisson			Scaled Poisson			Negative binomial		
	Coef.	SE	*P* value	Coef.	SE	*P* value	Coef.	SE	*P* value
Intercept	–3.977	0.2017	0.000	–3.977	0.7480	0.000	–3.902	1.3958	0.005
MaxT	0.446	0.0114	0.000	0.446	0.0424	0.000	0.471	0.0676	0.000
MaxT^2	–0.005	0.0002	0.000	–0.005	0.0008	0.000	–0.006	0.0013	0.000
RH	0.018	0.0017	0.000	0.018	0.0061	0.003	0.010	0.0147	0.475
Trend^2	1.56E-06	1.27E-06	0.219	1.56E-06	4.69E-06	0.740	1.63E-06	1.44E-06	0.257
Scale	1.000			13.750			1.000		

Coef.: The estimated parameter.

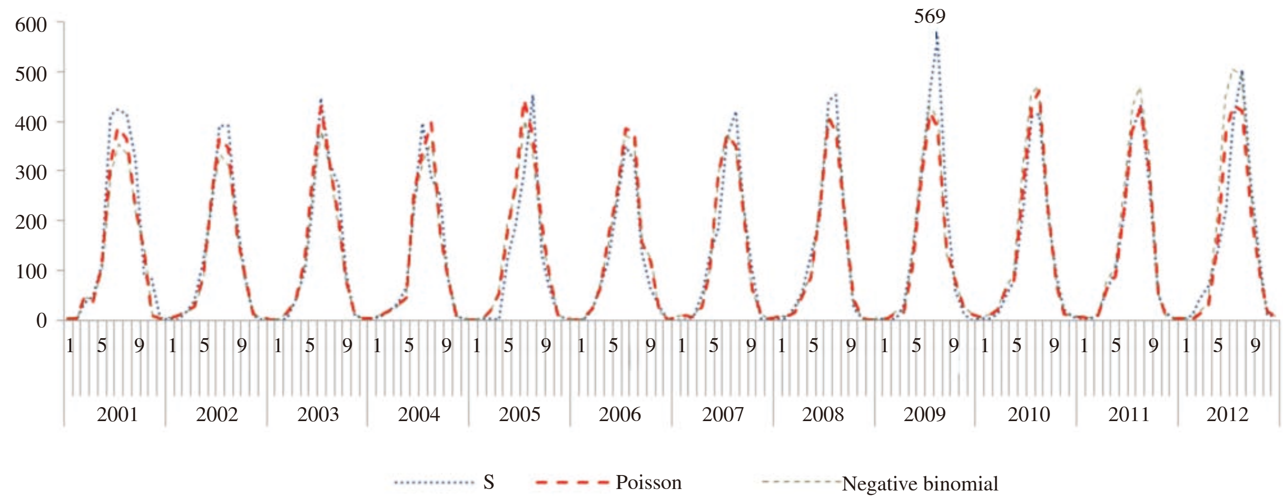

Figure 7. Fitted versus recorded scorpion sting cases.

was calculated to determine how the occurrence of scorpion sting cases was related to the influence of ManT and RH. With a variation in MaxT of 1–10 °C, the increase risk of occurrence of the scorpion stings would be from 1.60–110.71 with a *CI* 95%, 1.40:9.62 and with a variation in RH of 2%–20%, the increase risk of occurrence of the scorpion stings would be from 1.02–1.23 with a *CI* 95%, 0.96:0.98.

In Figure 7, the actual scorpion sting cases versus the fitted ones, generated by Poisson model and negative binomial model, were plotted and the simulated scorpion sting cases were closely approximated to the recorded cases except for August 2009 which was considered an outlier. The correlation between the recorded and simulated cases using negative binomial regression is very strong ($r = 0.96$).

The number of scorpion stings for the year of 2013 was predicted using temperature and RH condition in 2013[17]. The actual sting cases and the predicted ones were plotted in Figure 8 and the correlation between them was very strong ($r = 0.99$).

