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Snakebite incidence in rural sub-Saharan Africa might be severely underestimated

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ABSTRACT

Snakebites in sub-Saharan Africa account for 20,000 to 32,000 annual deaths. But since most data is retrieved from hospital or incomplete central databases, and many victims do not seek hospital treatment or prefer traditional remedies, the current numbers are likely underestimated. In order to reduce snakebite incidence by 50% by 2030 as targeted by World Health Organization, it is crucial to accurately quantify and understand the current rates of snakebite incidence, which can only be reliably measured through household surveys. In this study, we interviewed 1037 households in nine communities in Cabo Delgado, northern Mozambique. Our aim was to quantify true snakebite incidence and under-reporting, by comparing the total number of snakebites reported to our team during household surveys with the subset of reports that reached health centers. We additionally quantified snakebite incidence in terms of species, location of the attack, type of treatment, season, and gender of the victims. These data allow us to propose conservative extrapolations of snakebite incidence and mortality for the province of Cabo Delgado and for Mozambique. Of all snakebites reported in the surveys (N = 296), most incidents were treated exclusively by traditional doctors (N = 174; 59%) and 25% were not seen by any doctor. Most bites occurred on farms and during the rainy season. Using a conservative estimation where we assume our results to be extrapolatable for the whole of rural Mozambique, but considering snakebites in urban areas to be inexistent, we propose that in Cabo Delgado, every year at least 6124 people are victims of snakebites, of which at least 791 result in deaths. In Mozambique, we extrapolated that every year at least 69,261 people are victims of snakebite, of which at least 8950 result in death (one in eight snakebites is fatal). Our estimates are the first for Mozambique based on data retrieved in the country, and despite being an underestimation they increase snakebite incidence levels ten-fold and the number of deaths by 30-fold. Urgent and widespread surveys are needed to further assess the full extent of snakebites in sub-Saharan Africa, explore regional patterns and develop mitigation plans.

1. Introduction

Up to 5.5 million snakebites are estimated to occur globally every year, which result in around 1.8 million cases of snakebite envenoming and 94,000 deaths (Chippaux, 1998; Kasturiratne et al., 2008). Most of the victims are poor people under serious education and health care constraints (Gutiérrez et al., 2017; Harrison et al., 2009).

The World Health Organization set the goal of reducing the incidence of death and disability from snakebite by 50% by 2030, and to achieve this, snakebite prevention should be given equal if not higher priority than snakebite treatment (World Health Organization, 2019). However, a pre-requisite to develop mitigation plans is the production of reliable

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spatial and taxonomic data, and how it varies across regions and environments. Unfortunately, most low-income tropical countries lack any collected field data (Malhotra et al., 2021).

It is estimated that snakebites in sub-Saharan Africa account for 20,000 to 32,000 annual deaths (Gutiérrez et al., 2017). These figures are based on hospital returns or incomplete central databases of only a few countries and are bound to be underestimated. This is because many victims do not seek hospital treatment and prefer traditional remedies (Gutiérrez et al., 2006). For instance, in Nigeria and Kenya, only 8.5% and 27% of snakebite victims sought hospital care, respectively (Pugh et al., 1980; Snow et al., 1994). As a result, some people may die at home, with their deaths unrecorded (Fox et al., 2006). If hospitals are sought, it is often only when the envenomation is severe and traditional treatment is inadequate (Chippaux, 2011).

The preference for traditional healers may be common in many low-income countries where individuals lack access to public healthcare (Kasturiratne et al., 2008). While most of the available data on snakebites should be regarded as lower boundaries, the few available surveys might be biased towards problematic areas and result in the overestimation of the snakebite burden (Kasturiratne et al., 2008). Household data, compared to hospital surveys, are therefore more representative of the actual situation and less biased. However, such surveys are more expensive and time-consuming, meaning that very few countries have these data available (Chippaux, 2011).

In this study, we present data from household snakebite incidence in Cabo Delgado, northern Mozambique. The country has a population of over 30 million people, where most of the population (68%) live in rural areas and practice agriculture for a living (Chilonda et al., 2011), exposing millions to snakebites. The high number of medically important snakes in the country, the percentage of people living in rural areas, and the total absence of snakebite incidence data, confer Mozambique the status of high priority for studies of venomous snake demography and snakebite incidence modelling (Malhotra et al., 2021).

The subset of medically important snakes can be further subdivided into category one or two depending on their propensity to interact with humans and their clinical grading of toxicity. Northern Mozambique is one of the regions in Sub-Saharan Africa with the lowest numbers of Medically important snakes (Longbottom et al., 2018). Nevertheless, based on inferred distribution maps and species distribution modelling, at least seven medically important snake species (snakes that can potentially cause death, limb amputation or morbidity) occur in the area: Bibron's Stiletto Snake (*Atractaspis bibronii*), Puff Adder (*Bitis arietans arietans*), Black Mamba (*Dendroaspis polylepis*), Boomslang (*Dispholidus typus*), Mozambique Spitting Cobra (*Naja mossambica*), Forest Cobra (*Naja subfulva*) and Mozambican Vine Snake (*Thelotornis mossambicanus*) (Longbottom et al., 2018).

Here we complement our previous ethnobiological study (Farooq et al., 2021) and address snakebites in detail. Based on a survey of 1037 households in 2019 in Cabo Delgado, northern Mozambique (Fig. 1), we quantify the underestimation of the snakebite incidence in the country by taking into account incidents that were not reported to health centers. We additionally explore the snakebite incidence in terms of species, location of the attack, season, gender of the victims, and distance to the closest health center. We made conservative extrapolations for snakebite incidence and mortality for the province of Cabo Delgado and for Mozambique.

