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Article in *Transactions of the Royal Society of Tropical Medicine and Hygiene* · January 2025

DOI: 10.1093/trstmh/trae062

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Health economics of snakebite envenomation: A sub-Saharan African perspective

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Received 7 January 2024; revised 12 April 2024; editorial decision 15 August 2024; accepted 29 August 2024

Sub-Saharan Africa (SSA) is affected by the high direct and indirect costs of snakebite envenomation. With >30% of global mortality, different economic barriers still exist, and effective strategies must be employed to avert the burden and promote quality of life. With the WHO target of reducing the number of snakebites by one-half by 2030, different aspects concerning snakebite envenomation economics must be evaluated, and potential strategies must be developed. Strategies such as exploring the different snakebite prevention interventions, and the costs associated with these interventions, must be prioritized through extensive research and targeted surveys. Information obtained from these surveys can be used to draft effective policies to minimize snakebite envenomation incidence, reduce the economic burden associated with envenomation and improve the quality of life of people at risk. In this narrative review, we evaluate the different aspects concerning the health economics of snakebite envenomation and explore the financial capacity of SSA countries to mitigate envenomation. Additionally, we propose multiple steps that could be undertaken to mitigate the financial burden of envenomation in SSA. Furthermore, we propose critical research strategies to minimize direct and indirect costs arising from snakebite envenomation in the region.

Keywords: envenomation costs, envenomation economics, snakebite, snakebite economic burden

Introduction

Globally, approximately 5.5 million snakebites occur annually, and these result in substantial mortality of approximately 94 000 individuals.¹ Sub-Saharan Africa (SSA) contributes >30% of these annual mortalities following snakebites, demonstrating a significant health burden. These snakebites predispose individuals to serious complications, such as extremity amputation and blindness, and are remarkably common in African agricultural communities.^{1,2} Sadly, most affected subjects reside in resource-constrained areas, making prompt accessibility to healthcare more difficult.¹ To alleviate the impact of these snakebites, the WHO drafted the 2030 strategy to reduce the number of snakebites by one-half by 2030. The strategy was drafted using four major pillars: increasing community and stakeholder

engagement, equipping health structures, increasing affordability and access to treatment, and resource coordination on a global aspect.¹ In SSA, an estimated 20 000–30 000 people die annually from snakebites. However, the true number might be greater than the reported number, given the lack of comprehensive regional and nation-specific data-reporting mechanisms.¹ Besides, evidence has demonstrated hospital attendance of snakebite victims as 8.5–27% of all victims.¹ Other patients experiencing snakebites seek treatment from traditional healers, which may not be reported in surveillance data.

Many myths still exist concerning snakebite envenomation, even among professional medical practitioners in SSA. Most of these practitioners are unfamiliar with snakebite envenomation, while others still believe traditional treatment is more effective.³ Often, traditional healers use unconventional means,

such as urine, oils, burning the area, sucking the wound, tourniquet application and the use of black stone.² Snakebites often exert physical injuries with significant psychological implications, and appropriate management must be prioritized for better clinical outcomes.^{3,4} Also, evidence from Rwanda showed that snakebites are the second most common type of animal bite, following dog bites, and often occur among peasant farmers.⁵ Thus, their impact on the population's health economics cannot be neglected.

Treatment of snakebites poses a significant financial burden to patients. Schurer et al. reported that about 41% of subjects who experienced snakebites covered the treatment costs by taking out loans or selling their goods.² Timely and optimal use of antivenom is the standard treatment of snakebite and has shown good outcomes in previous studies. However, its availability across SSA is still very scarce.⁶ Also, the exact health burden of snakebite envenomation has not been fully explored in low-income countries, especially those in SSA. The absence of this crucial information affects both private and public health institutions' engagement during disease management, leading to more mortality and morbidity. This narrative review, therefore, offers a comprehensive narrative concerning the health economics of snakebite envenomation in the SSA region and offers substantial recommendations, especially concerning minimizing the financial burden caused by envenomation.

