Original Article

The impact of climate change on the burden of snakebite: Evidence synthesis and implications for primary healthcare

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Abstract

Introduction: Snakebite is a public health problem in rural areas of South Asia, Africa and South America presenting mostly in primary care. Climate change and associated extreme weather events are expected to modify the snake-human-environment interface leading to a change in the burden of snakebite. Understanding this change is essential to ensure the preparedness of primary care and public health systems. **Methods:** We searched five electronic databases and supplemented them with other methods to identify eight studies on the effect of climate change on the burden of snakebite. We summarised the results thematically. **Results:** Available evidence is limited but estimates a geographic shift in risk of snakebite: northwards in North America and southwards in South America and in Mozambique. One study from Sri Lanka estimated a 31.3% increase in the incidence of snakebite. Based on limited evidence, the incidence of snakebite was not associated with tropical storms/hurricanes and droughts in the United States but associated with heatwaves in Israel. **Conclusion:** The impact of climate change and associated extreme weather events and anthropogenic changes on mortality, morbidity and socioeconomic burden of snakebite. Transdisciplinary approaches can help understand these complex phenomena better. There is almost no evidence available in high-burden nations of South Asia and sub-Saharan Africa. Community-based approaches for biodiversity and prevention, the institution of longitudinal studies, together with improving the resilience of primary care and public health systems are required to mitigate the impact of climate change on snakebite.

Keywords: Climate change, epidemiology, extreme weather events, forecasting, planetary health, snakebite

Introduction

Snakebite is a public health problem in many countries, particularly in South Asia, sub-Saharan Africa and Latin America.[1-3] World Health Organization (WHO) estimates nearly 138,000 snakebite deaths, with 400,000 people facing permanent disabilities annually; majority of them presenting in primary care.[4] In 2019, the WHO released a global strategy, which aims to decrease death and disability due to snakebite to 50% by 2030.[4] The strategy recognises the need for empowering and engaging communities for prevention and improved access as well as strengthening health systems, that guarantee time-critical snakebite care.

Snakebite, at its core, reflects a human-snake conflict with the environment, climate and anthropogenic activity acting as mediators. Snakes being ectothermic animals, are susceptible to climate change—and the impact of climate change on snake population, their geographic range and behaviour continues to be

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Received: 23-03-2022 **Revised:** 12-05-2022
Accepted: 17-05-2022 **Published:** 31-10-2022

Access this article online	
Quick Response Code:	Website: www.jfmpc.com
	DOI: 10.4103/jfmpc.jfmpc_677_22

How to cite this article: Bhaumik S, Beri D, Jagnoor J. The impact of climate change on the burden of snakebite: Evidence synthesis and implications for primary healthcare. J Family Med Prim Care 2022;11:6147-58.

researched by ecologists and conservation scientists.[5-7] As such, climate change that alters the human-snake-environment interface would impact the burden of snakebite. The Intergovernmental Panel on Climate Change (IPCC), an intergovernmental body of the United Nations, estimated that global warming will lead to an increase beyond 1.5°C (from preindustrial levels) by 2030, much earlier than previously predicted.[8,9] Climate change will also increase the intensity and frequency of extreme weather events (heatwaves, floods, droughts and tropical cyclones).[10,11] The impact of climate change on health has been investigated for many conditions of significance to primary care such as mental health, water-borne and vector-borne diseases.[12-17] To the best of our knowledge, there is no evidence synthesis on the effect of climate change on the burden, spatiotemporal distribution and at-risk population of snakebite.

A comprehensive understating of the effect of climate change on snakebite will enable resourcing for primary care and public health planning on climate change resilience at regional, national and sub-national levels. We thus aimed to evaluate the scientific evidence on the impact of climate change, and consequent extreme weather events, on the burden of snakebite. The result of the review maps primarily to the strengthening health systems pillar of the WHO strategy, and also provides information relevant to the community engagement pillar.[4]

Methods

We did not register the evidence synthesis publicly but a priori protocol was developed with the lead author SB acting as guarantor. Protocol deviations are noted subsequently.