2. Methods

Members of our team (see Author contributions) interviewed 1037 households in nine communities (Fig. 1.) in Cabo Delgado, northern Mozambique. Our nine communities were distributed across the districts of Ancuabe, Balama, Chiure, Meluco, Montepuez and Namuno. There is a lack of official information on the real number of communities in our study area, but since there is only one leader per community and in 2005 there were at least 169 community leaders in the six districts, we made

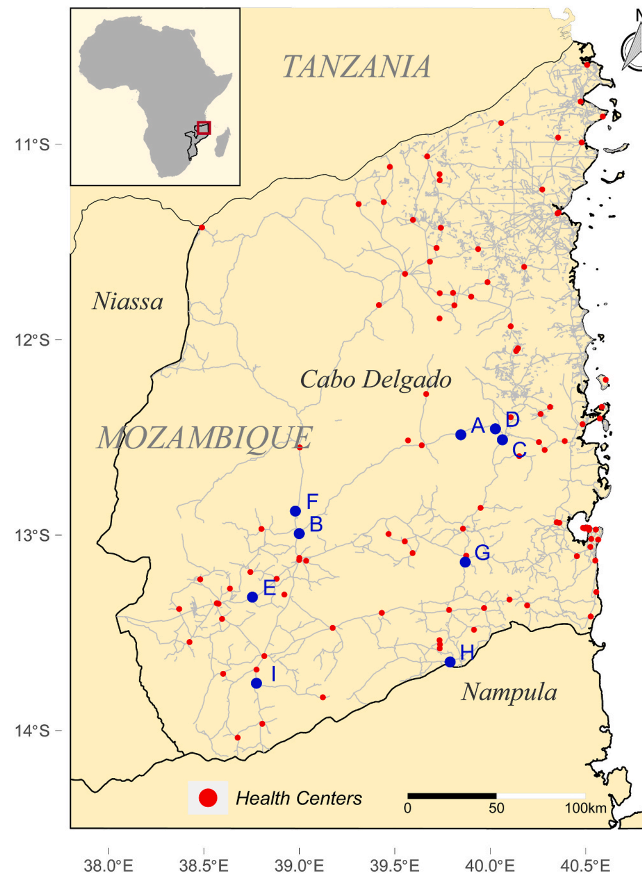

Fig. 1. Map showing the location of the surveyed communities (blue dots): A: Citate, B: Eduardo Mondlane, C: Mitambo, D: Muaguide, E: Muapé, F: Niuhula, G: Ntique, H: Ocua, I: Shopa. In grey are the roads and in red are the locations of the health centers. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the assumption that there are at least 169 communities within our study area (Perfis Distritais, 2005a; 2005b; 2005c; 2005d, 2005e). To each household, we asked if they knew of any amphibian or reptile incident (bite) affecting anyone in their community in the last 20 years, regardless of whether it happened to the person living in the inquired household. This was done to avoid omitting incidents from households (huts are built and put down frequently) that ceased to exist, emigrated families, and deadly bites. The interviewed households in each village were decided based on the indication by a local guide indicated by the leader of the community. The minimum number of households to interview was based on the sample size estimated based on a 95% confidence level, a margin of error of 5%, and an unknown population probability set to 50%. To avoid overestimating incidents by extrapolation, we used the cases obtained in each community (61–86% coverage) as the total number of bites for the whole community (100%). We recorded the name of the victim, the species that caused the incident, the location of the attack, the year, the season, the consequences of the bite in terms of symptoms and whether victims attended the hospital and/or traditional medicine. To avoid double-counting incidents we used the names of the victims to remove duplicates (all name information was omitted from the published dataset). Since local communities have good knowledge and unique names for the species occurring in the area (Farooq et al., 2021), we retrieved the name of the snake by asking for its local name. We also had field guides to show to the interviewees whenever the person didn't know the name of the snake, but this rarely happened. The full set of questions can be found in Table 1.

We focused our study on snakebites, so we excluded from the analyses data related to attacks by crocodiles (14 attacks in the last 20 years,

Table 1
List of questions used to conduct this study.

	Questions
1	Personal information: Age, gender and occupation of the interviewed person.
2	Whether they recall a snakebite event in the last 20 years in that locality.
3	The name of the victim(s) and year(s)
4	The species that caused the accident(s)*
5	Whether the victim(s) survived
6	Location of the attack(s): Home/Village/Farm/Unknown/Other
7	Season of the attack(s): Rainy/Dry/Unknown
8	In case of an attack, if the victim(s) went to a health center, a traditional doctor, both or none.

50% fatal), amphibians (3 bites, 0% fatal) and chameleons (2 bites, 0% fatal), but the information can be assessed in the raw data in the supplementary material.

The choice of which communities to survey was based on accessibility and proximity to inselbergs for the main purpose of conducting biodiversity surveys. This is especially important because household surveys may be biased to areas where there is an already known high frequency of snakebites (Chippaux, 2011). We did not incorporate the effect of proximity to inselbergs to the analyses because all medically important species in the study areas are widespread lowland species not relying on inselbergs.

We estimate that our 1037 inquired houses correspond to 7544 people by multiplying the number of existing houses in each community by 4.9, the estimated average number of members in a household for Cabo Delgado in 2019/2020 (Instituto Nacional de Estatística, 2021).

