

## Article

# Anthropogenic Risk to Poisonous Species in Mexico

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**Abstract:** In recent years, the morbidity and mortality rates caused by stings and bites of poisonous species have been constant in Mexico; such a phenomenon has been emphasized due to the dominance or modification of the natural geosystem. The modification in the availability of water resources has caused changes in the climate, extreme droughts, and floods that influence the distribution of species, generating risks where they did not occur before. With the aforementioned, it is important to identify risky points through the development of new cartography in the country, which allows an analysis from a spatial and geostatistical perspective. Based on the number of victims of stings or bites, there will be a sharp increase in exposure to poisonous animals where the distribution of these species overlaps with areas of high vulnerability as well as social and natural contact in Mexico. The aim of this study is to model the anthropogenic risk of poisonous species in Mexico in a spatial way (data from 2010–2017). The spatial analyses of this study were carried out throughout the Mexican territory and focused on species such as coral snakes, rattlesnakes, scorpions, and centipedes. The variables of vulnerability, danger, and exposure were considered to create a generalized risk model using the core area alternative in the zonation program, allowing a spatial analysis. The methodology consisted of six stages: (1) the identification of threats and records collected from chosen poisonous animals; (2) obtaining risk models by using the Zonation software that summarized all the species distribution modeling (SDM); (3) the development of a general anthropogenic vulnerability indicator; (4) obtaining the general exposure model with the index of accessibility to medical services; (5) obtaining risk models; and (6) the validation of risk models with morbidity and mortality rates by obtaining geostatistical models. The highlighted risk areas are the Pacific Ocean coast from Southern Sinaloa to the border of Michoacán, a corridor from central Veracruz to northern Oaxaca, central Guerrero, northern Michoacán, and northwestern Nuevo León.

**Keywords:** forecast; vulnerability; distribution; planning; mortality; health; dangerous animals



**Citation:** Rodríguez Soto, C.; Roque Vilchis, L.F.; Cadena Vargas, E.G.; Gómez Albores, M.A. Anthropogenic Risk to Poisonous Species in Mexico. *Sustainability* **2023**, *15*, 13214. <https://doi.org/10.3390/su151713214>

Academic Editors: Andrei Emil Briciu, Francisco da Silva Costa and Francisco Zepeda Mondragón

Received: 16 July 2023

Revised: 22 August 2023

Accepted: 30 August 2023

Published: 3 September 2023



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## 1. Introduction

Humans have burst into the natural territory of other species over time, resulting in the extension of the anthropogenic geosystem's intersection with the natural background or standards. When the competition to gain territory increases, each being develops mechanisms to adapt and defend itself; animals have developed survival strategies such as camouflage, mimicry, venom-producing glands, toxic substances on their skin, strong jaws, resistant exoskeletons, and unbelievable speed. These defenses stand up to anthropogenic expansion and keep their context, such as the existing fundamental niche and the displacement area of a species. In this way, the interaction between man and dangerous species creates a scenario of mutual vulnerability and danger. This study was focused on poisonous animals such as snakes, helodermas, arachnids, and scolopendras.

On the one hand, vulnerability is a defensive limit of a system against the danger represented by a threat, which can be any living being or object; it is called constant interaction exposure. The increase and intersection of these factors cause the risk areas. If vulnerability is a human cause and the danger is oriented toward that, it is called anthropogenic risk [1]. On the other hand, the possible exposure caused by anthropogenic expansion and competition with organisms could give rise to diseases; this is called biological risk [2]. This happens because of agriculture, deforestation, pesticides, and clandestine grassland fires, among other activities that cause the displacement of species.

In addition, it is expected that, as a consequence of climate change, the frequency and severity of extreme weather events will increase [3]. The impacts of this type of water-related event manifest themselves through a greater spread of communicable diseases and poisonous species [4], increasing the danger and causing economic and human losses.

The fauna in Mexico represents a wide outlook of species that stand for danger because they are poisonous and cause physiological damage in humans due to their toxins, parasites, or bacteria in their fluids. It is estimated that of the 2,500,000 people who are bitten, 125,000 die around the world [5]. The scorpion sting rates in Mexico report 200,000 accidents a year and from 3 to 5000 spider bites per year [6]. This is without taking snake bites into consideration, which are significant problems in the health sector. Having said that, the modeling of its distribution and displacement has become relevant along with human expansion to identify risk areas and further discussion in the healthcare system.

This type of spatial analysis applied to geophysical processes on the earth has great complexity because it is essential to analyze the natural and social geosystems before carrying out any ecological studies. It is needed to characterize the environment at the moment and space of the threat [5]. From this angle, the effects of each species on the human being are different in both ways: in the form in which they reach the environment, the probable routes of access, and the impact on it.

The importance of identifying risk areas in the presence of poisonous animals has been highlighted by authors such as Tay and collaborators [7], who carried out a study of scorpionism in Guanajuato. In the same way, Castillo and collaborators [8] performed an analysis of scorpionism in Mexico. Leynaud and Reati [9] conducted a foreign study on ophidism in Córdoba (Argentina) by using the SIGEpi program. And Pandey [10], who focused on ophidic risk in Nepal. Although some authors mentioned that the main objective was to identify risk areas, they also studied the interaction between danger and vulnerability; however, it relied on their own definition of risk. In this study, vulnerability, danger, and exposure variables were considered to apply the risk analysis. Each variable was formed through individual factors, which were used to create a methodological proposal that took into consideration this individuality to create a generalized model, using the “core area” alternative in the Zonation program that allows spatial analysis.