Eligibility criteria

We included studies that met any of the following two criteria:

1. The study is on or modelled, the impact of climate change on incidence/prevalence, risk, mortality, morbidity and socio-economic burden of snakebite.
2. The study is on, or modelled, the impact of extreme weather events (heatwaves, floods, droughts and tropical cyclones), specifically related to climate change or climate variation on incidence/prevalence, risk, mortality, morbidity and socio-economic burden of snakebite.

Studies were included irrespective of the setting, country of conduct, date of publication and publication language. We used snakebite risk as a broad term, as defined by the study authors, to be inclusive and in recognition of the complexities of defining it in relation to the human-snake-ecosystem interface. We did not include studies that reported the impact of climate change on snake population, their abundance or diversity, without reporting snakebite burden or risk. We did not include studies that focussed on the relationship between climatic, meteorological or seasonal variables with snakebite burden or risk if they did not explore the role of climate change.

Information sources

Electronic database search

We searched the following electronic databases: Ovid MEDLINE (R), Global Health (EBSCO), Embase Classic + Embase, Zoological Record Global Health and Environment file (through EBSCO). The full search strategies for all databases are presented in Appendix 1.

Other methods for searching

We hand searched the website of the WHO (Snakebite as topic section only), Kenya Snakebite Research and Intervention Centre (KSRIC), the Nigeria Snakebite Research & Intervention Centre (NSRIC) and the Global Biodiversity Information Facility (GBIF) to identify additional studies. We screened reference lists of included studies to identify additional studies for inclusion.

Screening process

In the first phase, two authors (S.B. and D.B.) independently screened each study retrieved based on titles and/or abstracts and marked each record as 'exclude' or 'include'. We conducted the simultaneous first phase of screening in a cloud-based artificial intelligence guided platform (Rayyan[18]) for evidence synthesis. Disagreements at this phase were resolved by discussion, between the two authors. In the second phase of screening, we obtained full texts of all studies marked as 'include' by consensus in the previous phase. All records were obtained and reviewed independently by two authors for consideration of inclusion based on the eligibility criteria.

Data management and analysis

We extracted data in a predesigned data extraction form using Microsoft Excel and disagreements were resolved by consensus between two authors (D.B. and S.B.). Authors of studies were not contacted for additional data and only data as reported in the published version were included. We synthesised the data narratively without conducting any additional statistical analysis.

Differences between protocol and full review

We did not initially plan to search Global Health (EBSCO) database, this was added and searched concurrently while other searches were run. We included the study on the relationship between climate variation patterns and snakebite to be inclusive and considering relatedness of the topic.

Ethics

The study is a review of existing published literature available in public domain with no human or animal participants. It does not require ethics approval.

Results

Selection of studies

We retrieved 474 records from five electronic databases and removed 118 duplicates to screen 356 titles and/or abstracts.

We identified one study from a website and six studies through manual checking (hand search) of references of included studies for full-text consideration. We finally, included eight studies that met the inclusion criteria. Reasons for exclusion at full-text level are presented in Appendix 2 and PRISMA flow chart for included studies is presented in Figure 1.

Characteristics of included studies

Of the eight included studies, four studies predicted the future impact of climate change on snakebite or snakebite risk.[19-22] Of these eight studies, three studies reported on the association/correlation between snakebite or snakebite risk and extreme weather events related to climate change (heatwave in Israel,[23] tropical storms/hurricanes,[24] and droughts[25] in the United States) and one study with climate variation (El Niño–Southern Oscillation/ENSO in Costa Rica[26]). Studies used a variety of data sources and analytical approaches. Characteristics of included studies have been detailed in Table 1.

Projected impact of climate change on incidence and risk of snakebite

We included four studies in this domain.

The study from Argentina[19] modelled future projections (2030, 2080) of suitable climate spaces (the change in multi-dimensional climatic conditions in an area over time) for five widely distributed venomous snakes using ecological niche modelling (ENM). The study found that by 2080, climate change would result in a moderate to a greater increase in potentially suitable spaces for snakes within Argentina for four species (*B. alternatus, B. diporns, C. durissus terrificus* and *M. pyrrhocryptus)* with only minor change predicted for *B. ammodytoides.* A north-to-south geographic shift is predicted with some urban centres in south and central Argentina becoming suitable climactic space for *B. diportus* and *C. durissus terrificus.*

The ENM study from Mozambique looked at 13 venomous snakes[20] and estimated a similar north-to-south shift in snakebite risk in Mozambique for the recent climate scenario (1950–2000), which would further expand in the future scenario (2070–99). The study predicted that by 2070–99 there would be an expected increase in snakebite risk in an additional 11.04% of areas. The study also predicted that 4.65% of areas, which are currently classified to have high snakebite risk might have a decreased risk by 2070–99.

