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RESEARCH ARTICLE

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Assessment of knowledge, attitude, and practice of healthcare providers regarding snakebite envenomation: a cross-sectional study among Sub-saharan african countries

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ABSTRACT

Background: Snakebite envenomation remains a critical health challenge across the culturally and ecologically diverse sub-Saharan Africa (SSA). This study examined healthcare providers' (HCPs') knowledge, attitudes, and practices (KAP), and their determinants towards snakebite envenomation.

Methods: A cross-sectional study was conducted across nine SSA countries using the validated Knowledge, Attitudes, and Practices of Snake Envenomation – Healthcare Providers Questionnaire (KAPSE-HCPQ). The fractional logistic regression was conducted to identify the factors associated with KAP.

Results: A total of 3,544 HCPs were enrolled through professional and digital networks. General practitioners represented approximately half of the participants (50.1%), whereas toxicologists were 3.2%. Considerable variations were reported across sub-Saharan countries. Uganda and Sierra Leone attained perfect median knowledge scores (100%, range: 93–100, 73–100, respectively) yet both demonstrated marked deficiencies in practice (range: 0–25% and 0–75%, respectively). Attitude scores ranged from the lowest in Ethiopia (79%, range: 75–85%) to the highest in Uganda (91%, range: 87–95%). Higher knowledge was significantly associated with advanced training, antivenom availability, curricular inclusion of toxicology, and self-study. Positive attitudes were significantly associated with prior clinical exposure, faculty-based education, informal information sources, and participants' countries. HCPs demonstrated incorrect practices, such as applying a tourniquet above the bite site, attempting to suck out the venom, incising the bite wound, and asking to run to the nearest health facility, which may accelerate the systemic venom spread. In contrast, pharmacists and HCPs unaware of management guidelines demonstrated poorer practices.

Conclusion: The study identifies a substantial gap between theoretical knowledge and clinical practice among HCPs across SSA, with variations by country, profession, training,

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Snakebite; envenomation; health care providers; antivenom; sub-Saharan Africa

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and resource availability. Urgent interventions training, protocol standardization, and reliable antivenom supply are required to improve snakebite outcomes.

KEY MESSAGES

- Although healthcare providers across sub-Saharan Africa generally have good knowledge and favorable attitudes towards snakebite management, their actual practices remain persistently inadequate, irrespective of their country's income level.
- Systemic barriers - limited formal training, absent institutional protocols, unreliable antivenom supply, and weak referral systems- are highly associated with inadequate clinical practice.
- Urgent standardization of training protocols and reliable antivenom supply are needed to improve snakebite outcomes across the SSA region

1. Introduction

Snakebite envenomation is one of the most neglected global health crises. The annual global incidence of snakebite is estimated to be about 5.4 million, with more than 130,000 deaths and more than 400,000 subjects left with permanent disabilities [1]. The World Health Organization (WHO) classified snakebite envenomation as a Category A neglected tropical disease in June 2017 [2].

Venomous snakes are classified into four main families: Atractaspididae, Colubridae, Elapidae, and Viperidae. In many rural agricultural regions, these snake habitats intersect with communities, putting farmers, women, and children at risk of envenomation [1,3]. Snake venom can induce a wide range of symptoms, including localized manifestations such as fang marks, pain, swelling, and local tissue damage. Nonetheless, the systemic effects can be far more severe. The wide range of snake venom composition leads to a variety of symptoms observed in affected cases. The venom's hemotoxins can result in damage to blood cells, cytotoxins cause tissue inflammation, and neurotoxins disrupt the nervous system [4]. The clinical consequences of snakebite depend on the snake species, individual patient characteristics, and the timely availability of the appropriate antivenom. Delays in management can increase the risk of fatality or result in long-term disabilities [5]. Complications of improperly treated subjects include disseminated intravascular coagulopathy, renal failure, compartment syndrome, and limb amputation [6].

The WHO specifically recommends antivenom as the primary treatment [7]. Although monovalent antivenoms are very effective when the specific snake species has been identified, practical challenges such as difficulties in snake identification, irregular supply chain, cost, and the need for specialized training make polyvalent antivenoms a more feasible option [8]. Polyvalent antivenom contains antibodies capable of neutralizing toxins from various snake species; making it the preferred choice [7]. Nevertheless, antivenom market failure and shortage of supply persist across sub-Saharan Africa (SSA), leaving many regions with limited or no access to this life-saving treatment [9]. Moreover, supportive care, such as ventilatory support, fluid resuscitation, and appropriate wound management, is also deficient [5].

Low- and middle-income countries (LMICs) in Africa, Asia, and Latin America are hotspots for snakebites. In Africa alone, it is estimated that between 435,000 and 580,000 snakebites occur each year that necessitate medical attention [10]. Africa is home to more than 400 unique snake species, including over 130 that are venomous, each varying in level of threat [11]. The WHO classified around 25 snake species as Category 1. These species are medically important due to their association with severe or potentially fatal envenomation [12]. SSA is a highly diverse region comprised of LMICs [13]. In 2024, SSA accounted for 16% of the global population, yet 67% of its inhabitants remained in extreme poverty [14]. The impact of snakebite envenomation in this area is very high. It is estimated that snakebites result in an annual burden of 1.03 million disability-adjusted life years. This figure is comparable to, or even exceeds, that associated with other neglected tropical diseases [15], and the number of fatalities reaches as high as 32,000 each year [16]. Interestingly, these statistics are based on hospital reports or incomplete centralized databases from a limited number of SSA countries, which may contribute to underreporting [17]. Moreover, SSA is characterized by vast geographic diversity and a rich cultural mosaic, resulting in different ways of managing snakebite. Snakes are deeply embedded in the myths and misconceptions of many communities. They believe that snakebites are best treated by traditional healers using home-based or spiritual remedies [18]. Traditional medicine remains commonly used due to these cultural beliefs, accessibility, and economic constraints [19]. Traditional healers use a holistic approach that includes the application of tourniquets, making skin incisions, providing herbal preparations, and administering so-called 'snake vaccines' prepared from snake heads mixed with herbs [20]. Furthermore, many regions in SSA lack well-equipped poison control centers with shortages of adequately trained healthcare providers (HCPs). These challenges are aggravated by negative attitudes among some HCPs, who may favour traditional medicine over evidence-based care owing to inadequate knowledge and persistent misconceptions about the effectiveness of traditional remedies [21].