The main objective of this study was to model spatially the anthropogenic risk posed by poisonous species in Mexico (data from 2010–2017). The black widow spider (*Latrodectus mactans*), the fiddler spider (*Loxosceles laeta*), the general of coral snakes (*Micrurus* spp.) and rattlesnakes (*Crotalus* spp.), the scorpions (*Centruroides* spp.), and centipedes (Scolopendrae family) are considered poisonous species of fauna, among others, having sighting records over the period 2010–2017 in Mexico. The poisonous species selected were determined by the sighting frequencies and the lethality of the venom. Human vulnerability is the sum of natural and social weaknesses, and exposure is represented by deficiencies in the medical system and the type of area (classified as rural or urban at the electoral section level). The intersection between danger, vulnerability, and exposure allows the mapping of anthropogenic risk or conflict zones to be analyzed from a geostatistical perspective.

The results of the present study will be useful for recognizing the risk scale to reduce exposure to risky areas, which would result in reducing the cost of antivenom production and redistribution to the clinics, hospitals, and medical centers that require it the most. It is also expected to increase protection brigades against poisonous animals to inform people about the existence of these species and reduce risk in the correct areas. As well as

the reorganization of Natural Protected Areas, and the related stakeholders. In addition, further studies on epidemiology or biology will ease the process and allow us to focus on local problems.

In short, the aforementioned elements show the contribution of the study in the balance of the three pillars of sustainability: ecological (contributing to developing conservation strategies for species in the highest risk sites), economic (reducing costs and making investment more efficient), and social (benefiting the health of the human population by reducing morbidity and mortality from poisonous species in an inclusive manner).

## 2. Materials and Methods

### 2.1. Study Area

Mexico is an almost two million km<sup>2</sup> heterogeneous country of territorial extension. The topography is overly complex, with more than 65% of the country's area above one thousand meters and a large variety of habitat types, from tropical forests to deserts, and a mixture of South and North American fauna and flora [11]. These characteristics have contributed to making Mexico one of the most megadiverse countries [12] and one of the most important biodiversity hotspots.

Mexico shares land borders with the United States of North America to its north and with Belize and Guatemala to its south. The country encompasses 32 states with 121 million inhabitants, of whom approximately 61 million are women and 58 million are men, with the dominant age group being 10 to 14 years [13]. The capital had 8.9 million inhabitants, and the least populated state was Colima with 747,801 inhabitants [14]. The largest state is Chihuahua with 247,412 km<sup>2</sup> and the smallest is Tlaxcala with 3997 km<sup>2</sup>; however, the capital is the one with the smallest area with 1495 km<sup>2</sup>, therefore having the highest population density in the country (5967 inhabitants/km<sup>2</sup>) above the national average of 61 inhab/km<sup>2</sup> [13].

The country connects two climatic zones: the temperate and the tropical, which both delimit the Nearctic and Neotropical biogeographic zones, so there is a great diversity of flora and fauna species. In addition, geographical features favor the existence of multiple climates; Köppen [15] has classified four: temperate (C), tropical (A), dry (B), and polar (ET) in the highest parts [16]. These conditions also expose the country to natural hydrometeorological (hurricanes, snowfalls, and tornadoes), geological (earthquakes and erosion), and climatological (droughts and floods) phenomena.

### 2.2. Species Data and Danger Scenario

Poisonous species ecological niche models represented a dangerous scenario, so the first data about poisonous species occurrence in Mexico were obtained to develop those models. The species were chosen based on the backgrounds and pieces of news records on the population affected by poisonous species, considering: (a) attacks registered in the period 2010–2017; (b) the potency of the poison; and (c) updated accessibility to specific records of species sightings [7,8,17–29] (Supplementary Material S1).

The species occurrence data were obtained from the Global Biodiversity Information Facility (GBIF, <http://www.gbif.org>, accessed on 20 December 2017) and the National System of Information on Biodiversity (SNIB, CONABIO, Mexico City, Mexico). It was considered only one record per species at one kilometer of the neighborhood in order to randomly homogenize the density and reduce spatial autocorrelation [30], and just considering expert-verified records.

In addition to this, Cuervo-Robayo bioclimatic surfaces [31] were used to develop ecological niche models. The study worked with the WGS 84 projection in geographic coordinates and raster format at a resolution of one km<sup>2</sup> and Pearson coefficients were used to test collinearity among attributes [32]. When two or more attributes were highly correlated ( $R > 0.5$ ), only one was retained as an independent attribute, and the other was eliminated. Moreover, for each species, the bioclimatic surfaces with the highest contribution to the ecological niche were selected based on the contribution of the variable

to the species distribution (Maxent percent of contribution) (Supplementary Material S2 shows the percent of contribution and selected variables for each species).