As discussed in Farooq et al. (2021), we assumed that references to the Brown House Snake will include the Stiletto Snake due to the overlap of the same local name – *Hiriri*. We collapsed the nine species with fewer attacks, except for the Southern African Python into a group called "Other snakes" which included the Eastern Tiger Snake (*Telescopus semiannulatus*), Rufous Beaked Snake (*Rhamphiophis rostratus*), Olive Grass Snake (*Psammophis mossambicus*), Olive Marsh Snake (*Natriciteres olivacea*), Boulenger's Garter Snake (*Elapsoidea boulengeri*), Common Slug Eater (*Duberria lutrix*) and Common Purple-glossed Snake (*Amblyodipsas polylepis*). This was done because these snakes together account for a negligible amount of bites and also, as discussed in Farooq et al. (2021), there is a high probability that these identifications are erroneous. As a probable example of erroneous reporting we documented, the Common Slug Eater (*Duberria lutrix)* and the Rufous Beaked Snake (*Rhamphiophis rostratus)* have not been reported anywhere else to cause snakebite incidents. The Southern African Python records were kept unchanged, since the snake is well known and also poached (Farooq et al., 2021), and will thus hardly be confused by any other species.

We grouped the information regarding the place where snakebites took place into five categories: farm, village, home, other places and unknown place. The "other places" included all bites that occurred on a mountain, road or river. The "unknown place" referred to snakebite cases where the interviewee was uncertain about where the bite took place. The gender of the victim was not asked during the interview, but we inferred it based on the names of the victims (none of the names reported are unisex names). To the snakebite incidences which were not possible to ascribe to a specific season, we refer to them as unknown.

To calculate the interaction between gender and season to the location of the bites we used the Fisher exact test. To calculate the overall interaction between gender and season with bites we used a binomial test and considered 50% as the null hypothesis in both instances. To test whether snakebite treatment was associated with the snake species, we ran a Fisher's exact test with Monte Carlo with 10,000 replicates. We followed this analysis with a multinomial test for each of the species with an expected probability of the observed pattern of snake treatment. We repeated this step excluding the species with the lowest p-value to avoid overestimation of the significance of other species in relation to the applied treatment. We ran this analysis on a subset of the data corresponding to snakes with more than 5 bites and where we excluded the variable of treatment by both medical and traditional doctors. This was done because the variable may include victims that visited either traditional or medical doctors first and subsequently changed their treatment method.

To assess whether distance has an effect on type of treatments and mortality we grouped the nine communities into two groups based on the largest gap between the ordered distances to the closest health center (UN, 2017). Group 1 contained the communities Citate and Niuhula, 20.1 and 21.7 km away from the closest health center respectively and group 2 containing the remaining communities which ranged between 13.8 and 0.4 km away from the closest health center. Using these groups, we tested (1) the preferred type of treatment: health center versus traditional, (2) the use of treatment: traditional and health center treatment versus no treatment, and (3) Number of deadly bites. This was done using Fisher's exact tests.

2.1. *Snakebite incidence*

To calculate the snakebite incidence in the communities, we made the assumption that we captured all snakebite incidents in each of the whole communities surveyed in the last 20 years – a clear underestimation due to memory bias. We used the number of bites per community, the number households and the average number of people per households in the region to extrapolate the number of bites per 100,000 people.

To calculate the snakebite incidence for the whole province and country we made the assumption that snakebite only occurs in rural areas. Since both these assumptions are likely underestimates, our extrapolations are also likely to be lower boundaries. We used estimations for rural population in Mozambique from www.macrotrends.net and for Cabo Delgado from INE (2017).

We consider likely that our data on snakebite incidents was heavily skewed towards cases in recent years, rather than farther back in the 20-year period considered (Fig. 1 – Supplementary material). Therefore, we made three estimations based on three overlapping subsets of the data: (1) last 20 years, (2) last 10 years and (3) last 5 years and used the average number of bites. This was done as an attempt to decrease the impact of recall biases and of people not living in the communities anymore (e.g. emigration or death). Finally, to understand the extent to which snakebite is underestimated, since not all snakebite incidents reach the hospitals, we compared our estimation of snakebite incidence with the subset of data that reached health centers. We made the assumption that if the victim was treated at a health center, there should be an entry for such instance.

3. Results

We inquired 1037 households that we estimate to correspond to 7544 (estimated population) people by multiplying the number of existing houses in each community by 4.9, the estimated average number of members in a household for Cabo Delgado in 2019/2020 (Instituto Nacional de Estatística, 2021) (Table 2).

The interviewed community members were on average 37 years old (Median = 35: ♂ = 36, ♀ = 32; SD = 14.22: ♂ = 14.4, ♀ = 14) and out of 1037 people head of households interviewed, 1025 practiced agriculture at least partially as subsistence activity (Table S1 – Supplementary material).

Most snakebite incidents occurred in farms, and bites from the Puff Adder and the Brown house/Stiletto Snake group were the most common across farms and villages. The Mozambique Spitting Cobra was responsible for the second highest number of bites in homes. Most Black Mamba bites took place in farms, and the same was true for the Snouted Night Adder (Fig. 2).

Despite no significant relationship of locations with gender ($p = 0.095$) or season ($p = 0.26$) the fraction of snakebite incidents on women

Table 2
Sites surveyed in this study and extrapolated population.