The study from Sri Lanka[21] projected an increase in the annual snakebite incidence by 31.3% (95% CI: 10.7–55.7) and the annual increase in snakebite incidence to 144,000 (95% CI: 122,000–166 ,000) due to climate change in 25–50 years into future (as reported in the study), for a climate scenario of 2.5% reduction in maximum relative humidity, (equivalent to a 0.5°C increase in maximum temperature levels). In an alternate climate scenario of an increase of temperature by 1°C for 6 dry months (with no change in the remaining 6 months), the overall monthly incidence of snakebite will increase to 62.2/100,000 (95% CI: 49.1–74.1) and the total number of snakebites as projected to increase to 147,000 (95% CI: 120,000–1,740,000) by 2038–63. The

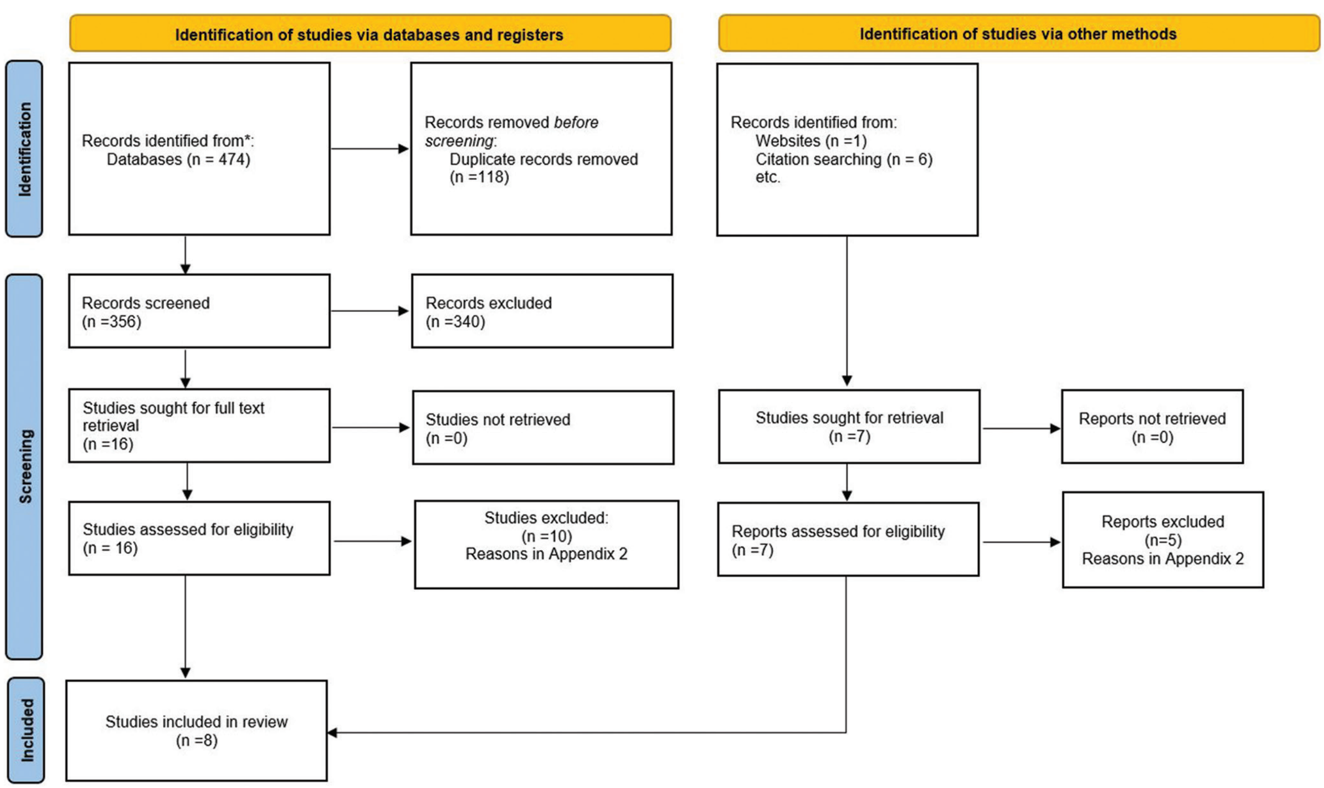

Figure 1: PRISMA Flow diagram showing a selection of studies

Table 1: Characteristics of included studies

Study ID	Country (ies) of study (& Study period)	Data source (s)	Methodology	Funding
Ediriweera 2018	Sri Lanka (2012-2013; projection 25-50 years in future)	Snakebite - from Community-based National Snakebite Survey (multistage cluster design) Meteorological measurements - Department of Meteorology, Sri Lanka	Log-linear models were developed and fitted to estimate expected monthly number of snakebites adjusting for seasonal trends and weather conditions, and taking onto account factors related to survey methodology	National Health Medical Research Council, Australia and Medical Research Council, UK Type of Funder: Public
Nori 2014	Argentina (Present - 2014; 2030; 2080)	Snake species/data records - herpetological collections of Colección Boliviana de Fauna, La Paz, Bolivia (CBF), Museo de Historia Natural Noel Kempff Mercado, Santa Cruz, Bolivia (MNKR), Museu de Zoologia, Universidade de São Paulo, São Paulo, Brazil (MZUSP), Fundación Miguel Lillo, Tucumán, Argentina (FML), Museo de Ciencias Naturales de La Plata, Argentina (MLP), Museo Argentino de Ciencias Naturales, Buenos Aires, Argentina (MACN), Centro de Zoología Aplicada, Córdoba, Argentina (CZA) and from relevant literature. Climatic data - WorldClim climate data archive.CCAFS-Climate data portal Snakebite data - Ministerio de Salúd de la República Argentin Population count - Raster dataset	Species distribution modelling was done to estimate the relationship between species records and environmental and/or spatial characteristics of the sites. Four different algorithms for seven projections of five studied species (one for present, one for each of the three selected Global Circulation Models (GCMs) for 2030 and 2080) were developed. A final map was developed from consensus maps of different GCMs estimating trends for each species. Vector maps were then developed for predicted future trends	Ministerio de Ciencia y Tecnología, Argentina and Secretaría de Ciencia y Tecnología–UNC Argentina Type of Funder: Public