Methodology

A comprehensive search was conducted in databases such as Google Scholar and PubMed using keywords such as 'health economics of snakebite envenomation', 'envenomation costs', 'snakebite impact in SSA' and 'snakebite economic burden'. The search was conducted by two independent researchers and articles published within the last 10 y were considered in this review. The selected articles were further reviewed by a single researcher to validate their inclusion in the current study.

Clinical and economic burden of snakebite envenomation

With poverty as one of the health determinants, SSA still struggles with the heavy financial costs of snakebite envenomation. Further, few studies have been carried out to determine the economic consequences of snakebite envenomation in SSA countries.² West African states have tried to explore the different components of snakebite envenomation economics, by first investigating the different species. Evidence shows that *Echis ocellatus* (saw-scaled viper) and puff adder are the most common venomous snakes known to cause high death rates in West Africa.⁷ The presence of these species prompted a critical assessment of their venom and their predisposition to mortality. However, Farooq et al. noted incomplete data concerning snakebite-related deaths in SSA.¹ Incomplete data concerning snakebite incidence, especially for these specific species and mortalities, further affects the budgeting process and resource allocation, such as treatment modalities in a region with an unstable economic environment. Also, the inconsistency in

health-seeking behavior eventually predisposes to an increase in morbidity, mortality and disability. Additionally, venomous toxicity provokes a sequela of local and systemic tissue damage. The local tissue damage normally causes unending sequelae like long-term disability and amputation, while the systemic damage involves neurotoxic patterns like bleeding, kidney damage, muscle breakdown, cardiotoxicity and thrombosis.⁷

Ahmed et al. estimate annual snakebite hospitalizations at 173/100 000 persons with a mortality rate of 1.39/100 000 population.⁸ Besides, approximately US\$7.4 million is lost annually to the cost of treatment and unemployment due to snakebites in Rwanda.² The victims and society are affected by financial losses as a result of victims having to make payments from loans, debts, life savings and donations from friends and loved ones.² On average, US\$26 is used per snakebite treatment in Kenya, and the cost increases proportionally with longer hospital stays.⁹ Further, there are minimal data concerning the treatment of snakebite effects, such as paralysis, among other SSA countries like Burundi, the Democratic Republic of Congo, South Sudan and Somalia. The paucity of data creates a significant challenge concerning budgeting, resource allocation and antivenom development in these countries. Besides, African countries, except South Africa, lack antivenom-manufacturing companies.¹⁰ As a result, despite their availability, a large percentage of victims cannot afford antivenoms because of the expensive out-of-pocket costs of treatment.⁸ The rural healthcare facilities primitively shoulder the economic burden of snakebites because of their proximity to the victims, yet they are not sufficiently equipped to handle the burden.⁸ To effectively identify gaps at the local hospital level, it is necessary to estimate the cost of managing snakebites to inform decision-making by the government and other important stakeholders to help in the most cost-effective disbursement of resources.⁹

Costs of snakebite envenomation treatment

The costs associated with snakebite envenomation treatment can be substantial and vary across different socioeconomic strata. Direct medical costs associated with snakebite envenomation treatment include expenses related to antivenom purchase, hospitalization and diagnostic procedures. Antivenom is the most significant component, accounting for up to 70% of the total treatment cost.¹¹ Antivenom costs vary widely, ranging from US\$5 to 2000 per vial, depending on the type, quality and availability of the antivenom.¹² On average, the cost per antivenom treatment was reported as US\$124, with a range of US\$55–640.¹³ However, a median price of US\$153 was also reported for SSA. Other factors affecting the costs of antivenom treatment include the severity of the envenomation, scarcity of effective antivenoms and the patient's location. The number of vials required for a single treatment can also vary widely, depending on the severity of the envenomation, and can range from 10 to 25 vials.¹² Hospitalization costs also vary depending on the duration of the hospital stay, the level of care required and the availability of healthcare resources. Diagnostic procedures can also add to the overall cost of treatment. However, there is minimal information concerning the cost of snakebite envenomation treatment across different SSA countries. The absence of this information creates

barriers concerning financial planning, affecting the quality of life of envenomation victims. Therefore, further studies, especially concerning the direct impact of envenomation, must be prioritized to understand its costs to help in proper resource allocation.