Site	Total households	Enquired households (percentage of total)	Estimated population
Citate	245	152 (62%)	1201
Eduardo Mondlane	222	141 (64%)	1089
Mitambo	200	135 (68%)	980
Muaguide	149	91 (61%)	730
Muapé	222	143 (64%)	1089
Niuhula	65	56 (86%)	319
Ntique	133	99 (74%)	652
Ocua	136	101 (74%)	666
Shopa	167	119 (70%)	818
Total	1539	1037 (67%)	7544

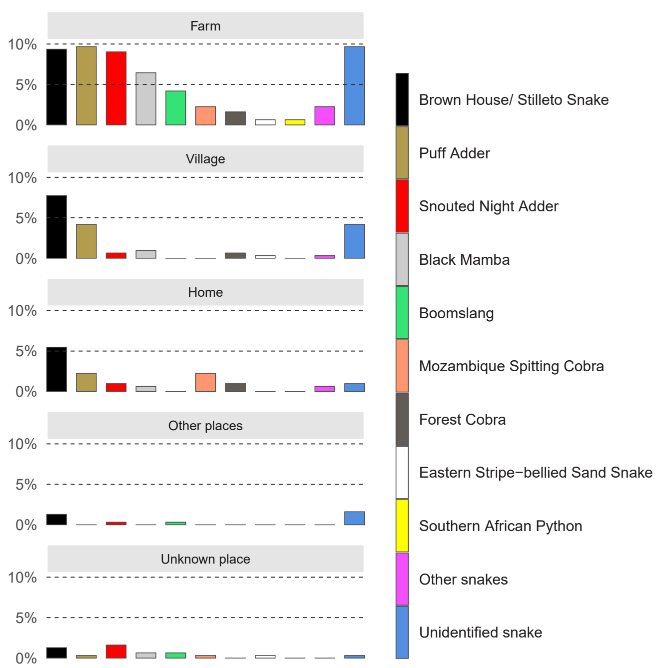

Fig. 2. Most attacks occur in farms (N = 176), followed by villages (N = 60), homes (N = 44), mountains, rivers, roads (Other places, N = 13) and unknown places (N = 17). Some species can be particularly problematic in villages and homes, such as the Stiletto Snake, the Puff Adder and the Spitting Cobra.

was higher at home and lower in other locations that include mountains, rivers and roads. In the villages and farms, the incidence of bites was similar between women and men. Most attacks occurred in the wet season across all locations. Only 18% of the bites resulted in death (Fig. 3).

Of all bites (N = 296), most snakebite incidents were treated exclusively by traditional doctors (N = 174/59%) and 25% were never taken care of by any doctor (traditional or with a medical university degree). A total of 55.4% untreated bites resulted in death (Fig. 4A). Compared to snakebites taken to health centers or traditional doctors, most bites that went untreated belonged to Black Mambas (N = 20, Traditional = 6).

Only 1.1% of the bites dealt by a traditional doctor resulted in death, while 9.4% died after going to a health center, but snakebites taken to traditional doctors were mostly in the Brown House/Stiletto Snake group (N = 61), while bites coming from the Puff Adder add a higher proportion in the cases treated in health centers (N = 7/32, versus Traditional = 19/174, No Treatment = 18/74, Both = 4/16) (Fig. 4B).

There was a significant interaction between the snake and the type of treatment ($p < 0.001$) and between the type of treatment and the species Puff adder ($p = 0.0475$), Brown House/Stiletto Snake grouping ($p < 0.0001$) and Black mamba ($p < 0.0001$). After excluding the data from the species with the lowest p-value, the Black mamba, we still got significant interactions for Puff adder ($p = 0.0025$), Brown House/Stiletto Snake grouping ($p = 0.0068$) and Boomslang ($p = 0.0254$).

Some of the results varied between villages based on distance to healthcare centers. We did not find indications that visits to healthcare centers rather than treatments by traditional healers were more likely in the villages closets to healthcare centers (*p*-value = 0.4). We did, however, find that the more isolated villages had a higher fraction of bites receiving no treatment (*p*-value = 1.6e-05) and also a higher mortality in the more isolated villages (p-value = 0.001).

3.1. *Snakebite incidence*

We retrieved 297 snakebite incidents of which 46 resulted in death. Our extrapolations suggest that an average of 352 people in every 100,000 could be victims of snakebites each year in rural Cabo Delgado, of which ~46 resulting in deaths. In our worst-case scenario (last 5 years) at least 533 people in every 100, 000 people on average could have been victims of snakebites annually in rural Cabo Delgado. Of those, ~66 would have resulted in death. In our best-case scenario, per 100,000 people, 196 snakebites could be estimated to have occurred, resulting in ~31 deaths.

When only considering cases that reach health centers, we extrapolated an average of a six-fold underestimation of total snakebite incidents and a 14-fold underestimation of death by snakebite (Table 3).