In 2019, the WHO established an ambitious objective of reducing the incidence of death and disability resulting from snakebites by half by the year 2030 [22]. Achieving this objective requires that snakebite prevention be given equal, if not greater, priority than treatment. Successful management depends on coordination between different sectors, including government, HCPs, researchers, and communities. However, lack of sufficient data, incomplete medical records, and underreporting have collectively weakened the surveillance system [23]. In addition, there is limited research in SSA countries assessing knowledge, attitudes, and practices (KAP) towards snakebite management. Research reported inadequate knowledge and awareness of HCPs, insufficient training, and poor management skills [24–28] despite the availability of established guidelines [12,29]. This gap between guidelines and clinical practice directly threatens patient survival and recovery. Of note, lack of adequate training, awareness, and resources for effective snakebite management is likely a key contributor to such observed gap [12,29].

This study hypothesizes that there is a significant gap between theoretical knowledge and clinical practice among HCPs in SSA regarding snakebite envenomation. Accordingly, the primary objective of the study was to assess the KAP of HCPs regarding snakebite envenomation in health facilities and hospitals across SSA. The secondary objective was to identify the key individual, training, and systemic factors that determine the KAP domains.

2. Materials and methods

2.1. Study design

This multinational cross-sectional study was conducted across nine SSA countries [Ethiopia, Ghana, Kenya, Nigeria, Sierra Leone, Somalia, Sudan, Uganda, Zambia]. Data were collected between April and September 2024.

2.2. Sampling technique

A non-random sampling technique (convenience and snowball) was used to recruit the study participants. They were identified through professional networks, healthcare institutions, and referrals from initial respondents. To optimize inclusion of participants, both online and face-to-face surveys were utilized. The study questionnaire was distributed online with mandatory responses for all questions. It was uploaded to a Google Form sent through multiple channels, including social media platforms (Facebook and X), WhatsApp, and email. Each participant was allowed to complete the questionnaire only once to avoid duplicate responses. Face-to-face data collection was conducted in settings where online participation was not feasible.

2.3. Sample size calculation and study population

We used Epi Info™ version 7.2.5 (Centers for Disease Control and Prevention, USA) to calculate sample size. As there was no previous multinational research on HCPs' KAP towards snakebite envenomation in SSA, a prevalence estimate of 50% was considered to ensure the sample size was maximized. The calculation was based on the single population proportion formula:

$$n = \frac{Z^2 \cdot p \cdot (1 - p)}{d^2}$$

where:

- n = required sample size
- Z = Z-score for 95% confidence level (1.96)
- p = assumed prevalence (0.5)
- d = margin of error (0.05)

The minimum number of respondents was 385 per country. Participants were included if they were licensed, actively practicing HCPs. The minimum age for nurses and allied health technicians, and physicians was 18 and 24 years, respectively, reflecting the standard age for completing employment certification and entering medical practice.

2.4. Data collection

2.4.1. Data collection procedures

Data collectors were recruited by the Global Researcher Club. Before collecting data, the study principal investigators held two orientation sessions with all collectors on the study objectives, eligibility criteria, data collection methods, and ethical considerations.

2.4.2. Data collection tool

We used the Knowledge, Attitudes, and Practices of Snake Envenomation - Healthcare Providers Questionnaire (KAPSE-HCPQ) that was developed and validated in a prior multinational study across eleven SSA countries [30] (Appendix I Supplemental File). Its psychometric properties were established through expert review for content validity, exploratory and confirmatory factor analysis for structural validity, and internal consistency testing (Cronbach's $\alpha > 0.7$ for all domains). The validation cohort was independent of the study sample presented here [30]. In the present study sample, the internal consistency of the KAPSE-HCPQ remained acceptable, with Cronbach's alpha values > 0.7 for all three domains [31]. To facilitate coordinated and simultaneous data collection, a network of country-specific collaborators was appointed, with each collaborator serving as a national focal point.

2.4.3. Questionnaire structure

The questionnaire was divided into five sections:

The first section gathered sociodemographic details such as age, gender, country, job title, current profession, years of experience, and highest level of education. Professions were grouped into two categories: medical personnel (which includes general practitioners and specialist physicians such as emergency physicians, critical care physicians, and toxicologists) and paramedical personnel (nurses and pharmacists). Additionally, participants' employment status was classified as public (governmental), private, or both. Furthermore, five questions were incorporated to assess participants' previous experience and training related to the management of snakebites. These questions evaluated whether HCPs had undergone formal training in snakebite management, the length of that training, their sources of information about snakebite care, their previous experience with snakebite patients, and the methods or strategies they utilized in handling these cases. The second section assessed the respondents' awareness regarding locations that provide toxicological services, the presence of a management protocol or referral system, the availability of snake antivenom, and the specific types that are stocked in the health facility. The third section of the questionnaire assessed HCPs' knowledge of snakebite envenomation through fifteen questions covering three main domains, with responses recorded as 'Yes', 'No', or 'Do Not Know'

- Clinical knowledge (neurological symptoms from cobra bites and hemorrhagic manifestations from other venomous snakes).
- Diagnostic knowledge (knowledge of the international guidelines' criteria for starting antivenom therapy, which includes progressive local edema, elevated prothrombin time, low platelet count,

and high International Normalized Ratio (INR), paralysis – all important markers for therapeutic decision-making).

- Complications and risk factors (acute renal failure, compartment syndrome, disseminated intravascular coagulopathy, myolysis, skin necrosis, factors influencing envenoming severity, including patient age, general health, bite depth and location, and time elapsed before treatment).

The fourth section assessed participants' attitudes toward snakebite management through eleven questions covering:

- Perceived patient-related factors contributing to complications (delays in seeking care, inappropriate first aid measures, and inadequate medical attention).
- Participants' perspectives on factors associated with poor prognosis (financial constraints, long distances to toxicology services, refusal of antivenom, preference for traditional remedies, and limited availability of antivenom).
- Participants' recommendations to improve the quality of care (conducting workshops, incorporating toxicology modules into the medical curriculum, and offering postgraduate degrees in clinical toxicology.

Respondents' attitudes were measured on a 5-point Likert scale, reflecting the degree of agreement or disagreement with each attitude.

The fifth section of the questionnaire assessed participants' practices regarding first aid measures for snakebite victims. It included four items addressing commonly reported practices such as the application of tight ligatures or tourniquets, attempts to suction venom, making incisions at the wound site, and instructing the patient to walk or run to the nearest health facility. Responses to each item were recorded as 'Yes' or 'No', reflecting participants' agreement or disagreement with each stated practice.