In SSA, the few effective antivenoms available are generally scarce, locally unaffordable and inaccessible where they are most needed. In 2016, Sanofi-Pasteur's discontinuation of FAV Afrique, the most widely distributed and dependable antivenom, neutralizing bites from 10 venomous snakes in the subregion, further worsened the situation.¹³ Its loss deteriorated into a serious public health crisis, making managing snakebites even more challenging. However, MicroPharm Limited from the UK, along with scientists from Liverpool School of Tropical Medicine, funded by the Wellcome Trust, are currently collaborating with Sanofi-Pasteur to re-establish the manufacture and supply of Fav-Afrique antivenom.¹⁴ The modality of the antivenom produced under this project focuses on neutralizing category 1 venomous African snakes, such as *Echis ocellatus*, *Bitis gabonica* and *Bitis arietans*, which are predominant in Nigeria and Gabon.^{15,16} Further, it is crucial to assess the health economics of antivenoms in the context of other competing public health priorities to guide policy. Preliminary economic evaluations have been conducted on antivenoms and their manufacture, but more research is needed to explore the cost-effectiveness of antivenom utility in treating snakebite envenomation. Besides, understanding the health economics of antivenoms will help policymakers make informed decisions to ensure that effective and affordable antivenoms are available to those who need them the most.¹²

Indirect costs associated with snakebite envenomation treatment are also significant. Often, these are rarely considered, especially when evaluating the economic impact of envenomation. These include productivity losses due to disability, prolonged recovery and rehabilitation.¹² The loss of income caused by a prolonged recovery and disability can be particularly devastating for individuals from lower socioeconomic strata who may depend on daily wages for survival, most particularly manual laborers and agriculture workers and their families.¹² These groups are often dependent on their physical ability to perform their jobs, and any disability resulting from snakebite envenomation can have devastating effects on their livelihoods. Significantly, across West African countries, such as Sierra-Leone and Benin, the cost of disability-adjusted life years has been estimated at US\$281 and 83, respectively, indicating the higher treatment costs required for those affected.¹³

Moreover, individuals in lower-income or marginalized communities may have limited access to healthcare facilities or antivenom therapy, which can lead to delays in treatment and prolonged recovery times, exacerbating the indirect costs of snakebite envenomation.¹¹ Thus, enhancing the health sector of different SSA countries to offer envenomation treatment can minimize the impact of the indirect costs associated with the disease. Noteworthy, the responsibility of caring for a disabled individual in SSA is assumed by family members, which may lead to a decrease in their productivity and income.² Furthermore, the costs associated with rehabilitation can be quite significant, particularly for those who require prolonged care and support. Individuals needing physical or occupational therapy may experience extended recovery times due to a lack of access to rehabilitation services, which can exacerbate the loss of productivity and

economic hardship. Therefore, streamlining some of these costs, especially antivenom production costs by various health ministries in SSA, could minimize these indirect costs and promote better outcomes.¹¹

Access to antivenom and treatment services

Accessibility to antivenom is one of the major challenges among envenomation victims, especially in Africa. Accessibility challenges involve availability and affordability, varying among urban and rural facilities and public and private facilities. In 2023, the availability of antivenom in stock was 4.2% in Uganda, 7.6% in Zambia and 4.2% in Rwanda.^{17,18} This availability across these countries is minimal compared with the envenomation experienced by these countries. Besides, most antivenoms may be accessible in urban areas, unlike rural areas, creating a significant challenge in management because rural areas are prone to experiencing more snakebites than urban areas.^{19,20} Other potent barriers to access cut across the entire journey of the antivenom from manufacturing up to when it reaches the patient in terms of inadequate production, inadequate safety profile of the antivenom, registration of antivenom in intended places and lack of an effective distribution model. Addressing these challenges requires a collective effort among stakeholders, including manufacturers, transporters, local healthcare leaders and those affected by envenomation.