Besides, the species distribution models were developed with species occurrence data and selected bioclimatic variables and the MaxEnt algorithm version 3.3.3 k setting the default parameters [33], evaluated with independent data of species occurrences (25% of the records), using the Area Under Curve ROC (AUC) (>0.8) [34]. Ten repetitions were applied for each approach with cross-validation to ensure the reliability of the models [35,36]. Just models with an AUC > 0.8 were ensembled to represent the species distribution and develop the danger scenario map throughout the Zonation software (V4.3) [37], with the core area removal rule. The ensemble method used a weighted average based on the values of the AUC [38]. The danger scenario symbolizes the probability of finding a greater or lesser number of poisonous species (potential richness).

### 2.3. Vulnerability Factors

Were identified as vulnerability factors those that increase human weakness in the presence of poisonous species and were classified into two types: (1) anthropological, caused by the incapacity of the territorial organization, the unequal distribution of resources, and the administrative delimitation (state, municipality, locality, etc.), using data from the 2010 census of electoral sections created by the Instituto Nacional Electoral (INE) and INEGI [39]; (2) natural, that would be land cover, soil degradation, and slope. The factors that increase vulnerability were chosen from the literature consulted and are presented in Supplementary Material S3.

In order to represent the anthropological vulnerability a Pearson correlation matrix (>0.6) was created with the percentages of each anthropogenic variable to choose the non-collinear ones and to standardize only the data of the necessary variables with the 'Z' scoring technique. The Principal Components Analysis (PCA) factor was obtained using SPSS and based on the variance of the data; finally, to obtain a scale from 0 to 100, it was applied the Linear Standardization Technique (LET, Equation (1)) to represent the most vulnerable areas, with values from 0 to 1 creating vector and raster cartography.

$$LET = \frac{\text{value} - \text{value}_{\min}}{\text{value}_{\max} - \text{value}_{\min}} \quad (1)$$

The natural factors that had an influence on the displacement or establishment of the considered species were:

1. The land cover: obtained from the VI series [40], reclassified and weighted in the next categories: Urban (1), Primary vegetation (2), Natural and induced grassland and agriculture (3), Secondary vegetation (4), and other (0). This weighting was applied assuming that the population expands towards areas of moderate vegetation cover where it is very likely to find a poisonous animal and avoids settling in a dominant vegetation cover area where it is still unable to build due to land accidents.
2. Soil degradation: obtained from the Secretaría de Medio Ambiente y Recursos Naturales [41], weighted as follows: (4) Moderate degradation, (3) Light degradation, (2) Strong degradation, and (1) Extreme degradation Considering that the high degradation of the soil only benefits the displacement of species but not their permanence (an existing fundamental niche).
3. Slope: The TerrSet software of Clark Labs and the Digital Elevation Model at 1 km resolution offered by the INEGI were used in order to obtain the slope and aspect and choose which of them was more associated with the distribution of species, using the points of presence through a correlation, resulting in the slope being the one with the highest association.

#### 2.4. Exposition Factors

Two subsystems were considered as danger boosters: (1) the type of electoral section, considering its population size (rural—urban) [13], and (2) the influence of medical services on each section (accessibility), since the lack of communication involves human damage altering the social and part of the health care systems.

The medical services influence was measured with the spatial interaction and separation indicator [42], modified by our collaborator Cadena, which associates the distance of the electoral sections with the medical services (MS) and an obstacle or friction variable (Equation (2)). First, the centroids of electoral sections were obtained, and after that, the 2015 National Statistical Directory of Economic Units (DENUE) provided by INEGI [43] was downloaded. From the DENUE, they were filtered through the MS focused on the cure of the disease by bacterial manifestations caused by toxins, mainly in the tissues [44], through the code of the North American Industrial Classification System (NAICS) of INEGI (cod\_act). The Euclidean distance from the MS to the centroid of the closest section was obtained with the Near tool. 6 km was considered the maximum tolerance of the nearest; this criterion was taken based on local information from SEDESOL and ISSEMYM. The accessibility index for MS was also classified into five categories with natural brakes.

$$\text{Accessibility index} = \frac{\sum_j dij}{b} \left( \frac{\text{sum of cost indicator (distance from origin } i \text{ to destination } j)}{\text{Friction parameter to the distance}} \right) \quad (2)$$

The obstacle variable was the average rate of MS employees in the section, which is the probability that a person traveled from far away and employees could not attend to them, or the opposite, that a person traveled a shorter distance (6 km) and they were treated. The rate was obtained for every 10,000 inhabitants (Equation (3)) and was standardized linearly on a scale from 0 to 1.

$$\text{Average rate of MS employees} = \frac{\text{sum of the average of MS employees in the section}}{\text{Total population of the section}} \times 10,000 \quad (3)$$

With the average between the distances and the average rate of employees, the accessibility indicator was obtained considering an obstacle, which means the probability that they will not attend to the patient in the MS.

#### 2.5. Risk Model

For the risk model construction, the Zonation GUI software (V4.3) [37] was used with the core area removal rule. Such a model considered the dangerous scenario, vulnerability, and exposition. Following Moilanen et al. [35], beneficial attributes were assigned a value of 1, while constraints were assigned a value of  $-0.5$ , so that bias was prevented as much as possible.