2.5. Data quality check

Several steps were taken to make sure the data were accurate and reliable. We used the previously approved KAPSE-HCPQ questionnaire, which had already been validated. Data collectors received the same training to ensure the questionnaire was administered consistently across all countries. Data were collected through online and face-to-face surveys to reach participants in areas with limited internet access. The online survey accepts only one response per participant to avoid duplicate entries, and all questions were required to avoid missing responses. During data cleaning, 127 responses were removed due to logical inconsistencies. For example, some physicians or pharmacists were reported to be under 24 years old, which did not meet the inclusion criteria requiring completion of basic professional training. Throughout the data collection period, responses were regularly reviewed to detect and resolve any unusual entries before starting the analysis

2.6. Statistical analysis

Correct answers to the knowledge questions were coded as 1, while incorrect answers or 'don't know' were coded as 0, as they reflect inaccurate knowledge and a lack of understanding. Participants indicated their attitudes using a five-point Likert scale, which reflects the degree of agreement or disagreement with each statement. Items assessing first aid practices as perceived or reported by participants were coded as 1 for disagreement with incorrect practices (correct response) and 0 for agreement with incorrect practices or 'don't know', as they reflect misconceptions or lack of appropriate knowledge. The data were cleaned and summarized using medians and interquartile ranges (Q1–Q3) for continuous variables, while frequencies and percentages were calculated for categorical variables.

Fractional logistic regression models were conducted to identify the factors associated with KAP regarding snakebite envenomation. This model is appropriate for outcomes measured as continuous proportions bounded between 0 and 1. To use fractional logistic regression, each domain score was transformed into a proportion by dividing the individual's total score by the maximum score for that domain. This transformation resulted in standardized scores ranging from 0 to 1, where 0 indicates the lowest possible score, and 1 indicates the highest possible score. Results of fractional logistic models were presented as Average Marginal Effects (AMEs). AME represents the average absolute change in the predicted proportion of the outcome that is associated with a one-unit change in the predictor, holding other variables constant. For example, an AME of 0.10 means that the outcome increases by 10 percentage points when the predictor increases. Confidence intervals (95% CI) were reported. Variables were considered statistically significant if the p-value < 0.05. Model diagnostics and assumptions were evaluated, including checks for model specification and robustness of inference. KAP scores were calculated by summing the item scores within each domain of KAP. All analyses were conducted using IBM SPSS (International Business Machines Corporation, Armonk, New York, USA) version 26 and Stata version 16 (StataCorp LLC, College Station, TX, USA).

2.7. Ethical consideration

Ethical approval was granted by the Ethical Committee of the Faculty of Medicine, Alexandria University, Egypt (IRB No. 00012098; Serial No. 00018699). Collaborating researchers from each country were instructed to seek local ethical approvals where required by national regulations. The research was conducted according to the ethical principles stated in the Helsinki Declaration (1964) and its subsequent amendments [32]. Voluntary and unpaid participation was ensured, with the study title and objectives clearly stated at the beginning of the questionnaire. An initial mandatory question was added to obtain the informed consent of the participant 'Do you agree to participate in the survey?' with 'Yes' or 'No' options; only those selecting 'Yes' could continue. To ensure data privacy, no personally identifiable information was collected, online responses were submitted *via* a secured Google Form with restricted access, and all data were stored and analyzed in anonymized, aggregated form. Confidentiality was ensured throughout the study.

3. Results

3.1. Selection and inclusion process of countries

Initially, 50 countries in SSA were considered for inclusion. Out of these, 29 countries were excluded due to the lack of a national focal point for coordination. Of the remaining 21 countries, an additional 12 were excluded because they did not reach the required sample size. As a result, 9 countries were included in the study with complete and valid samples. The countries and their respective sample sizes are as follows: Ethiopia (394), Ghana (399), Kenya (389), Nigeria (392), Sierra Leone (395), Somalia (388), Sudan (396), Uganda (396), Zambia (395) (Figure 1).

3.2. Study population characteristics

A total of 3544 participants were included in the study, with a median age of 30.0 (IQR 27.0–35.0) years, 54.0% were male, 50.1% were general practitioners, whereas toxicologists represented 3.2%, and 61.0% worked in governmental facilities (Appendix II Supplemental Table S1). Median years of professional experience were 5 years (IQR 3.0–8.0). Educational attainment ranged from diploma to fellowship level, with nearly half holding a bachelor's degree (Appendix II Supplemental Tables S2, S3, S4, S5). Overall median scores were knowledge: 87.0% (IQR 60.0–100.0), attitude: 87.0% (IQR 80.0–93.0), and practice: 0% (IQR 0.0–50.0) (Table 1).

3.3. Sources of knowledge and availability of snakebite management services

Self-reading was the most reported source of knowledge (43.8%), followed by textbooks (35.6%) and undergraduate curricular exposure (30.7%) (Figure 2a). Participants reported that toxicological services were available in hospitals (48.0%), clinics (26.8%), and tertiary hospitals with no toxicological unit