Also, health infrastructure and service delivery factors, for example, procurement, transportation, distribution and administration for managing snakebite envenomation, limit effective envenomation treatment in SSA. About 80% of health workers in Kenya, Uganda and Zambia reported that their health facilities lack appropriate medication, such as antivenom and equipment to manage snakebites.¹⁷ Similarly, in Cameroon, it was shown that there was a lack of adequate infrastructure and supportive drugs for snakebite treatment.²¹ Besides, most snakebite victims were in rural areas that lacked appropriate facilities and resources to care for patients. These areas lack intensive care equipment, have limited or no cold chain management, and the healthcare staff have minimal knowledge and skills concerning envenomation management.²²⁻²⁴ Additionally, referral systems and the laboratory investigation capacity in these low-income countries are poor and limited to urban areas, creating another significant challenge to antivenom access and treatment availability.^{13,25,26} However, we recommend implementation research concerning the feasibility of healthcare infrastructure in SSA to deliver envenomation treatment to snakebite victims.

Economic analysis of snakebite interventions

Snakebite preventive interventions are essential in minimizing the incidence of envenomation among vulnerable groups such as farmers and individuals living in rural areas. Some of these interventions include wearing gloves and gumboots, especially those manufactured with fang-proof capacity, health education concerning snakebite incidence and risk factors, and eliminating holes and entry points into animal houses.²⁷ Other interventions include eliminating dump areas that can offer safe habitation for snakes, eliminating overgrown bushes around homes, increasing

awareness of snake incidence in a given area and relocating these snakes to gazetted locations.²⁸ Most of these interventions are costly and require financial input from affected individuals and health ministries in the countries concerned. However, no substantial information has been published concerning the economic analysis of these snakebite prevention interventions. Most of the literature considers the cost-effectiveness of managing the disease by evaluating the antivenom treatment rather than the preventive aspect.^{11–13} Therefore, more directed research exploring the costs involved in preventing snakebites in different SSA countries must be conducted to avail information necessary during the healthcare planning.

Challenges and opportunities

Globally, snakebite envenomation poses a significant public health challenge, worse in the tropical and subtropical areas.²⁹ Although there has been progress in comprehending and treating snakebites, there are still significant challenges in managing this condition efficiently. These challenges provide opportunities for innovation, collaboration and advancements in health economics. The high cost of antivenom is one of the key constraints to timely management, augmented by the absence of antivenom-manufacturing facilities.¹⁸ Additionally, the quality and safety of some antivenoms, production inefficiencies, low manufacturing volumes, storage limitations and distribution problems are the barriers associated with antivenom availability.³⁰ Other barriers include the remoteness of villages, the long distance between the point of snakebite and the managing hospital, and the cost of transport.³¹ Additionally, most of these rural communities lack antivenom, a highly efficacious intervention for envenomation. Moreover, the lack of protocols and guidelines for managing snakebites, as well as a fear of adverse reactions, are also associated with a lack of timely and adequate management.³¹ The absence of protocols results in economic hiccups for staff in facilities involved in treating snakebite victims. Further barriers that have been identified include local beliefs and traditions, a lack of knowledge and skills for snakebite management among the community and healthcare workers, as well as limited referral infrastructure.^{23,26} However, the continued trust of traditional healers and herbalists offers an opportunity for their integration into the envenomation treatment chain. Besides, their inclusion can also be relevant in identifying the financial costs involved, upon which relevant adjustments in budgeting can be made by the different health ministries. Also, focused research concerning their role in promoting health education about envenomation can inform various policymakers, guiding their decisions about envenomation treatment.