Yañez-Arenas 2016	North and South America (Present - 2015; 2050)	Species unit selection - The Reptile Database, Integrated Taxonomic Information System, Campbell and Lamar 2004) & recent systematic studies. Occurrences of species - Global Biodiversity Information Facility, VertNet data portals. Data layers for characterising climates - WorldClim climate data archive. Snakebite - states or provinces of Argentina, Bolivia, Brazil, Colombia, Mexico, USA, Venezuela (different time periods) and also country level snakebite information for Central Africa	Current and future snakebite risk was modelled using ecological niche models (ENMs) for 90 venomous snake taxa. Four snakebite risk indices (representing probability of being bitten by a venomous snake at a particular location) were developed. The predictive ability of each was tested with snakebite data from published papers and reports and one which best explained snakebite incidence was chosen. Snakebite risk categorisation was done using rescaled snakebite risk maps	Consejo Nacional de Ciencia y Tecnología, Ecuador Type of Funder: Public
Zacarias 2019	Mozambique (Current estimates - 1950-2000 ; Future estimates - 2070-2099)	Species occurrence records - Global Biodiversity Information Facility, Vertnet. Environmental variables - Worldclim database	Ecological niche modelling was done for current and future distribution of all 13 dangerous snakes in Mozambique to assess the likely impacts of climate change estimated as the difference between lost and gained climatic suitable area per species. A normalised index of snakebite risk was developed based on species diversity and species-specific traits for each time slice. This index was superimposed on to data on human population density to identify burden prone areas	Conselho Nacional de Desenvolvimento Científico e Tecnológico & Financiadora de Estudos e Projetos, Ministério da Ciência, Tecnologia, Inovações e Comunicações and Fundação de Amparo à Pesquisa do Estado de Goiás, Brazil Type of Funder: Public
Schulte 2020	Texas, USA (2000 - 2017)	Weather data - National Weather Service (NWS), County classification – as per Federal Emergency Management Agency (FEMA) Snakebite data - the Texas Poison Control Network	Comparison between following two groups of counties of Texas in USA was done (sing pooled analysis of the 9 storms using descriptive methods and χ^2 testing for proportions) 1. Counties designated for individual	Not reported

Contd...