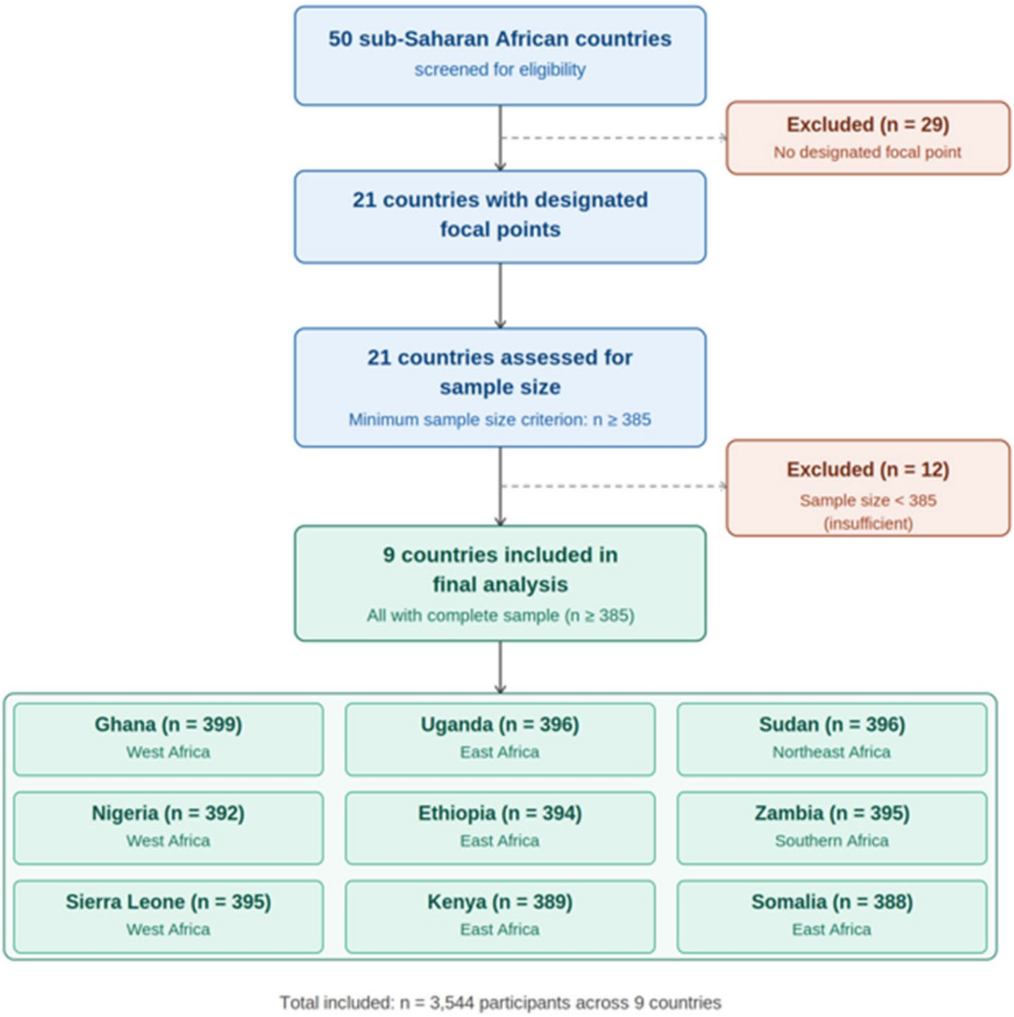

Figure 1. Flow chart of the study sample distribution across the countries of sub-Saharan Africa.

(19.7%), tertiary hospitals with toxicological services (12.8%), while home services were limited (7.9%) (Figure 2b).

Approximately 63% of respondents had previously managed a snakebite case; however, more than half of the respondents (54.4%) reported receiving no formal training in snakebite management. Only 16% confirmed the presence of institutional snakebite management protocols or referral systems. Antivenom availability was inconsistent: 33.2% reported occasional availability, 17.2% regular availability, and 10% were unaware of availability status. Reported clinical responses to snakebite cases varied, including first aid with referral (40.2%), admission and treatment (27.8%), or direct referral (11.2%) (Table 2).

3.5. Analysis of knowledge, attitudes, and practices across respondent characteristics

Significant heterogeneity was observed across countries for KAP domains ($p < 0.001$). Practice scores were generally low across most countries, although relatively higher medians were reported in Sierra Leone and Somalia. In contrast, knowledge scores were highest in Uganda and Sierra Leone. Education level, occupation, job type, previous clinical exposure, training history, institutional protocol availability, and antivenom accessibility all significantly affected knowledge and attitude scores (all $p < 0.001$). However, practice scores were consistently low and varied little across most subgroups. Respondents reporting 'no idea' regarding antivenom availability had the lowest KAP scores. Distribution of first aid practice scores is demonstrated in Supplemental figure S1. Formal toxicology education and self-directed learning as

Table 1. Characteristics of healthcare providers ($n = 3544$).

Variables	Labels	Frequency (%)
Age (years)	Median (Q1–Q3)	30.0 (27.0–35.0)
Sex	Male	1913 (54.0)
	Female	1631 (46.0)
Profession	General practitioner	1777 (50.1)
	Emergency	383 (10.8)
	Toxicologist	113 (3.2)
	ICU	179 (5.1)
	Pharmacist	242 (6.8)
	Nurse	329 (9.3)
	Other	521(14.7)
Job category	Government	2161 (61.0)
	Private	949 (26.8)
	Both	434 (12.2)
Last degree of education	Bachelor	1770 (49.9)
	Diploma	890 (25.1)
	Master	419 (11.8)
	PhD	299 (8.4)
	Fellowship	166 (4.7)
Country	Ethiopia	394 (11.1)
	Ghana	399 (11.3)
	Kenya	389 (11.0)
	Nigeria	392(11.1)
	Sierra Leone	395 (11.1)
	Somalia	388 (10.9)
	Sudan	396 (11.2)
	Uganda	396 (11.2)
	Zambia	395 (11.1)
Country income level	Low-income countries	1537 (43.4)
	Lower-middle-income countries	2007 (56.6)
Year of experience	Median (Q1–Q3)	5.0 (3.0– 8.0)
Knowledge %	Median (Q1–Q3)	87.0 (60.0–100.0)
Attitude %	Median (Q1–Q3)	87.0 (80.0–93.0)
Practice %	Median (Q1–Q3)	0.00 (0.0–50.0)
(Agreement with first-aid measures)		
	Applying a tourniquet above the site of the bite	2935 (82.80)
	Attempting to suck out the venom	2401 (67.7)
	Cutting the bite wound	2445 (69.0)
	Walking or running to the nearest health facility	2443 (68.9)

HCPs: healthcare providers; ICU: intensive care unit; Q1–Q3:first and third quartiles (interquartile range).
Data are presented as n (%) for categorical variables and as Median (Q1–Q3) for continuous variables.

sources of knowledge were significantly associated with higher knowledge and attitude scores, but not with practice (Table 3).

3.6. Factors associated with knowledge about snake poisoning

The results indicated that higher knowledge scores were independently associated with advanced academic qualifications in multivariable fractional logistic regression analysis, namely having a Doctoral degree, working in both the public and commercial sectors, and having organized training within the last three to six years. Participants who reported on administering first aid before being referred showed greater levels of clinical engagement. Systemic and institutional factors played an important role, where respondents who reported anti-venom availability as rare, occasional, or regular were significantly associated with higher knowledge scores than those who didn't know. Similarly, higher knowledge levels were associated with greater use of textbooks, independent reading, and formal toxicology courses during undergraduate or graduate studies. Higher knowledge scores were also independently associated with informal sources like friends and family. On the contrary, pharmacists and those working in facilities lacking snakebite management protocols were associated with significantly lower knowledge levels. Country differences persisted even after adjustment; Uganda and Kenya presented the strongest positive associations. The model showed an acceptable fit. McFadden pseudo-R^2 was 0.179 and the overall Wald χ^2 test was statistically significant ($p < 0.001$). Information criteria (AIC and BIC) supported the model fit. No evidence of multicollinearity was observed (Table 4; Supplementary Figure S2, (Appendix II Supplemental Table 6).