Scenarios were smoothed for each species using the smooth function within the Zonation software, so that isolated scattered pixels are considered less relevant than scattered neighboring pixels of polygons, to avoid the so-called “salt-and-pepper effect”. The amplitude of the smoothing process was based on the dispersion ability expected from the species. Core areas were regarded as risk areas.

The type of species was prioritized, weighing each one considering the potential of its venom and the frequency of sightings [6–8,18–29]. See Supplementary Material S1 for weighting details.

The Zonation algorithm was executed by taking into account the following: weights, vulnerability, and exposure factors to obtain a refined model. However, a municipal model was also created by applying the rule of land use measurement (planning) to a rasterized file of municipalities throughout the country. The risk models were manually classified into four risk categories: (1) No apparent (0–0.5), (2) Low (0.5–0.7), (3) Medium (0.7–0.9), and (4) High (0.9–1.0).

### 2.6. Model Validation and Neighborhood Analyses

The model was evaluated with affected person records (expenses) and deaths (2010–2016) from the Sistema Nacional en Información de Salud (SINAIS) through the International Classification of Diseases (ICD-10), which specifies the origin of the damage, besides creating municipal data. The general morbidity and mortality rates were also calculated by using the annual municipal growth, which was measured with the annual population increase rate (APIR) and determined the percentage increase or decrease in the population. For this, the 2010 population census and the 2015 population count of the INEGI were used, applying Equation (4); the exponent dividend is the difference in years in the period studied, 2010–2015.

$$APIR = \left( \left( \frac{\text{higher population}}{\text{lower population}} \right)^{\frac{1}{5}} - 1 \right) \times 100 \quad (4)$$

From the APIR, the annual mean population was estimated, whose formula is presented in Equation (5), where  $Pop_{X+1}$  is the population of the year to be estimated and  $Pob_X$  is the population of the base year, and the TIPA is between two time periods; this process was accelerated in SPSS.

$$Pop_{X+1} = (Pob_X) \left( 1 + \left( \frac{APIR}{100} \right) \right) \quad (5)$$

The respective rates to create the raster files were obtained through the account of all the records of deaths and discharges, considering the average population.

Finally, Pearson cross-correlation coefficients were calculated with the morbidity and mortality raster files and the municipal risk model using the TerrSet software to detect highly correlated variables. Through the validated models in the Geoda software [45], with the predetermined parameters of the software (999 permutations and 0.5 of significance), the Moran univariate index (criterion queen and first order neighborhood) was obtained to know the spatial autocorrelation of municipal risk, and the LISA model was created to visualize the clusters for the analysis of the behavior of this phenomenon by means of a neighborhood study.

## 3. Results

### 3.1. Threat and Danger

A total of 3152 records of 40 species were filtered; *Crotalus scutulatus* was the species with the most data and *Scolopendra viridis* with the least (394 and 5, respectively) (Figure 1). *Bothrops asper*, *Crotalus atrox*, *Crotalus molossus*, *Latrodectus mactans*, *Micrurus diastema*, and *Loxosceles* gender were weighted as more important due to their probability of sighting and the mortality of their poison. In Supplementary Material S1, the species data and distribution model values are between 0.84 and 0.99, 50% with Nearctic affinity, 40% with Neotropical affinity, and 10% with continuous distribution. The bioclimatic variables that showed a better contribution to the species ecological niche were the seasonality of temperature, seasonality of precipitation, precipitation of the driest month, and precipitation of the coldest quarter, emphasizing the impact of water resources on the distribution of the species included in the study.

According to the prioritization model, the highly dangerous areas are located in Jalisco, Michoacán, Hidalgo, Oaxaca, Chiapas, Monterrey, Tamaulipas, and Veracruz, in addition to the coastal corridor of the Sea of Cortez (Figure 2). Added to these areas, 20% of the municipalities have high danger.