Table 1: Contd...

Study ID	Country (ies) of study (& Study period)	Data source (s)	Methodology	Funding
			assistance (impact counties) by the Federal Emergency Management Agency (those in which damage due to tropical storms and hurricanes is worst) 2. All other counties (non-impact counties).	
Phillips 2019	California, USA (1997-2017)	Snakebite cases (excluding non-venomous bites) - California Poison Control System County-level drought data - US Drought Monitor for 2000–2017. Air temperature & precipitation - National Aeronautics and Space Administration's North America Land Data Assimilation Systems (NLDAS) dataset from 1979 to 2017. Demographic time series data - US Census Bureau (UCB) annual summaries including population data from the UCB summarised by National Institutes of Health's National Cancer Institute from 1960 to 2016; county-level demographic data from the UCB including age and sex characteristics for 2016, Geological and ecological classifications from US Environmental Protection Agency, Land cover - National Land Classification Database Multi-resolution Land Characteristics Consortium	Aggregation of venomous snakebite reports was done by location and correlated per county with weather data, air temperature, precipitation, population data, eco-regions and land characteristics. A time series decomposition by seasonality and trend, regression and autocorrelation was conducted to understand association.	Not reported
Shashar 2018	Israel (2008–2015)	Medical evacuations - Magen David Adom (MDA), (the sole emergency medical service provider for the country). Environmental Data - Monitor stations (National Air Monitoring Network website) operated by the Ministry of Environmental Protection.	Conditional logistic regression was applied to estimate the association. Analysis was stratified by regions and seasons.	Not reported
Chaves 2015	Costa Rica (2005 – 2013)	Snakebite data from Costa Rican Ministry of Health collected under the administration of the Costa Rican Social Security Trust. Average elevation estimates from Global Land Survey Digital Elevation Model. Satellite images were acquired from the Goodard Earth Science Data and Information Services Center of NASA. For ENSO, data was obtained from US National Oceanic and Atmospheric Climate Prediction Centre.	**1. Spatial analysis** - considering each canton for "(i) average elevation;(ii) annual average precipitation; (iii) poverty gap index, which quantifies the percentage of houses with income below the poverty line; (iv) percentage of destitute housing (i.e., lacking services and made of inadequate materials)." **2. Time series analysis** - temperature and rainfall time series was used to quantify impact of ENSO (El Niño Southern Oscillation) on snakebites.	University of Costa Rica, Nagasaki University, and Taiwan Ministry of Science and Technology Type of Funder: Public

study noted a baseline overall monthly incidence of snakebite of 45.7/100,000 (95% CI: 35.4–59.0) leading to 119,000 snakebite deaths (95% CI: 103,000–134,000) in the year 2012.

One ENM study[22] modelled the effect of climate change on snakebite risk multi-nationally for 90 venomous taxa in the entire North and South America. The study projected that by 2050, almost all countries in North and South America would have an increased risk of snakebite with areas in Mexico, Guatemala, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Ecuador and some parts of southern United States of America (USA) being classified as high-risk. The study forecasted that there will be a shift in snakebite risk areas northward in Canada and Southward in Argentina and Chile by 2050. An increase in 2.74-18.38% of rural population being exposed to the risk of snakebite by 2050 is estimated.