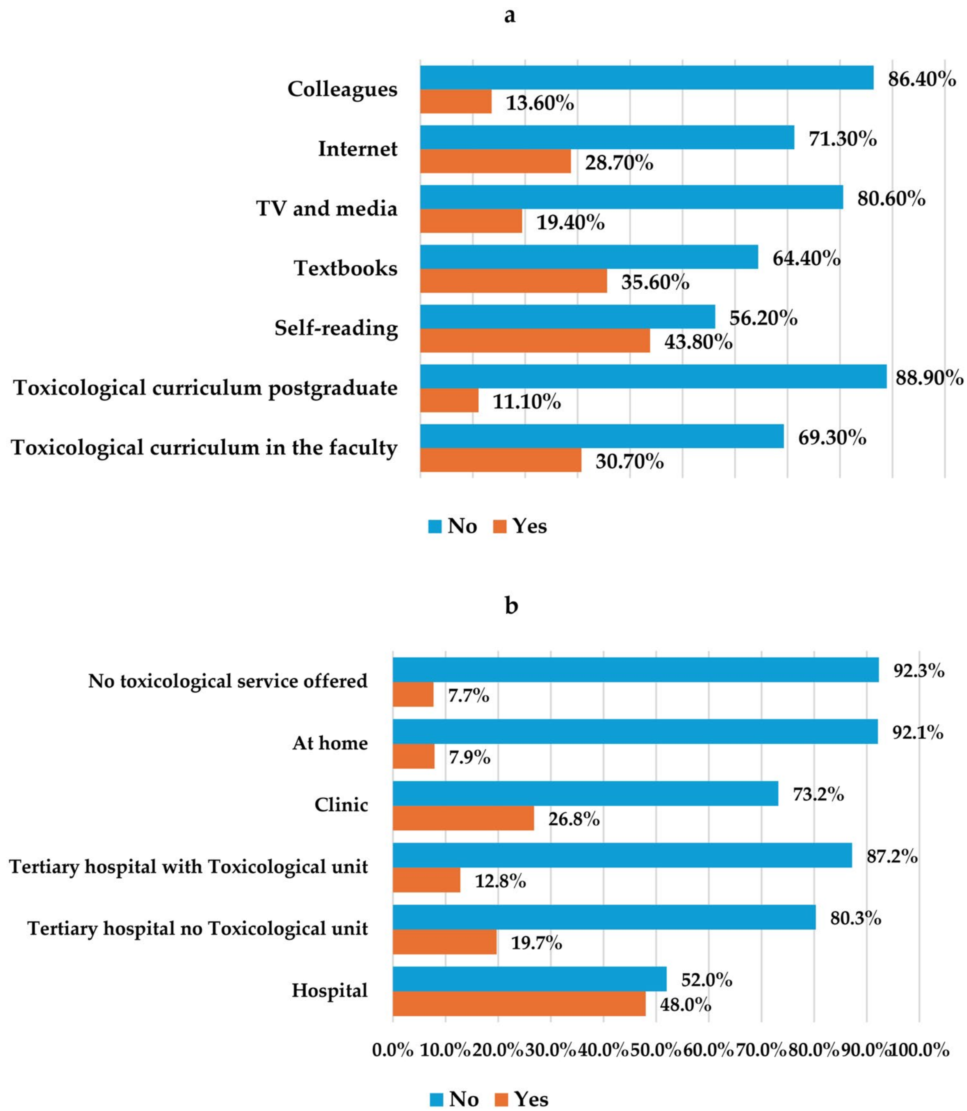

Figure 2. a. Sources of knowledge about snakebite management. b. Place of offering toxicological service to victims 3.4. Characteristics of snakebite management and venom care services.

3.7. Factors associated with attitudes towards snake poisoning

The results indicated that positive attitudes toward snakebite management were independently associated with being male, holding a Doctoral degree, and working in the private or mixed public–private sector. Clinical engagement demonstrated strong associations: prior management of snakebite cases, admitting and treating patients, and providing first aid before referral were significant determinants of a higher attitude score. As involvement in self-directed learning and the inclusion of toxicology in college curriculum were positively associated with attitudes, educational exposure also remained significant. On the other hand, living in middle-income countries, working in an emergency department, lacking institutional management procedures, and expressing concern about procedural knowledge were all independently linked to less positive attitudes. Significant inter-country variation persisted, with respondents from Ghana, Nigeria, Sierra Leone, Somalia, Sudan, Uganda, and Zambia demonstrating higher attitude scores compared with Ethiopia. The attitude model showed significant improvement over the null model. McFadden pseudo-R^2 is 0.160, and the overall Wald test was statistically significant ($p < 0.001$). The model's suitability was also supported by accepted information criteria (AIC and BIC). No evidence of multicollinearity was observed between the independent variables (Table 5 and Supplemental Figure S3, Appendix II Supplemental Table S7).

Table 2. Characteristics of toxicological services provided to victims of snakebite ($n = 3544$).

Characteristics	Label	No (%)
Have you been in a situation that needed to deal with a victim of snakebite?	Yes	2235 (63.1)
	No	1309 (36.9)
Time to get training on how to deal with snakebites	Didn't get training	1929 (54.4)
	Less than 3 years	758 (21.4)
	Three to 6 years	472 (13.3)
	More than 6 years	385 (10.9)
A health care facility has snakebite management protocol or referral system	Yes	568 (16.0)
	No	1524 (43.0)
	Don't know	1452 (41.0)
Snake antivenom accessible at the health care facility dealing with snakebite	No idea	364 (10.3)
	Not available	878 (24.8)
	Rarely	517 (14.6)
	Sometimes	1177 (33.2)
	Always	608 (17.2)
Actions taken when people report to a health facility with snakebites	Refer immediately	397 (11.2)
	Give first aid treatments and refer	1426 (40.2)
	Admit and treat.	985 (27.8)
	Call for assistance from another health facility.	65 (1.8)
	Never dealt with a snakebite case	595 (16.8)
	I do not know	76 (2.1)

3.8. Factors associated with participants' responses to snakebite first aid practice

The fractional logistic regression analysis identified several factors significantly associated with participants' responses to snakebite first aid items (Table 6). Positive associations (higher scores), indicating better identification of incorrect practices, were observed among participants from Sierra Leone and Somalia, as well as those holding a diploma or fellowship, and those working as toxicologists. In addition, participants who reported admitting and treating patients or calling for assistance demonstrated significantly higher scores. Working in lower-middle-income countries was also positively associated with higher scores. Conversely, significantly lower scores were observed among participants from Ghana, Kenya, Nigeria, Sudan, Uganda, and Zambia (all $p < 0.001$). At the professional level, pharmacists ($p < 0.001$) and those in other professions ($p < 0.001$) were associated with lower scores. Additionally, participants who reported not knowing the appropriate management of snakebite cases had significantly lower scores ($p < 0.001$). The practice model demonstrated a statistically significant improvement over the null model ($p < 0.001$). Acceptable model fit as indicated by McFadden's pseudo-R^2 (0.163) and information criteria (AIC and BIC). The model showed no evidence of multicollinearity among the independent variables (Table 6 and Supplemental Figure S4, Appendix II Supplemental Table 8).