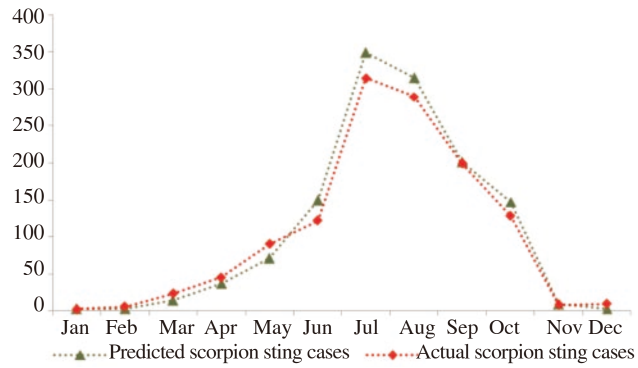

Figure 8. Predicted versus recorded scorpion sting cases for the year of 2013.

4. Discussion

El Bayadh Province is facing to scorpionism and ranks among endemic provinces that record annually a high number of scorpion stings and a high lethality percentage. The public health authorities of the province should reinforce the surveillance data system by the integration of forecasting models, which will help in devising appropriate strategies to manage the scorpion accidents.

The epidemiological analysis shows that scorpions sting around the clock with peaks occurring in the time slot 6 pm-midnight, corresponding to an activity period of the population in this region. They sting all year long with monthly peaks in July and in August, corresponding to the warmest and the driest months of the year. The age group of 15–49 years, which represents the active population, was the most affected with 62% of cases followed by children less than 14 years old with 24% of cases. The ends of the upper limbs and lower limbs were the most often affected parts of the human body and they represented 91.7% of reported cases. Consequently, humans bear significant responsibility for scorpion accidents through their negligence or ignorance or by both, and the high incidence, largely, is incumbent upon them. The vast majority of stung people did not present complications. They received one antivenom vial and were kept under supervision for 6 h in health services. Even though the awareness campaigns organized regularly have contributed significantly in improving the time between the sting and the first medical consultation, however, these campaigns have proved to be limited in the prevention against scorpion sting accidents and the frequency of events remains high. It is recommended going beyond mere information campaigns, and finds effective ways to involve the population in the consultations and decision making related to this issue and this over the long term.

Important elements in any health surveillance system are the data analysis, data interpretation and ultimately prediction. The integration of forecasting methods into a passive system of health surveillance have become more and more necessary in order to monitor and prevent any unusual situation. It will improve the design of intervention strategies. It has been shown through this study that the development of forecasting models is essential for the management of scorpion stings. Indeed, the prediction of future cases will help to be in a state of readiness and anticipate the demand of antivenom vials and symptomatic drugs necessary in the health facilities.

The first mathematical approach applied to scorpionism to predict scorpion sting incidence is attributable to Chowell *et al.* who analysed the impact of climatological variables to predict the incidence of scorpion stings in humans in Colima's state in Mexico by performing a multiple linear regression[16]. Other studies on the impact of climatological factors on scorpion stings were performed using simple statistical analyses and correlations[21,22]. Selmane has used time series analysis based on Box and Jenkins method and regression analysis to show the link between scorpion stings and weather conditions[23-25]. In this work, we used regression models for count data, and to our knowledge, this is the first time that this statistical approach is applied to scorpionism. First, we have correlated the number of recorded scorpion sting cases with several climatic factors to detect any association between them. The scorpion sting cases were highly correlated with temperature and RH. The statistical modelling was then performed through Poisson, scaled Poisson and negative binomial regression models. In the modelling process, the dependent variable is the monthly scorpion sting cases and the independent variables are the monthly climatological variables. We showed that negative binomial model is more appropriate for this particular data set and we used the estimated coefficients to compute the increase in the number of scorpion sting cases and the relative risk, and to predict the number of scorpion sting cases for the year of 2013.

From the analysis and modelling of the monthly-recorded data from January 2001 to December 2012, it is concluded that the scorpion activity in El Bayadh Province is an environmental and climatic driven phenomenon and the temperature and humidity are the main climate factors and temperature has the highest effect. If we have a good forecast of the meteorological variables, we may use the negative binomial model to predict the number of scorpion sting cases using those weather variables.

The present study shows an improvement in the forecasting of scorpion sting cases in terms of weather condition. This is a valuable step towards the understanding of the impact of weather factors on the stings of the scorpions. It will help to design intervention strategies in affected provinces. However, it is clear that there is a need for further research to examine whether the incorporation into the model of other climatic factors, as well as the environmental conditions, and human behaviour can improve the prediction process. As the lethality is high in some provinces, the identification of species involved in the scorpion envenoming and the evaluation of the zoo-geographic distribution of scorpion fauna is also suggested.

Conflict of interest statement

We declare that we have no conflict of interest.

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