Extreme weather events related to climate change and snakebite

We found three studies[23-25] under this domain. One study from the United States found no statistically significant difference in snakebites between counties in Texas affected by tropical storms/cyclones (nine incidences between 2000 and 2017) and counties not affected by it, either overall or 30 days after landfall[24]: this did not change by patient demography, type of snake and care patterns pre- and post-storms. The other study from the United States also found no statistically significant decrease in incidence of snakebite per million (mean during drought = 15.10; mean outside drought = 18.57; 95% CI = 0.12–6.83; $P = 0.04$) due to droughts between 1997 and 2017 in California.[25] However, it found a statistically significant correlation in snakebite incidence after a period of no drought, which declined during periods of drought ($r = -0.41$, $P < 0.01$). The study from Israel[23] found that the incidence of snakebite was significantly associated with heatwave, both during the cold (OR 1.62; 95% CI = 1.01–2.60) and hot (OR 1.50; 95% CI = 1.18–1.92) seasons. None of the studies had provided futuristic estimates of how extreme weather-related events would impact snakebite. All the studies used retrospective facility data on snakebite.

Climate variation and snakebite

Only one study was found in this domain which investigated the effect of El Niño/La Niña–Southern Oscillation (ENSO) on snakebite in Costa Rica between 2005 and 2013.[26] The ENSO is a climatic cycle, resulting from periodic variation in sea surface temperature and the air pressure of the atmosphere overlying it. The ENSO affects both temperature and precipitation in large parts of the world and the impact of global warming on ENSO remains uncertain. The study[26] found that the peak monthly incidence of snakebite coincided with both the hot and cold phases of the ENSO in Costa Rica. The study also found that increase in temperature (above the average), high poverty index gap and percentage of destitute housing (especially in rural areas) were predictive of increase in the incidence of snakebite while the increase in rainfall (above average) was predictive of a decrease in snakebite incidence.

Discussion

Summary of main results

Our evidence synthesis summarises the impact of climate change on the burden of snakebite. Overall, the evidence is scarce, with limited studies available in the domain. The scarcity of studies on the impact of climate change from high-burden nations like India, Pakistan, Bangladesh and countries in sub-Saharan Africa highlights a crucial evidence gap.

Review findings in the context of previous research

To our knowledge, there is no other evidence synthesis on the topic. The predicted increased incidence of snakebite in the next few decades, seen in the existing studies in our review is quite in contrast with what might be expected due to likely overall decline in snake population due to anthropogenic causes, including climate change, changing land-use patterns and deforestation over a long time.[27-29] The increase in snakebite might be due to several factors: medically important snakes might be more resilient to climate change (e.g. rattle snakes[30]), rapid adaption to changes in climate and environment (e.g. Burmese pythons acting like an invasive species[31]) or benefitting from climate change (example improved food supplementation for urban-adapted snakes[32]). Climate change might also alter the hibernation of snakes, thus changing the duration and nature of human-snake conflict.[33,34] In addition, climate change is also expected to trigger human migration in many parts of the world due to associated problems of sea-level rise and food insecurity. Overall, the complex interface of environment-human-snake would change due to climate change and this needs to be understood better. Available evidence from our evidence synthesis shows that global climate change will lead to a shift in snakebite risk more northwards in North America and southwards in South America, including in Argentina.[19,22] The results are in alignment with findings from ecological studies, which have found a similar shift in snake species distribution in the American hemisphere.[35] A northward change in spatial distribution of snakes due to climate has also been noted in a study in China.[7]

Implications for policy, practice and research

The increase in snakebite and geographic shift of burden seen in studies included in our review, implies that newer areas and communities, which do not have snakebite as a public health problem currently, might potentially see an increasing incidence of snakebite because of climate change, in the future. Primary care systems in newer areas need to be adequately prepared for this change. Based on the IPCC's 2021 sixth assessment report,[8] it is reasonable to believe that the estimated change in burden of snakebite in included studies would be much earlier than expected. Plans to increase resilience of primary care and public health systems to climate change (which focuses prominently on response to extreme weather events, infectious diseases, food and water security[36-40]) must also consider snakebite. While adjusting supply chain and logistics for anti-venom supplies to a particular geolocation might be more manageable, securing enough and appropriate anti-venom supply (in the background of shifting snake populations) and training health workers on snakebite management might be more difficult requiring longer-term initiatives. Changes in species distribution might also lead to demand for newer varieties of specific snake anti-venom, which might not have been produced historically. There is a need for health system resilience plans to factor in the need for managing the dynamic nature of the burden of snakebites due to climate change. Integrating snakebite surveillance within infectious disease surveillance programs[40] might be considered.