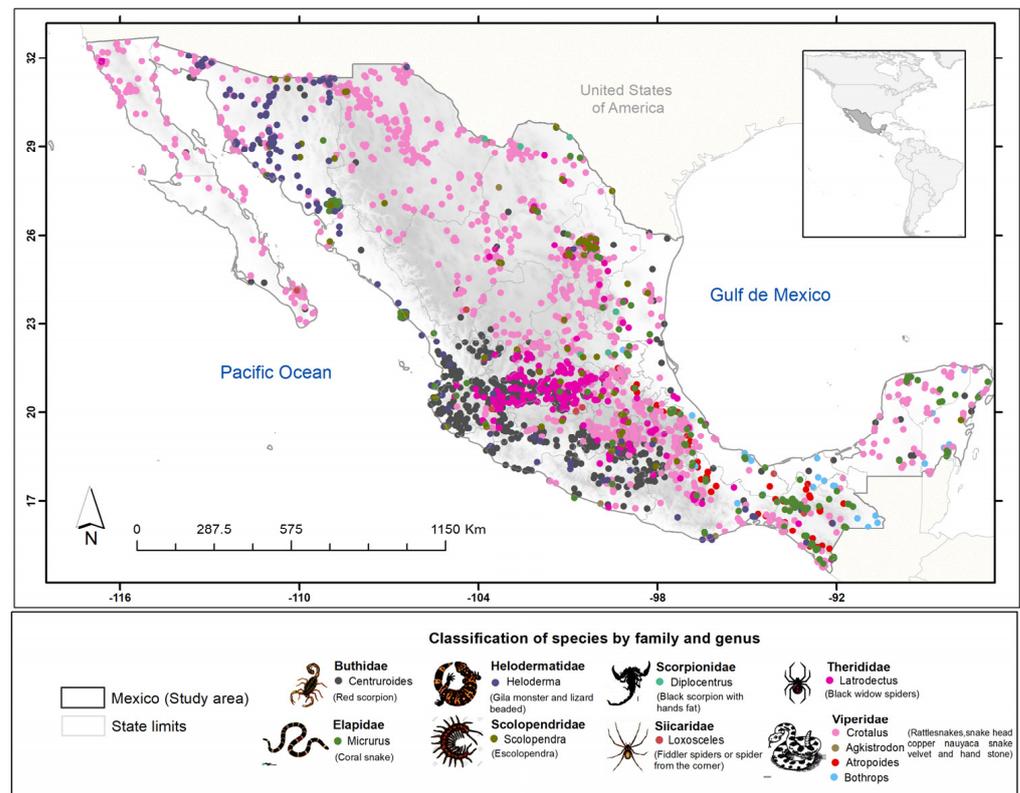


Figure 1. Poisonous species occur in Mexico (snakes, helodermas, arachnids, and scolopendras).

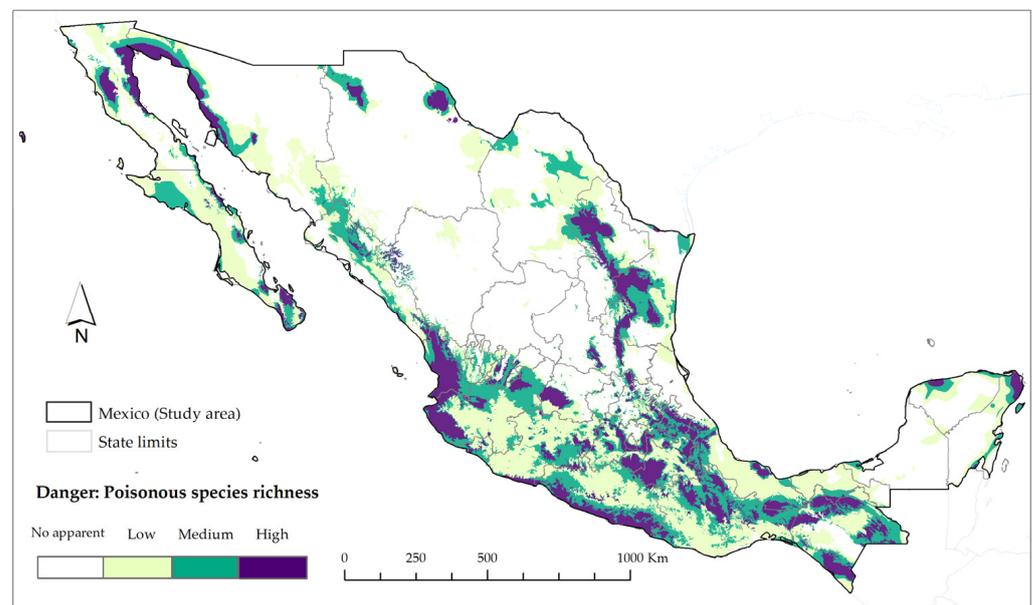
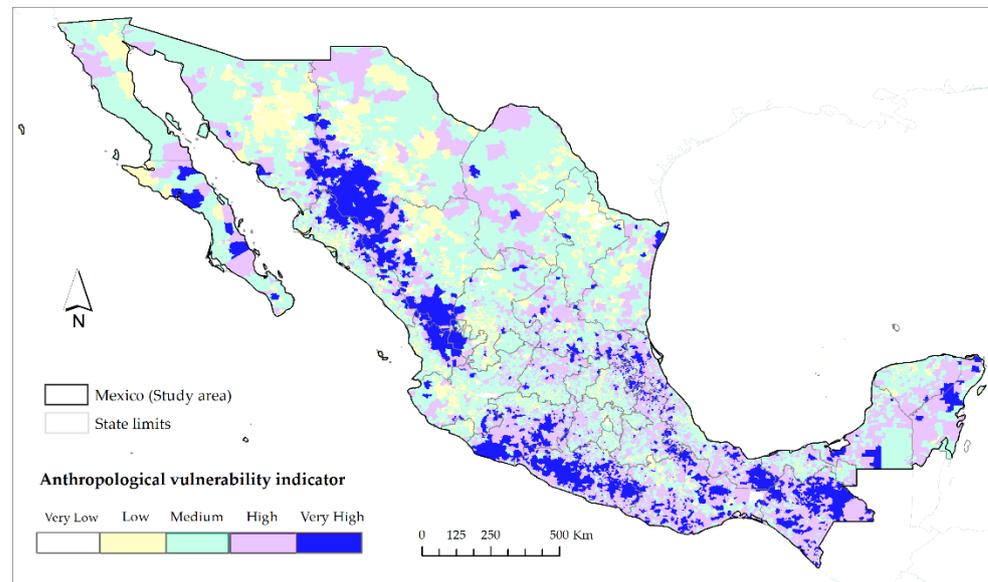


Figure 2. Danger model (poisonous species richness). Spatial prioritization model based on the distribution of presence patterns of 40 poisonous species.