Accessing antivenom in affected regions is a major challenge, as remote and impoverished areas lack the resources to procure and distribute antivenom promptly.⁶ The variability in snake venom composition creates another barrier to developing a universal antivenom. Existing antivenoms may be ineffective against specific snake species, leading to inadequate treatment outcomes.¹⁴ Furthermore, delays in seeking medical care and lack of awareness about proper first aid measures contribute to the severity of snakebite envenomation cases. Additionally,

investing in producing cost-effective and region-specific antivenoms in SSA could mitigate the severity of snakebite envenomation. Governments and international organizations can work together to subsidize the cost of antivenoms, making them affordable for those who need them.¹⁰ Collaboration between governments, non-governmental organizations (NGOs), pharmaceutical companies and research institutions is crucial for tackling the economic challenges of snakebite envenomation, such as high production, transportation and storage costs. Governments can play a pivotal role in creating policies facilitating antivenoms' production, distribution and affordability. NGOs can contribute by raising awareness, providing education and supporting community-based initiatives for snakebite prevention. Pharmaceutical companies can collaborate with research institutions to develop innovative antivenom formulations that are effective against a broader range of snake species. These collaborations can also focus on improving antivenoms' stability and shelf life, as well as overcoming logistical challenges in remote areas.

Various stakeholders, such as traditional healers, health ministries, professional medical workers, anthropologists, ethnobiologists and ecologists, are critical to address gaps concerning the health economics of envenomation. Raising public awareness about snakebite prevention and first aid measures can help to reduce the economic burden by preventing severe cases that require extensive medical intervention.³² Even although developing novel technologies, such as point-of-care diagnostic tools, requires extensive research and innovation, they can also contribute to more efficient and cost-effective snakebite management.¹⁸ These tools can aid in rapidly identifying snake species and venom composition, enabling healthcare providers to administer targeted treatment promptly.^{18,33} Understanding the socioeconomic factors influencing snakebite incidence and healthcare-seeking behavior can inform public health campaigns and policy development, especially those directed at minimizing the costs of envenomation treatment.³⁴ Noteworthy, addressing the economic snakebite challenges requires a multifaceted approach, including innovation, collaboration and targeted research. Opportunities in improving health economics encompass ensuring affordable antivenom access and fostering cross-sector partnerships. By addressing research gaps, such as antivenom genetic variability, snakebite prevention costs and universal antivenom production and accessibility, the global community can reduce the impact of snakebite envenomation on public health.

Conclusions

Snakebite envenomation is a significant health and economic challenge, affecting clinical outcomes, economic stability and public health in SSA. Evidence has revealed that high mortality rates, disabilities and economic hardships are prevalent due to limited access to antivenoms, inadequate healthcare infrastructure and economic disparities. Key findings from this review highlight the complexity of health economics of snakebite envenomation, suggesting the need for strategic interventions and research initiatives to mitigate these burdens. The implications for policy and practice require strategic interventions, such as enhancing antivenom accessibility, strengthening healthcare systems and

infrastructure, increasing public awareness and creating other targeted interventions that are essential to reduce the incidence and severity of snakebite envenomation in rural and remote areas. This paper revealed that addressing affordability, availability and quality concerns related to antivenom treatments through targeted policy interventions is critical to alleviating the economic burden and improving clinical outcomes. Also, this review highlighted that future research should prioritize bridging data gaps, developing innovative diagnostic tools and fostering collaborations among stakeholders such as governments, NGOs, pharmaceutical companies and research institutions to combat this multifaceted challenge. Furthermore, as indicated, targeted policies, strategic policy implementations, innovative solutions and collaborative efforts are vital in reducing snakebite envenomation's clinical, economic and social impacts, ultimately mitigating the burdens and advancing healthcare outcomes and public health in SSA.

Authors' contributions: IA conceptualized the manuscript and formulated the search strategy. IA and JMG searched the articles from different databases. IK reviewed the identified articles for inclusion. OK developed the Introduction section. GAG developed the Clinical and economic burden of snakebite envenomation section. JNT developed the Cost of snakebite envenomation treatment section. UMH developed the Access to antivenom and treatment services section. AA developed the Economic analysis of snakebite intervention section. JMG developed the Challenges and opportunities section. JKT finalized the manuscript's content. IA compiled the first draft of the manuscript. All the authors reviewed the first draft of the manuscript. IK reviewed the final draft of the manuscript.

Funding: None.

Competing interests: None.

Ethical approval: None.

Data availability: This was a secondary study that obtained information from already existing articles.

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