There were only two studies[20,21] from South Asia and Africa. Together these regions represent majority of the current burden of snakebite.[1,3] Both studies predicted higher incidence of snakebites due to climate change. The evidence on extreme weather events related to climate change is scarce. Even in countries, where the impact of climate change has been studied, for all except the study from Sri Lanka,[21] the analysis was based on existing facility-level data. Robust community-based cohort studies, linked with climate parameters and repeated over time are much needed in countries with high burden of snakebite.

The current evidence based on the impact of climate change on snakebite is limited to the understanding of the incidence of snakebite or snakebite risk using a spatial lens. The effect of climate change on mortality, morbidity and socio-economic burden of snakebite remains unexplored. It is important to note that none of the current studies have considered how snakebites would be impacted due to human migration expected due to climate change. Climate refugees often live in scarcely inhabited regions, a common strategy used during many refugee crises. This might also exaggerate human-snake conflict. Communities with lesser snake-human interaction may not be familiar with strategies to avoid snakes and snakebites.[41] Awareness, education and other community-based strategies to mitigate snakebite are essential.[4] Community-based initiatives is important not only from a prevention perspective but also from a snake conservation and biodiversity perspective, including in areas where snake populations (and consequently snakebites) are declining.[41] Snakes play a crucial role, not only in the ecosystem but also prevents agricultural loss and have a role in controlling the transmission of diseases spread by rodents and biomedical research.[42]

Understanding the issue in greater granularity using transdisciplinary approaches is required. Multi-disciplinary research teams consisting of primary care professionals, public health specialists, climate scientists and mathematical modellers together with herpetologists, ecologists, anthropologists, economists and agricultural scientists are essential. A cohesive response by multi-national and government agencies working on health and climate science to fund modelling studies and long-term cohort studies in countries with high snakebite burden and vulnerable to climate change is urgently required.

Strengths and weaknesses of the review

In our study, we used a specific eligibility criterion for the inclusion of studies, and searched multiple electronic databases (including environmental) using a robust search strategy, supplementary searches and independent screening and data extraction. We acknowledge that not searching Latin American electronic databases is a limitation (our team does not have linguistic capacity in Spanish and Portuguese) but contend, that this does not change the overall implications of the study.

Conclusion

Current evidence indicated that climate change will lead to a change in snakebite burden and there is a need for primary healthcare systems to be prepared for this. However, more transdisciplinary research is required to comprehensively understand the issue going beyond incidence, especially in countries with a high burden of snakebite. Community-based approaches for biodiversity and prevention, together with improving resilience of primary care and public health systems are required to mitigate the impact of climate change on snakebite.

Author contributions

Conceptualisation, methodology, formal analysis, project administration, writing of first draft -SB; Data curation - DB, SB; Supervision- JJ; Validation, Writing – review & editing- SB, DB, JJ, Guarantors- SB, DB, JJ

Financial support and sponsorship

SB is supported by the University International Postgraduate Award (UIPA) by the University of New South Wales (UNSW), Sydney, Australia. The evidence synthesis has been supported internally by The George Institute for Global Health, as a part of a deep-thinking report on snakebite.

Conflicts of interest

There are no conflicts of interest.

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Appendix

Appendix 1: Search Strategies

This appendix consists of search strategies used for Bhaumik S *et al*. The impact of climate change on the burden of snakebite: Evidence synthesis and implications for primary healthcare

Contents

Ovid MEDLINE (R) and Epub ahead of print, in-process & other non-indexed citations, daily and versions (R) <1946 to December 11, 2020>

Search Strategy:

1. exp Climate Change/or climate change.mp. (44058)
2. (climate adj (resilience or adaption or mediated or vulnerability or induced)).mp. [mp = title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] (884)
3. exp Snake Bites/(4733)
4. Snakebit*.mp. (2416)
5. ((bite* or envenom*) adj2 Snake*).mp. (5823)
6. exp Snake Venoms/(18504)
7. (snake adj2 venom).mp. (5698)
8. exp Snakes/or snake*.mp. [mp = title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] (28883)
9. 1 or 2 (44363)
10. 3 or 4 or 5 or 6 or 7 or 8 (36989)
11. 9 and 10 (86)

Embase classic + Embase <1947 to 2020 December 11>

Search Strategy:

1. exp Climate Change/or climate change.mp. (54404)
2. (climate adj (resilience or adaption or mediated or vulnerability or induced)).mp. (889)
3. exp Snake Bites/(7037)
4. Snakebit*.mp. (7780)
5. ((bite* or envenom*) adj2 Snake*).mp. (4124)
6. exp Snake Venoms/(28432)
7. (snake adj2 venom).mp. (18087)
8. exp Snakes/or snake*.mp. (38137)
9. 1 or 2 (54688)
10. 3 or 4 or 5 or 6 or 7 or 8 (50011)
11. 9 and 10 (118)
12. limit 11 to exclude medline journals (11)

Global health <1910 to 2020 week 48>

Search Strategy:

1. exp Climate Change/or climate change.mp. (11392)
2. (climate adj (resilience or adaption or mediated or vulnerability or induced)).mp. (133)
3. exp Snake Bites/(3171)
4. Snakebit*.mp. (1775)

5. ((bite* or envenom*) adj2 Snake*).mp. (3823)
6. exp Snake Venoms/(0)
7. (snake adj2 venom).mp. (3522)
8. exp Snakes/or snake*.mp. (13042)
9. 1 or 2 (11436)
10. 3 or 4 or 5 or 6 or 7 or 8 (13042)
11. 9 and 10 (16)

Zoological record < 1978 to November 2020>

Search Strategy:

1. exp Climate Change/or climate change.mp. (25800)
2. (climate adj (resilience or adaption or mediated or vulnerability or induced)).mp. (852)
3. exp Snake Bites/(0)
4. Snakebit*.mp. (222)
5. ((bite* or envenom*) adj2 Snake*).mp. (195)
6. exp Snake Venoms/(0)
7. (snake adj2 venom).mp. (996)
8. exp Snakes/or snake*.mp. (23585)
9. 1 or 2 (26166)
10. 3 or 4 or 5 or 6 or 7 or 8 (23585)
11. 9 and 10 (144)

Environment file (EBSCO host) December 14 2020,

1. (snake or snakebite OR "snake venom" OR "snake anti-venom) AND ("climate change" OR climate resilience" or "Climate adaption" OR "climate mediated" OR "climate vulnerability" OR "climate induced") (217)

Expanders- Apply related words; Apply equivalent subjects

Appendix 2: Reasons for Exclusion of Full Text

This appendix consists of reasons for exclusion at full text level for Bhaumik S *et al*. The impact of climate change on the burden of snakebite: Evidence synthesis and implications for primary healthcare

Study ID	Reason for exclusion
Angarita-Gerlein 2017[1]	Reported relationship between climatic, meteorological or seasonal parameters with snakebite or snakebite risk, with no relation to climate change
da Costa 2019[2]	Reported relationship between climatic, meteorological or seasonal parameters with snakebite or snakebite risk, with no relation to climate change
Ebrahimi 2018[3]	Reported relationship between climatic, meteorological or seasonal parameters with snakebite or snakebite risk, with no relation to climate change
Fry 2018[4]	Wrong study design (Review)
Huber 2009[5]	Study not related to snakebite/snakebite risk
Lawing 2011[6]	Study did not report data on snakebite/snakebite risk
Mukeka 2020[7]	Study did not report data on snakebite/snakebite risk
Na 2014[8]	Reported relationship between climatic, meteorological or seasonal parameters with snakebite or snakebite risk, with no relation to climate change
Sullivan 2014[9]	Study not related to snakebite/snakebite risk
Tauzer 2019[10]	Did not study the impact of climate change on snakebite/snakebite risk
Yañez-Arenas 2014[11]	Reported relationship between climatic, meteorological or seasonal parameters with snakebite or snakebite risk, with no relation to climate change
Yañez-Arenas 2018[12]	Reported relationship between climatic parameters with snakebite or snakebite risk, with no relation to climate change
Yousefi 2020[13]	Reported relationship between climatic, meteorological or seasonal parameters with snakebite or snakebite risk, with no relation to climate change
Ochoa 2020[14]	Wrong study design (review): review did not include any primary study that met inclusion criteria
Longbottom 2018[15]	Reported relationship between climatic, meteorological or seasonal parameters with snakebite or snakebite risk, with no relation to climate change

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