### 3.2. Anthropological Vulnerability

The variables considered to calculate the anthropological vulnerability indicator using the Pearson correlation were the population from 0 to 14 years old, 60 years old and over, 15 years old and over without schooling, population without right of residence, houses with dirty floors and without electricity, and female-headed households; the PCA factor explained 80% of the information of these variables (Supplementary Material S4).

A total amount of 9119 sections with high vulnerability and 2735 with very high vulnerability were identified, where the Sierra Madre Occidental corridor, Chihuahua Southwest to Nayarit Est, and Sierra Madre del Sur corridor stand out (Figure 3, Supplementary Material S5).



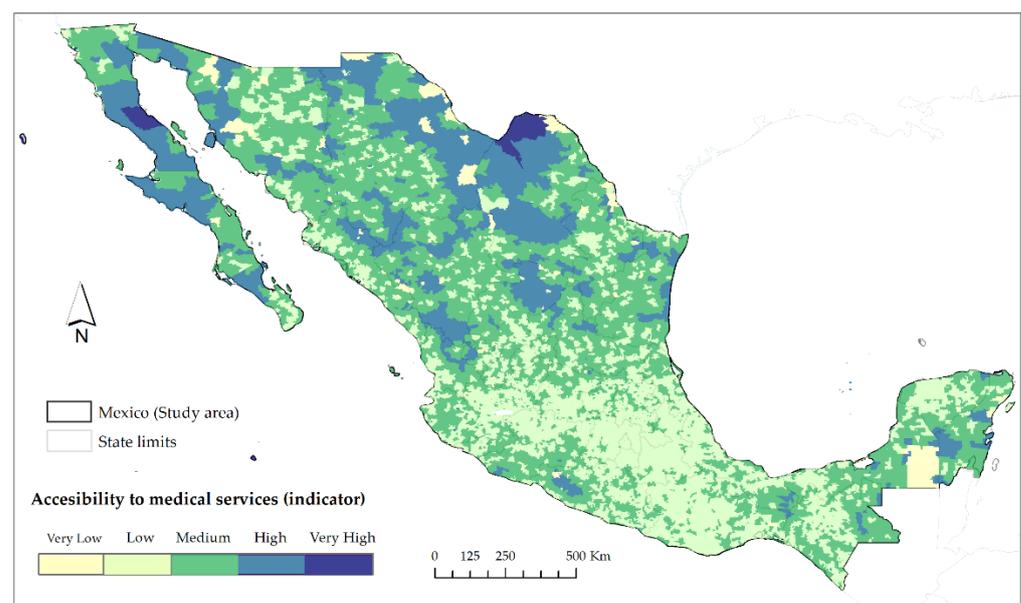
**Figure 3.** Anthropogenic vulnerability indicator, classified into five categories.

### 3.3. Natural Factors That Benefit the Displacement of Species

The land use weighted model shows that the secondary vegetation stands out in the area around the Neovolcanic axis, Tamaulipas, Chihuahua, and Yucatán Peninsula.

### 3.4. Exposition

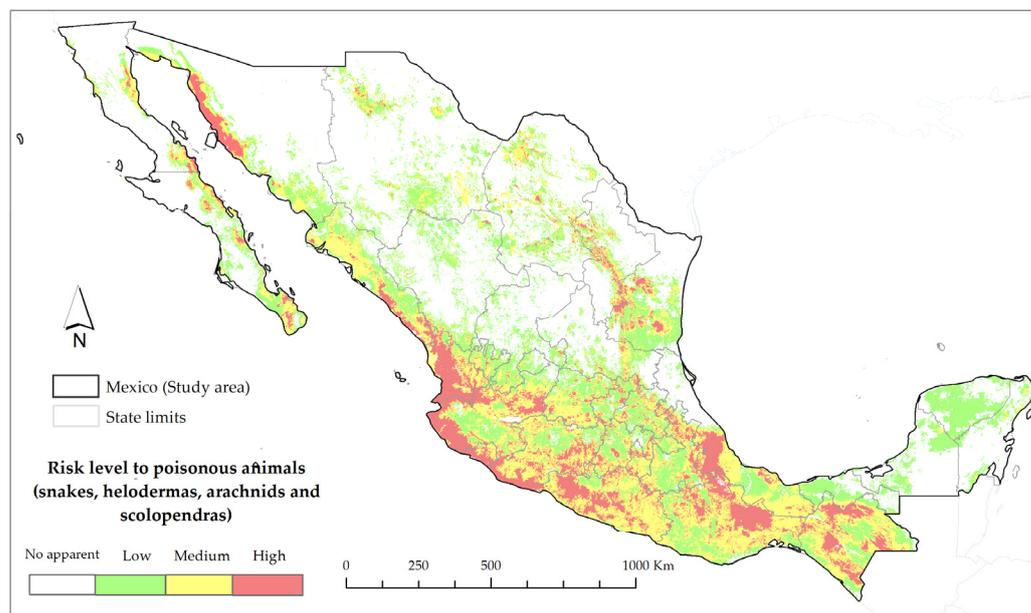
The sections with fewer populations are in Baja California, Baja California Sur, Coahuila, Chihuahua, Durango, Guerrero, Nuevo León, San Luis Potosí, Sinaloa, Sonora, Tamaulipas, and Zacatecas. The MS accessibility index shows areas of low accessibility in north and south-central Mexico (Figure 4).