Using a conservative estimation where we assume our results to be true for the whole of rural Mozambique (68% - 19,667.795 people), but considering snakebites in urban areas to be inexistant, we extrapolate that in Cabo Delgado, every year 6124 people are victims of snakebites, of which 791 result in death. If the same relation would apply to the national level, we extrapolated that in Mozambique, every year 69,261

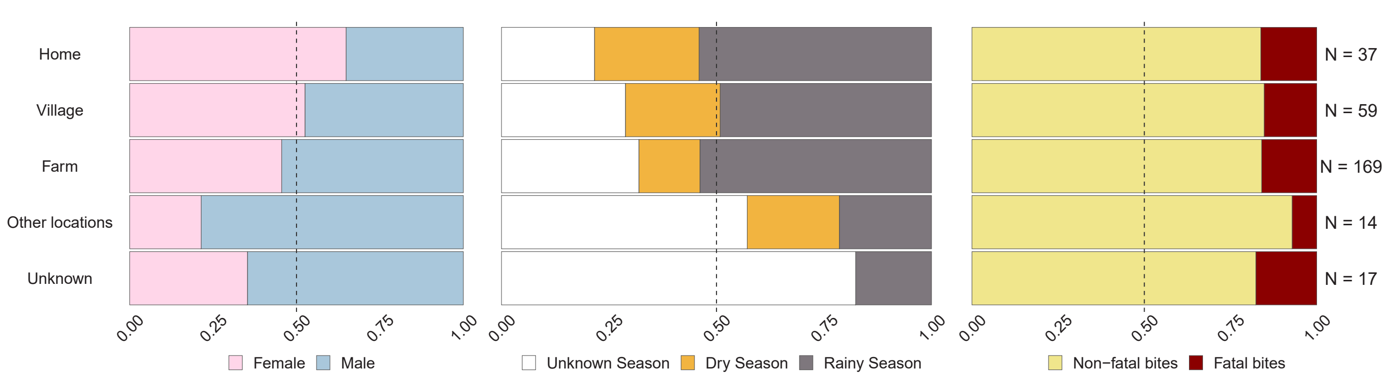

Fig. 3. Most attacks at home occurred to women, while in farms they affected both genders to the same extent. Most attacks occurred in the wet season and were not fatal. There was no significant relationship between gender, season and consequence of bite in relation to the location of the bite.

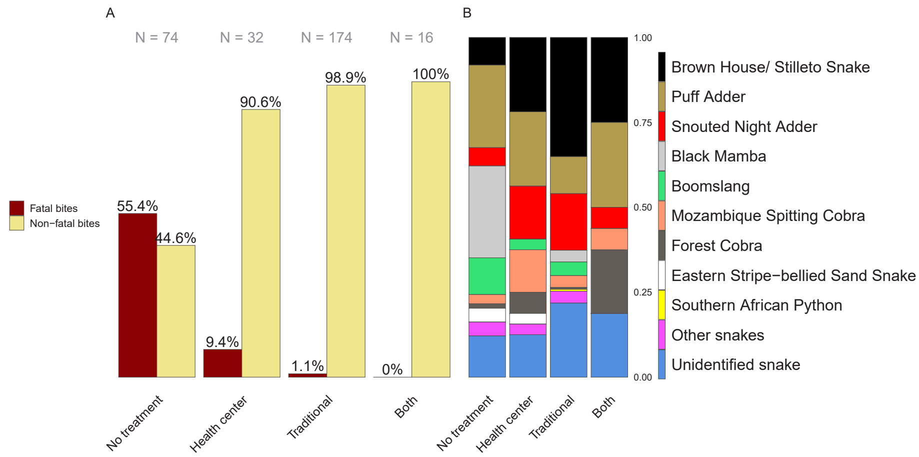

Fig. 4. A. Several bites were not seen by any doctor or traditional doctor, and a percentage of 82% of all bites are never taken to health centers. B. Most bites that are not treated were attributed to Black Mambas, which may explain the high percentage of deaths in untreated snakebites when compared to bites handled in health centers and/or by traditional doctors.

Table 3
Snakebite incidence extrapolation for 100,000 people in rural Cabo Delgado.

	Last 20 years (Study area)	Last 10 years (Study area)	Last 5 years (Study area)	Yearly bites in the last 20 years per 100,000 people (rural areas)	Yearly bites in the last 10 years per 100,000 people (rural areas)	Yearly bites in the last 5 years per 100,000 people (rural areas)	Yearly average for 100,000 people (rural areas)	Cabo Delgado	Mozambique
Total snakebites	296,00	247,00	201,00	196,18	327,41	532,87	352,16	6124,07	69,261,37
Deadly snakebites	46,00	30,00	25,00	30,49	39,77	66,28	45,51	791,44	8950,97
Snakebite victims reaching health centers	48,00	40,00	35,00	31,81	53,02	92,79	59,21	1029,64	11,644,95
Deadly snakebites that reach health centers	3,00	2,00	2,00	1,99	2,65	5,30	3,31	57,63	651,77

people are victims of snakebites, of which 8950 result in death. In cities, due to its inherent land transformation, snakebite drops as population density increases (Chippaux, 2011), therefore, we assumed the most conservative scenario of zero bites.

4. Discussion

4.1. The impact of species behaviour on snakebite patterns

As documented in other studies in the continent (Tchoffo et al., 2019), our survey also shows that most snakebite attacks occur in farms. There they are primarily caused by Puff Adders, followed by (in decreasing order of importance) the easily confused Brown House/-Stiletto Snake, the Snouted Night Adder and the Black Mamba.

Even though Boomslangs have a potent hemotoxic venom, they are not known to cause high numbers of attacks (Wood et al., 2016). There were no Boomslang bites reported in homes or in villages: all the bites occurred either in farms or other locations. In villages, most bites were caused by the Brown House/Stiletto Snake grouping, the Puff Adder and the Black Mamba. In homes, most bites were caused by Brown House/Stiletto Snake grouping followed by the Mozambique Spitting Cobra and then the Puff Adder. This was an expected finding since the Mozambique Spitting Cobra is well known for attacking people in their sleep in their homes (Vermaak et al., 2010).