4. Discussion

The objective of this study was to assess the KAP of HCPs in SSA countries concerning snakebite envenomation. Furthermore, the study identified factors influencing these KAP scores providing valuable insights to inform strategies and interventions for improving clinical outcomes in snakebite patients.

This survey was conducted among 3,544 HCPs across nine SSA countries. The median knowledge score and attitude score were 87.0% (IQR 60.0–100.0%) and 87.0% (IQR 80.0–93.0%), respectively. In contrast, the median practice score was 0.0% (IQR 0.0–50.0%), indicating a substantial gap between knowledge and practice. However, this gap must be interpreted within the context of the workforce in the health systems studied. Notably, half of the respondents were general practitioners, while very few were toxicology specialists. This suggests that the responsibility for snakebite management falls largely on general practitioners, who lack in-depth expertise.

Determinants of higher knowledge included holding a doctoral degree, having 3–6 years of clinical experience, the availability of antivenom at the facility, training in toxicology, and engagement in self-directed learning. Determinants of a positive attitude were prior experience in snakebite

Table 3. Factors associated with knowledge, attitude, and practices scores on snakebite management (median [Q1–Q3]).

Variable	Category	Knowledge	*p*-value	Attitudes	*p*-value	Practices	*p*-value
Country	Ethiopia	60 (33–87)	<0.001	79 (75–85)	<0.001	25 (0–50)	<0.001
	Ghana	80 (53–93)		87 (82–93)		0 (0–25)	
	Kenya	93 (80–100)		82 (75–85)		0 (0–25)	
	Nigeria	67 (40–87)		85 (80–91)		0 (0–25)	
	Sierra Leone	100 (73–100)		89 (84–93)		50 (0–75)	
	Somalia	80 (67–93)		85 (80–91)		25 (0–50)	
	Sudan	80 (67–93)		89 (84–95)		0 (0-0)	
	Uganda	100 (93–100)		91 (87–95)		0 (0–25)	
	Zambia	73 (53–93)		89 (85–95)		0 (0–50)	
Sex	Female	80 (53–100)	<0.001	87 (80–93)	0.042	0 (0–50)	0.396
	Male	87 (60–100)		85 (80–91)		0 (0–50)	
Education level	Bachelor	87 (60–100)	<0.001	87 (80–93)	<0.001	0 (0–50)	0.001
	Diploma	87 (53–100)		85 (80–91)		0 (0–50)	
	Master	80 (60–100)		89 (82–93)		0 (0–50)	
	PhD	87 (67–100)		85 (78–91)		0 (0–50)	
	Fellowship	73 (47–93)		85 (80–91)		0 (0–25)	
Profession	General practitioner	87 (67–100)	<0.001	87 (82–93)	<0.001	0 (0–50)	<0.001
	Emergency	87 (47–100)		82 (76–87)		0 (0–50)	
	Toxicologist	100 (87–100)		87 (84–91)		25 (0–75)	
	ICU	67 (40–87)		82 (76–87)		0 (0–50)	
	Pharmacist	67 (40–87)		87 (84–93)		0 (0–0)	
	Nurse	87 (53–100)		89 (84–93)		0 (0–25)	
	Other Profession	80 (53–93)		87 (82–93)		0 (0–25)	
Job category	Government	80 (53–100)	<0.001	85 (80–91)	<0.001	0 (0–50)	0.772
	Private	87 (60–100)		87 (82–93)		0 (0–50)	
	Both	93 (67–100)		89 (82–95)		0 (0–50)	
Having protocol	No	87 (53–100)	<0.001	89 (82–93)	<0.001	0 (0–50)	0.678
	Yes	60 (33–87)		84 (76–89)		0 (0–50)	
	Don't know	87 (73–100)		85 (80–91)		0 (0–50)	
Dealing with a victim of snakebite	No	73 (40–100)	<0.001	85 (78–91)	<0.001	0 (0–25)	<0.001
	Yes	87 (67–100)		87 (82–93)		0 (0–50)	
Time to get training on snakebites	Didn't get training	80 (47–100)	<0.001	87 (80–93)	<0.001	0 (0–50)	0.175
	Less than 3 years	87 (67–100)		85 (80–89)		0 (0–50)	
	3 to 6 years	93 (73–100)		87 (80–91)		0 (0–50)	
	More than 6 years	93 (67–100)		89 (82–93)		0 (0–50)	
Actions taken when going to health facilities	Refer immediately	80 (53–100)	<0.001	85 (80–91)	<0.001	0 (0–25)	0.039
	Give first aid treatments and refer	87 (67–100)		87 (82–93)		0 (0–50)	
	Admit and treat.	87 (67–100)		87 (82–93)		0 (0–50)	
	Call for assistance	73 (60–93)		84 (76–87)		0 (0–50)	
	Never dealt with a snakebite case	60 (33–87)		82 (76–89)		0 (0–25)	
	I do not know	53 (27–73)		79 (73–89)		0 (0–25)	
Snake antivenom accessible at health facility	No idea	53 (20–80)	<0.001	84 (78–89)	<0.001	0 (0–25)	<0.001
	Not available	87 (53–100)		89 (80–93)		0 (0–50)	
	Rarely	80 (60–100)		85 (82–91)		0 (0–50)	
	Sometimes	87 (67–100)		85 (80–91)		0 (0–25)	
	Always	93 (73–100)		87 (82–92)		0 (0–50)	
Country classifications	low–Income Countries	80 (53–100)	<0.001	85 (78–91)	<0.001	0 (0–50)	<0.001
	Lower–Middle–Income Countries	87 (60–100)		87 (82–93)		0 (0–25)	
Knowledge source							
Toxicological curriculum in the faculty	No	80 (53–100)	<0.001	85 (80–91)	<0.001	0 (0–50)	0.622
	Yes	93 (73–100)		89 (84–93)		0 (0–50)	
Toxicological curriculum postgraduate	No	80 (53–100)	<0.001	85 (80–93)	<0.001	0 (0–50)	0.075
	Yes	93 (73–100)		89 (82–93)		0 (0–50)	
self–reading	No	80 (53–93)	<0.001	85 (78–91)	<0.001	0 (0–50)	0.827
	Yes	87 (67–100)		89 (82–93)		0 (0–50)	
Textbooks	No	80 (53–93)	<0.001	85 (80–91)	<0.001	0 (0–50)	0.687
	Yes	93 (73–100)		89 (84–93)		0 (0–50)	
TV and media	No	80 (53–93)	<0.001	85 (80–91)	<0.001	0 (0–50)	0.507
	Yes	100 (80–100)		89 (82–93)		0 (0–50)	
Internet	No	80 (53–93)	<0.001	85 (80–91)	<0.001	0 (0–50)	0.265
	Yes	93 (67–100)		89 (82–95)		0 (0–50)	
Family and friends	No	80 (53–100)	<0.001	85 (80–91)	<0.001	0 (0–50)	0.192
	Yes	100 (80–100)		91 (85–95)		0 (0–50)	

All values are presented as Median (Interquartile range, IQR) for knowledge, attitude, and practices. The p values were calculated using the Kruskal–Wallis's test for multi-category comparisons and the Mann–Whitney U test for binary variables, with statistical significance defined as $p < 0.05$.