**Figure 4.** Medical services accessibility index by electoral section.

### 3.5. Risk Model

The risk model emphasizes the northwest and south Pacific Coasts as well as the Sierra Norte de Oaxaca y Sierra Madre Oriental regions (Figure 5).



**Figure 5.** Anthropogenic risk level for poisonous animals (snakes, helodermas, arachnids, and scolopendras).

There are three high-risk corridors in the northwest of the country: (1) from the south of Puerto Peñasco to Hermosillo in Sonora; (2) another one from the east of Ensenada (Baja California Norte) to Loreto (Baja California Sur); and (3) from La Concordia to Ahome in Sinaloa and to the northwest of Tecuala in Nayarit. This extends from the Pacific coast to Lázaro Cárdenas harbor in Michoacán, dispersing in San Luis Acatlán in Guerrero, as well as to the west and center of the country.

In the northeast, the greater risk corridor begins in Aquismón in San Luis Potosí, which crosses the west, center, and southeast of the country, and disappears in Ixtlán de Juárez in Oaxaca; there is also an important corridor from the center of Mina in Nuevo León to the northeast of Hidalgo in Tamaulipas.

Some prominent high-risk sites are in the west of the country: Cadereyta de Montes in Querétaro and Apatzingán in Michoacán. In the center: south of Mexico City and the State of Mexico. In the southeast, in Chiapas, there are two corridors that start in Ostucán and end in Pantelhó and Chiapa de Corzo, respectively. In addition, there are corridors such as Puebla and the west of Veracruz ending in the north of Ixtlán de Juárez in Oaxaca.

### 3.6. Model Validation and Neighborhood Analysis

Oaxaca state showed the municipalities with the highest mortality rate (Santa María Nativitas with 16 deaths, San Juan Petatlán with 10, San Juan Comaltepec with 7, San Juan Tamazola with 6, Santa María Camotlán with 6, and Santiago Choápam with 5; all for every 10,000 inhabitants). The general morbidity rate showed bigger data in Puebla State (Tecomatlán with 1020 expenses, Tulcingo with 762, Piaxtla with 600, Albino Zertuche with 269, Chinantla with 157, Chila de Sal with 90, and Xicotlán with 58) (Supplementary Material S6).

The spatial correlation matrix between the risk model and the general incidence rate of disease and mortality rate was remarkably high (0.98 for both; Table 1).

**Table 1.** Spatial correlation matrix between the municipal risk model and mortality and morbidity rates.

Model	Morbidity Ratio	Mortality Ratio	Municipal Risk
Incidence rate	1	1	0.98
Mortality rate		1	0.98
Municipal risk			1

The Morlow risk obtained was 0.84, which explains a high positive spatial auto-correlation (Supplementary Material S7); 25% of the country's municipalities (628) have high risk, as do their neighbors, and 17% (422) of the municipalities have low risk, as do their neighbors. This divides the territory into two clusters: the high-risk cluster is distributed in three zones: (1) from Nayarit to southern Guanajuato; (2) from southern Jalisco to Guerrero; and (3) from eastern Hidalgo to southern Chiapas; the low-risk cluster encompasses two zones: (1) the states of the country above 21° N latitude and (2) the Yucatan Peninsula. The LISA test and the Univariate and bivariate Moran's Index of risk are shown in Supplementary Material S8.

#### 4. Discussion and Conclusions

The high spatial correlation between the risk model and morbidity as well as mortality rates reflects the relevance of the study to making decisions aimed at reducing the impact of poisonous species on the human population.

There is a positive relation between the risk model (poisonous species richness), the priority areas for reptile conservation in Mexico [13], and the distribution areas of *Bothrops asper*, *Centruroides elegans*, *Centruroides exilicauda*, *Centruroides infamatus*, *Centruroides limpidus*, *Centruroides nigrescens*, and *Centruroides noxius*, highlighting the states of Colima, Guerrero, Jalisco, Mexico, Michoacán, Nayarit, Oaxaca, Puebla, and Veracruz. Adding that 43% of the listed species are protected by NOM-059-SEMARNAT-2010, 5% by IUCN, and 17.5% by CITES implies the need to set up management and conservation strategies that do not pose a greater threat to these species in risky areas.

Water is the crucial element for the presence of the studied species, according to the ecological niche models. The availability of water and temperature changes have allowed us to find these species in places where they were not before, thus increasing the anthropogenic risk level for poisonous animals. Highlighting species with tropical affinity benefited from climate change, such as rattlesnakes [46], scorpions [47], and spiders [48], which show displacement to the north. Therefore, the integration of epidemiological, spatial, and ecological studies will be necessary to anticipate future changes and devise effective interventions [49].