Over 50% of the bites not taken to either health centers or traditional doctors resulted in deaths. This is likely associated with the fact that the highest proportion of bites in cases that were not hospitalized were attributed to Black Mambas. This snake produces a deadly neurotoxic venom that can kill an adult in less than an hour, therefore preventing the victim from reaching either health centers or traditional doctors. Despite 82% of the bites never being hospitalized, there was a much higher proportion of bites from Puff Adder, Mozambique Spitting Cobra and Forest Cobra in the hospitalized cases when compared with the arguably less dangerous bites coming from the Brown House/Stiletto Snake grouping. These communities have previously been shown to hold a very good understanding of snakes and snakebites (Farooq et al., 2021), and they may therefore potentially opt between traditional medicine and health center according to the dangerousness of the snake responsible for the bite. This likely explains the fact that traditional doctors had a lower rate of mortality when compared to health centers. The lack of a relationship between distance to healthcare centers and probability of visiting them potentially suggest a preference for traditional treatments even if health centers exist nearby. Based on this interpretation, the association between the probability of getting any treatment at all and distance suggest a lack of both health care centers and traditional healers in the more isolated communities.

4.2. Snakebite incidence and treatment

Our study shows that only 18% of cases seek help from health centers, a percentage that falls between results documented in 8.5% in Nigeria (Pugh et al., 1980) and 27% in Kenya (Snow et al., 1994). That result, taken together with our finding that most people rely on traditional medicine, suggests that most snakebites remain undocumented, thereby underestimating the true extent to which snakebites affect rural communities (Fox et al., 2006; Gutiérrez et al., 2006). Many studies have shown how effective hospital treatments can be at preventing death by snakebites, where snakebite fatalities range between 0.3 and 0.8% (Blaylock, 1982, 2004; McNally and Reitz, 1987). Our study unveils quite a complex interplay between bites and treatment. We see that 56% of people seek traditional medicine, compared to the 18% that seek health centers, and that traditional medicine has higher survival rates (98.9% versus 90.6%). However, we show here that this is a result of the variability in the dangerousness of each bite. Local communities as a whole have great knowledge of snake identification and snakebite symptoms (Farooq et al., 2021), and they use this information to select which bites should be taken to the hospital. Serious bites, such as the ones from Puff Adders are mostly taken to hospitals (22% of the bites in health centers versus 10% in traditional medicine) which eventually results in a higher mortality rate when compared to local treatment. Contrary to the above statement, all treated Black Mamba bites were treated by traditional healers (Fig. 4B). A possible explanation may be the fact that unlike in Puff Adders, the venom from Black Mambas is fast acting, causing death in under an hour (Craik and Schroeder, 2013). Therefore, due to the envisaged seriousness of the bite by the communities, they quickly seek immediate care from an easily accessible traditional healer within the community instead of going to hospitals that may be located far from the affected communities. Less serious bites such as the ones caused by the Brown House/Stiletto Snake group were mostly dealt with traditional medicine or ignored (35% of the bites in threated by traditional medicine versus 10% no treatment and 20% in health centers). We further note that even among rural areas, our estimate of snake mortality may be very conservative since mortalities were found to be higher in more isolated villages and we may have visited villages that are closer to health care centers than average. The potential magnitude of this effect is however not at present testable since no data is available on the size and placement of villages in the area.

Based on our estimates, in Mozambique each year nearly 7000 people may be victims of snakebites, which may result in some 319 deaths (Halilu et al., 2019). Our estimations were based on unrealistic assumptions, such as people being informed of every snakebite incident across the whole community, the fact that they would remember every snakebite incident in the last 20 years, and that there are no bites in urban areas in the country. Despite our conservative estimation, we extrapolated that every year, nearly 70,000 people are victims of snakebites, of which nearly 9000 result in death. Our numbers suggest that snakebites in the literature may have been underestimated by an order of 10 and deaths by almost 30 times. In Africa, it is estimated that snakebite incidence varies from 100 to 650 bites per 100,000 inhabitants resulting in over 10 deaths every year (Mackessy, 2016). Our extrapolation is aligned in terms of snakebite incidence, which falls between 196 and 352, but the number of deaths that we extrapolate here is between 31 and 66, 3 to 7 times higher.

The snakebite incidence is heterogeneous in sub-Saharan Africa (Chippaux, 2012), therefore extrapolations to the region can be problematic. Although, in this study, we assumed that Northern Mozambique is on par in the region in terms of the presence of category one and two of snake species, while in reality, spatially, Northern Mozambique is assumed to contain a lower fraction of such snakes when compared to other areas in Sub-Saharan Africa (Longbottom et al., 2018). Furthermore, snakebite incidence tends to be less pronounced as areas become more developed (Chippaux, 2011). For our provincial and national estimates, we considered urban areas to have zero snakebite incidents and extrapolated the data only to the rural percentage of the country (70%) and assumed that estimation to be same for the whole population (100%) of the province and country.

Comparing our collection of snakebite incidences with the cases that would have been retrieved by health center databases, we see that estimations based on hospital entries may underestimate the number of snakebites six times and deaths by 14 times. The great underestimation of deadly snakebites is likely associated with deaths where the victims die before reaching hospital facilities. Snakebites that are treated by traditional doctors will also not be registered at health centers and will contribute to the underestimation of the snake incidence in the region. Since many attacks result in rapid death and most snake victims are taken to traditional doctors, to conduct this work in communities rather than in hospitals is crucial to more accurately quantify the snake incidence in the region.