Table 4. Factors associated with healthcare providers' knowledge of snakebite envenomation in Sub-saharan Africa.

Variable	Category	AME	(95% CI)	*p*-value
Age (years)		0.001	(−0.003–0.005)	0.704
Country	Ghana	0.112	(0.012–0.212)	0.028
	Kenya	0.232	(0.146–0.318)	<0.001
	Nigeria	0.103	(−0.001–0.206)	0.051
	Sierra Leone	0.090	(0.038–0.142)	0.001
	Somalia	0.070	(0.021–0.118)	0.005
	Sudan	0.082	(0.030–0.134)	0.002
	Uganda	0.246	(0.155–0.336)	<0.001
	Zambia	0.107	(0.018–0.195)	0.018
Sex	Male	0.001	(−0.013–0.014)	0.916
Education level	Diploma	−0.019	(−0.058–0.021)	0.353
	Master	0.004	(−0.02–0.028)	0.718
	PhD	0.088	(0.049–0.127)	0.001
	Fellowship	−0.006	(−0.027–0.015)	0.567
Profession	Emergency	−0.030	(−0.081–0.021)	0.241
	Toxicologist	0.012	(−0.027–0.052)	0.546
	ICU	−0.018	(−0.049–0.013)	0.261
	Pharmacist	−0.037	(−0.062–−0.013)	0.003
	Nurse	−0.029	(−0.080–0.023)	0.277
	Other Profession	−0.012	(−0.034–0.009)	0.265
Job category	Private	0.013	(−0.011–0.037)	0.271
	Both	0.035	(0.003–0.067)	0.032
Years of experience		−0.002	(−0.007–0.003)	0.528
Having protocol	No	−0.044	(−0.079–−0.008)	0.018
	Don't know	0.031	(0.009–0.053)	0.005
Dealing with a victim of snakebite	Yes	0.027	(0.00–0.055)	0.053
Time to get training on snakebites	Less than 3 years	0.014	(−0.018–0.047)	0.384
	3 to 6 years	0.034	(0.004–0.063)	0.024
	More than 6 years	0.030	(−0.012–0.073)	0.158
Actions taken when going to health facilities	Give first aid treatments and refer	0.027	(0.008–0.047)	0.007
	Admit and treat	0.032	(−0.002–0.065)	0.064
	Call for assistance	−0.016	(−0.098–0.066)	0.703
	Never dealt with snakebite case	−0.041	(−0.088–0.006)	0.085
	I do not know	−0.059	(−0.12–0.002)	0.059
Snake antivenom accessible at health facility	Not available	0.078	(−0.008–0.164)	0.076
	Rarely	0.088	(0.008–0.168)	0.031
	Sometimes	0.099	(0.044–0.154)	<0.001
	Always	0.108	(0.037–0.181)	0.003
Country income classification	Lower-middle-income countries	−0.061	(−0.129–0.008)	0.082
Knowledge source				
Toxicological curriculum in faculty		0.069	(0.040–0.098)	<0.001
Toxicological curriculum Postgraduate		0.053	(0.019–0.086)	0.002
Self-reading		0.035	(0.017–0.054)	<0.001
Textbooks		0.069	(0.039–0.099)	0.001
TV and media		0.034	(−0.047–0.114)	0.416
Internet		0.02	(−0.028–0.068)	0.416
Family and friends		0.088	(0.034–0.142)	0.001

Reference categories: Country: Ethiopia, Sex: female, Education: bachelor, job: government, Profession: general practitioner, Country income classification: Low-income countries. Time to get training on snakebites: didn't get training. Actions taken when going to health facilities: refer immediately, snake antivenom accessible at health facility: no idea. Model fit was satisfactory, with a log pseudolikelihood of −1766.891 and McFadden's pseudo-R^2 of 0.179, indicating meaningful improvement over the intercept-only specification. The model was jointly significant under clustered inference (Wald χ^2 (64) = 526.85, $p < 0.001$), and information criteria supported the adequacy of the specification (AIC = 3549.783; BIC = 3599.167). Multicollinearity diagnosis shows that all VIF values were less than 5 and ranged between 1.038 and 3.717. Furthermore, the tolerance values exceeded 0.2 for all variables, indicating the absence of a significant multicollinearity problem in the Knowledge Model (Supplemental Table S6). AME: Average Marginal Effect; *p*-value is significant at <0.05.

management, training in toxicology, receiving information from family and friends, and country-specific factors, particularly in Uganda and Zambia. Practice scores differed significantly across countries, with HCPs in Sierra Leone and Somalia scoring higher, while pharmacists scored lower than other HCPs. A lack of familiarity with existing snakebite management guidelines was independently associated with poorer practice scores. In terms of participants composition; Kenya reported a higher number of emergency physicians, whereas Nigeria had a greater representation of pharmacists. Uganda and Zambia showed larger proportions of nurses, while Sierra Leone and Somalia included relatively more HCPs with advanced academic qualifications and clinical specialties closely aligned with practice.

Table 5. Factors associated with healthcare providers' attitudes toward snakebite envenomation in Sub-saharan Africa.