In the case of the MS accessibility index, based on the SEDESOL and the ISSEMYM and considering the Regulatory System of Equipment through the Secretaría de Salud (SS), it was demonstrated that in most municipalities (90%) there is no accessibility. Therefore, it was assumed that a large part of the morbidity rates reported annually by scorpionism in Mexico can be treated only by having nearby health centers or the economic resources to afford a private one. Although a high accessibility index to MS shows that there are areas with high mortality rates and a medium risk level where the treatment of patients might not have been the right one or because of a lack of antidotes, In this context, the information obtained in this study is essential to drawing up guidelines to deal with poisonous species bites, planning drug supplies, mainly antidotes, and training medical staff on bite treatments [50].

An important risk factor is the lack of knowledge about poisonous species; therefore, there is a need to design and provide training for the population to differentiate between poisonous and nonpoisonous species as well as the appropriate treatment for a bite. In addition to this, link different institutions and decision-makers to mitigate damage in a harmonized way.

Some risk zones are identified in territories with anthropogenic use and high population density, agreeing with Tay and collaborators [11], who mention that attacks are more common in homes than in the countryside. Likewise, there are risk areas located in some “metropolises” such as Tepic (Nayarit), Francisco I. Madero (Culiacán, Sinaloa, Mexico), General Escobedo (Nuevo León, Mexico), and Puerto Vallarta (Jalisco, Mexico).

From the variables that formed the risk model, it was deduced that the slope is the attractor variable due to its greater influence on the ecological niche of the species and on the climatic variations [19]. The variables that cause instability in the risk model are human settlements, land use, and vegetation if the degradation is moderate; an example is the effect of natural, induced grassland or agriculture, although modified coverages allow the displacement of species [51].

There are some other characteristics of the ecology of species that may influence the risk index but have not been considered in this study, such as mating times, recovery, hibernation, and migration. For example, scorpions Chowell and collaborators [52] mention a modification in the presence due to winds, hurricanes, and landslides [53].

It is important to remember that the accessibility index considered the linear distance and not the real one (Manhattan); as a result, the real time of displacement was not taken into consideration. This characteristic should be considered in local studies for the states that obtained greater risk, such as Chiapas, Guerrero, or Veracruz, in order to create local risk models that are not based on specific species but on any taxonomic category and give more importance to MS for real distance and time of transfer.

In a visual way, the LISA test gives us a more concrete idea of the two large clusters of municipalities with and without risk that have formed in the country and whose phenomenon, the Moran index, is associated with a high neighborhood. To understand the influence of the neighborhood, the LISA test shows municipalities without risk but with neighbors with risk, and vice versa. Most of these are within the boundaries of relief areas with a low probability of human expansion and species displacement; on the contrary, there are no boundaries between low-risk municipalities and high-risk neighbors, and as a consequence, it is very likely for the risk to spread; it only depends on the displacement of the population to high-risk municipalities, as well as natural phenomena or climate change conditions that may affect the movement of species.

This article is an attempt to catch the health authorities’ attention about poisoning by poisonous species and to direct the limited resources to efficient care. As well as to prepare therapeutic protocols adapted to their needs. It contributes to the strengthening of a developing field of knowledge by applying multidisciplinary methodologies such as systematic spatial planning in the epidemiological study of poisonous species.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su151713214/s1>, Supplementary Material S1. General results of threats (poisonous species) and their Spatial Distribution Model; Supplementary Material S2. Percentage of the contribution of the Bioclimatic Variables in the potential distribution and selected variables (blank) for the 40 species included. In blue, the variables eliminated for each species due to their low percentage of contribution or their high coincidence with other variables are shown; in Supplementary Material S3. Types of vulnerabilities anthropological and natural facts; Supplementary Material S4. Anthropological variables were selected after applying Principal Components Analysis (PCA) and extracting the Z factor to create the anthropological vulnerability index; Supplementary Material S5. Counting of electoral sections by level of anthropological vulnerability index based on natural breaks; Supplementary Material S6. Comparison between the number of victims records due to the bite/sting of poisonous animals in the municipalities with the most registered cases with respect to their mortality and morbidity rates (period 2010–2016 for mortality rate and period 2012–2015 for morbidity rate); Supplementary Material S7. Moran’s univariate Index; Supplementary Material S8. Risk cluster based on the Zonation model. (LISA and Moran’s results).

**Author Contributions:** C.R.S. and L.F.R.V. developed the analysis and drafted the manuscript. C.R.S., directed the research, reviewed the data, reviewed the manuscript, developed the methodology, and directed revisions. M.A.G.A. and E.G.C.V. provided statistical and geospatial analysis and

participated in drafting the manuscript. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research did not receive funding for its development.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data is contained within the article or supplementary material.

**Acknowledgments:** We thank the National Earth Observation Laboratory of the Autonomous University of the State of Mexico for allowing us to use the equipment for data analysis.

**Conflicts of Interest:** The authors declare no conflict of interest.

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