There is still important research that would help to accurately quantify the impact of snakebites on the people living in Mozambique, such as (1) understanding the availability of qualified personal and antivenom to treat snakebites, (2) retrieving information on long-lasting damage (e.g., amputations or wounds that require surgery) derived from snakebite in order to estimate snakebite burden in the country and (3) retrieve information on the demographics of the affected victims (e.g., percentage of children and working-class). Without retrieving such data, it won't be possible to accurately quantify the impact of snakebite in Mozambique and hence to measure the target of The World Health Organization in reducing death and disability by snakebite by 50% by 2030.

Ethics approval and consent to participate

This study was authorized by the Natural Sciences Faculty at Lúrio University's (Research and Extension Office – Ref: 91/UniLúrio/FCN/GPGPE/ 2022) and the National Health Institute (Operational Research Nucleus of Pemba (NIOP) – Ref: 097 SPS/CD/NIOP/GCG/ 2022). At the local level, it was also authorized by both the district offices where the communities were situated and by the chiefs of the surveyed communities, who not only authorized but supported our study throughout the whole period.

Authors' contributions

Harith Farooq: Conceptualization, Methodology, Resources, Data curation Writing – original draft, Visualization, Supervision, Project administration. **Claudio Bero:** Investigation, Writing – review & editing. **Yolanda Guilengue:** Investigation, Writing – review & editing. Clementina Elias: Investigation, Writing – review & editing. **Yasalde Massingue:** Investigation, Writing – review & editing. **Ivo Mucopote:** Investigation, Writing – review & editing. **Cristóvão Nanvonamuquitxo:** Methodology, Supervision, Project administration, Writing – review & editing. **Johan Marais:** Writing – review & editing. **Søren Faurby:** Conceptualization, Methodology, Writing – review & editing. **Alexandre Antonelli:** Conceptualization, Writing – review & editing.

Data availability

The data will be shared in the supplementary material

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.toxicon.2022.106932.

References

Blaylock, R., 1982. Snake bites at triangle hospital: January 1975 to June 1981. Cent. Afr. J. Med. 28 (1), 1–11.

Blaylock, R., 2004. Epidemiology of snakebite in Eshowe, KwaZulu-Natal, South Africa. Toxicon 43 (2), 159–166.

Chilonda, P., Xavier, V., Luciano, L., Gemo, H., Chamusso, A., Zikhali, P., Faria, A., Govereh, J., Manussa, S., Acubar, B., 2011. Monitoring agriculture sector performance, growth and poverty trends in Mozambique. 2010 Annual Trends and Outlook Report. Maputo: Mozambique Strategic Analysis and Knowledge Support System, in collaboration with MINAG, ICRISAT, IFPRI and IWMI. https://www.resakss.org/sites/default/files/pdfs/MozSAKSS_ATOR_2010.pdf.

Chippaux, J.P., 1998. Snake-bites: appraisal of the global situation. Bull. World Health Organ. 76 (5), 515.

Chippaux, J.-P., 2011. Estimate of the burden of snakebites in sub-Saharan Africa: a meta-analytic approach. Toxicon 57 (4), 586–599. https://doi.org/10.1016/j.toxicon.2010.12.022.

Chippaux, J.-P., 2012. Epidemiological investigation on envenomation: from theory to practice. J. Venom. Anim. Toxins Incl. Trop. Dis. 18 (4), 446–450.

Craik, D.J., Schroeder, C.I., 2013. Peptides from mamba venom as pain killers. Angew. Chem. Int. Ed. 52 (11), 3071–3073. https://doi.org/10.1002/anie.201209851.

Farooq, H., Bero, C., Guilengue, Y., Elias, C., Massingue, Y., Mucopote, I., Nanvonamuquitxo, C., Marais, J., Antonelli, A., Faurby, S., 2021. Species perceived to be dangerous are more likely to have distinctive local names. J. Ethnobiol. Ethnomed. 17 (1), 69. https://doi.org/10.1186/s13002-021-00493-6.

Fox, S., Rathuwithana, A., Kasturiratne, A., Lalloo, D., De Silva, H., 2006. Underestimation of snakebite mortality by hospital statistics in the Monaragala District of Sri Lanka. Trans. R. Soc. Trop. Med. Hyg. 100 (7), 693–695. https://doi.org/10.1016/j.trstmh.2005.09.003.

Gutiérrez, J.M., Theakston, R.D.G., Warrell, D.A., 2006. Confronting the neglected problem of snake bite envenoming: the need for a global partnership. PLoS Med. 3 (6) https://doi.org/10.1371/journal.pmed.0030150.

Gutiérrez, J.M., Calvete, J.J., Habib, A.G., Harrison, R.A., Williams, D.J., Warrell, D.A., 2017. Snakebite envenoming. Nat. Rev. Dis. Prim. 3 (1), 1–21. https://doi.org/10.1038/nrdp.2017.63.

Halilu, S., Iliyasu, G., Hamza, M., Chippaux, J.-P., Kuznik, A., Habib, A.G., 2019. Snakebite burden in Sub-Saharan Africa: estimates from 41 countries. Toxicon 159, 1–4. https://doi.org/10.1016/j.toxicon.2018.12.002.

Harrison, R.A., Hargreaves, A., Wagstaff, S.C., Faragher, B., Lalloo, D.G., 2009. Snake envenoming: a disease of poverty. PLoS Neglected Trop. Dis. 3 (12) https://doi.org/10.1371/journal.pntd.0000569.

Instituto Nacional de Estatística, 2017. IV Recenseamento Geral da População e Habitação (CENSO). http://www.ine.gov.mz/ivrgph-2017/mocambique/censo-2017-brochura-dos-resultados-definitivos-do-iv-rgph-nacional.pdf/view.

Instituto Nacional de Estatística, 2021. Inquérito Sobre O Orçamento Familiar - IOF 2019/2020, Relatório Final. https://www.open.ac.uk/technology/mozambique/sites/www.open.ac.uk.technology.mozambique/files/files/IOF%202019_20%20Final%2022_09_2021.pdf.

Kasturiratne, A., Wickremasinghe, A.R., de Silva, N., Gunawardena, N.K., Pathmeswaran, A., Premaratna, R., Savioli, L., Lalloo, D.G., de Silva, H.J., 2008. The global burden of snakebite: a literature analysis and modelling based on regional estimates of envenoming and deaths. PLoS Med. 5 (11), e218.

Longbottom, J., Shearer, F.M., Devine, M., Alcoba, G., Chappuis, F., Weiss, D.J., Ray, S. E., Ray, N., Warrell, D.A., de Castañeda, R.R., 2018. Vulnerability to snakebite envenoming: a global mapping of hotspots. Lancet 392 (10148), 673–684. https://doi.org/10.1016/S0140-6736(18)31224-8.

Mackessy, S.P., 2016. Handbook of Venoms and Toxins of Reptiles. CRC press.

Malhotra, A., Wüster, W., Owens, J.B., Hodges, C.W., Jesudasan, A., Ch, G., Kartik, A., Christopher, P., Louies, J., Naik, H., Santra, V., Kuttalam, S.R., Attre, S., Sasa, M., Bravo-Vega, C., Murray, K.A., 2021. Promoting co-existence between humans and venomous snakes through increasing the herpetological knowledge base. Toxicon X 12, 100081. https://doi.org/10.1016/j.toxcx.2021.100081.

McNally, S., Reitz, C., 1987. Victims of snakebite. A 5-year study at Shongwe hospital, kangwane, 1978-1982. South Afr. Med. J.= Suid-Afrikaanse tydskrif vir geneeskunde 72 (12), 855–860.

Perfis, Distritais, 2005a. Perfil do Distrito de Ancuabe, Província de Cabo Delgado. Ministério da Admnistração Estatal. Républica de Moçambique. http://www.ine.gov.mz/documentos/outros-documentos/perfil-do-distrito-de-ancuabe-cabo-delgado.pdf/at_download/file.

Perfis, Distritais, 2005b. Perfil do Distrito de Balama, Província de Cabo Delgado. Ministério da Admnistração Estatal. Républica de Moçambique. https://www.portaldogoverno.gov.mz/index.php/por/content/download/2858/23342/version/1/file/Balama.pdf.

Perfis, Distritais, 2005c. Perfil do Distrito de Chiure, Província de Cabo Delgado. Ministério da Admnistração Estatal. Républica de Moçambique. http://www.portaldogoverno.gov.mz/por/content/download/2862/23362/version/1/file/Chiure.pdf.

Perfis, Distritais, 2005d. Perfil do Distrito de Meluco, Província de Cabo Delgado. Ministério da Admnistração Estatal. Républica de Moçambique. https://www.portaldogoverno.gov.mz/index.php/por/content/download/2869/23397/version/1/file/Meluco.pdf.

Perfis, Distritais, 2005e. Perfil do Distrito de Namuno, Província de Cabo Delgado. Ministério da Admnistração Estatal. Républica de Moçambique. http://www.portaldogoverno.gov.mz/por/content/download/2863/23367/version/1/file/Namuno.pdf.

Pugh, R., Theakston, R., Reid, H., Bhar, I., 1980. Malumfashi endemic diseases research project, XIII: epidemiology of human encounters with the spitting cobra, Naja nigricollis, in the Malumfashi area of northern Nigeria. Ann. Trop. Med. Parasitol. 74 (5), 523–530.

Snow, R., Bronzan, R., Roques, T., Nyamawi, C., Murphy, S., Marsh, K., 1994. The prevalence and morbidity of snake bite and treatment-seeking behaviour among a rural Kenyan population. Ann. Trop. Med. Parasitol. 88 (6), 665–671.

Tchoffo, D., Kamgno, J., Kekeunou, S., Yadufashije, C., Nana Djeunga, H.C., Nkwescheu, A.S., 2019. High snakebite underreporting rate in the Centre Region of Cameroon: an observational study. BMC Publ. Health 19 (1), 1040. https://doi.org/10.1186/s12889-019-7363-3.

UN, O.C.H.A., 2017. Mozambique: Health Facilities. https://data.humdata.org/dataset/mozambique-health-facilities.

Vermaak, S., Visser, A., le Roux, T., 2010. A deadly bed partner: m'Fesi (Mozambique spitting cobra). SA Orthopaedic J. 9, 58–62.

Wood, D., Sartorius, B., Hift, R., 2016. Snakebite in north-eastern South Africa: clinical characteristics and risks for severity. S. Afr. Fam. Pract. 58 (2), 62–67. https://doi.org/10.1080/20786190.2015.1120934.

World Health Organization, 2019. Snakebite Envenoming: a Strategy for Prevention and Control.