Variable	Category	AME	(95% CI)	*p*-value
Age (years)		0.001	(−0.001–0.002)	0.369
Country	Ghana	0.048	(0.044–0.052)	<0.001
	Kenya	0.006	(−0.009–0.021)	0.464
	Nigeria	0.038	(0.037–0.039)	<0.001
	Sierra Leone	0.046	(0.042–0.050)	<0.001
	Somalia	0.025	(0.022–0.027)	<0.001
	Sudan	0.056	(0.052–0.061)	<0.001
	Uganda	0.087	(0.065–0.108)	<0.001
	Zambia	0.075	(0.064–0.086)	<0.001
Sex	Male	−0.003	(−0.005–-0.001)	<0.001
Education level	Diploma	−0.008	(−0.018–0.002)	0.13
	Master	0.009	(−0.001–0.019)	0.073
	Doctoral	0.012	(0.003–0.022)	0.013
	Fellowship	−0.009	(−0.024–0.005)	0.193
Profession	Emergency	−0.007	(−0.011–-0.002)	0.002
	Toxicologist	−0.010	(−0.031–0.010)	0.323
	ICU	0.001	(−0.002–0.004)	0.566
	Pharmacist	0.020	(0.002–0.038)	0.034
	Nurse	−0.001	(−0.012–0.01)	0.873
	Other Profession	0.001	(−0.003–0.004)	0.884
Job category	Private	0.004	(0.001–0.007)	0.008
	Both	0.011	(0.003–0.017)	0.003
Years of experience		0.001	(−0.002–0.002)	0.719
Having protocol	No	−0.010	(−0.015–-0.005)	<0.001
	Don't know	0.001	(−0.006–0.006)	0.95
Dealing with a victim of snakebite	Yes	0.010	(0.004–0.017)	0.001
Time to get training on snakebites	Less than 3 years	−0.012	(−0.028–0.004)	0.142
	3 to 6 years	−0.008	(−0.037–0.022)	0.61
	More than 6 years	−0.011	(−0.022–0.000)	0.061
Actions taken when going to health facilities	Give first aid treatments and refer	0.010	(0.007–0.014)	<0.001
	Admit and treat.	0.010	(0.004–0.016)	<0.001
	Call for assistance	−0.019	(−0.038–0.000)	0.046
	Never dealt with snakebite case	−0.001	(−0.009–0.007)	0.792
	I do not know	−0.024	(−0.047–-0.001)	0.043
Snake antivenom accessible at health facility	Not available	0.001	(−0.007–0.007)	0.982
	Rarely	0.008	(−0.022–0.039)	0.593
	Sometimes	0.009	(−0.011–0.03)	0.368
	Always	0.012	(−0.014–0.039)	0.367
Country income classification	Lower-middle-income countries	−0.004	(−0.006–-0.002)	<0.001
Knowledge source				
Toxicological curriculum in faculty		0.015	(0.013–0.017)	<0.001
Toxicological curriculum Postgraduate		0.003	(−0.001–0.007)	0.127
Self-reading		0.007	(0.00– 0.013)	0.04
Textbooks		0.011	(−0.001–0.023)	0.074
TV and media		−0.007	(−0.019–0.004)	0.207
Internet		0.001	(−0.015–0.016)	0.966
Family and friends		0.021	(0.015–0.028)	<0.001

Reference categories for the analysis were as follows: Ethiopia for country, female for sex, bachelor's degree for education, government employment for job type, general practitioner for profession, low-income classification for country income, 'did not get training' for snakebite training, 'refer immediately' for actions taken at health facilities, and 'no idea' for antivenom accessibility. The model demonstrated a statistically significant improvement over the null model, as indicated by a log pseudolikelihood of −1435.292, a pseudo-R^2 of 0.160, and a significant Wald χ^2 (64) = 342.21 ($p < 0.001$). Model fit and parsimony were supported by information criteria values (AIC = 2886.585, BIC = 2935.969), confirming the appropriateness of the selected covariates. Supplemental Table S7 indicates the absence of multicollinearity among the independent variables, as the VIF values were within an acceptable range (<5) and all tolerance values were greater than 0.2. These results are similar to those of the Knowledge Model. AME denotes Average Marginal Effect, and statistical significance was defined at $p < 0.05$.

This research shows that self-directed reading was the primary source of knowledge about snakebites, whereas formal curricula for health professionals were perceived as the least effective source of knowledge acquisition. The reliance on self-directed reading reflects the shortage of pre-service and in-service training programs, where knowledge about the management of snakebites is often inadequately addressed, outdated, or treated as a secondary topic [33].

The knowledge score [87.0% (60.0–100.0)] suggests a substantially higher level of knowledge than what has been reported in most of the current literature. On the other hand, systematic reviews have estimated the average global knowledge level to be around 56% [34]. Moreover, studies conducted in

Table 6. Factors associated with healthcare providers' practices regarding snakebite envenomation in Sub-saharan Africa using a fractional logit model.

Variable	Category	AME	(95% CI)	*p*-value
Country	Ghana	−0.143	(−0.17–-0.116)	<0.001
	Kenya	−0.179	(−0.183–-0.175)	<0.001
	Nigeria	−0.173	(−0.19–-0.155)	<0.001
	Sierra Leone	0.129	(0.106–0.153)	<0.001
	Somalia	0.071	(0.059–0.084)	<0.001
	Sudan	−0.217	(−0.258–-0.175)	<0.001
	Uganda	−0.154	(−0.206–-0.102)	<0.001
	Zambia	−0.088	(−0.12–-0.057)	<0.001
Education level	Diploma	0.022	(0.019–0.026)	<0.001
	Master	0.018	(−0.004–0.040)	0.105
	PhD	0.006	(−0.028–0.04)	0.729
	Fellowship	0.028	(0.009–0.047)	0.005
Profession	Emergency	0.012	(−0.084–0.107)	0.809
	Toxicologist	0.038	(0.027–0.051)	<0.001
	ICU	0.016	(−0.017–0.048)	0.344
	Pharmacist	−0.089	(−0.097–-0.081)	<0.001
	Nurse	−0.019	(−0.048–0.011)	0.219
	Other Profession	−0.029	(−0.037–-0.02)	<0.001
Dealing with a victim of snakebite (Yes)		0.017	(−0.024–0.058)	0.426
Country income classification	Lower-middle-income countries	0.058	(0.047–0.068)	<0.001
Actions taken when going to health facilities	Give first aid treatments and refer	0.012	(−0.004–0.028)	0.134
	Admit and treat.	0.009	(0.009–0.01)	<0.001
	Call for assistance	0.053	(0.01–0.097)	0.016
	Never dealt with a snakebite case	0.001	(−0.011–0.011)	0.979
	I do not know	−0.015	(−0.019–-0.011)	<0.001
Snake antivenom accessible at health facility	Not available	0.012	(−0.047–0.071)	0.699
	Rarely	0.021	(0.019–0.021)	<0.001
	Sometimes	0.001	(−0.019–0.019)	0.992
	Always	0.009	(−0.016–0.035)	0.479

The following categories served as the reference for interpretation: Ethiopia (country), bachelor's degree (education), general practitioner (profession), low-income countries (income classification), 'refer immediately' (action taken at health facilities), and 'no idea' (antivenom accessibility). The model achieved a log pseudolikelihood of −1710.061 with a pseudo-R^2 of 0.163, reflecting a clear gain in fit relative to the intercept-only specification. Information criteria were AIC = 3436.121 and BIC = 3485.505, indicating a reasonable balance between fit and complexity, and the overall joint test under clustered inference was significant (Wald χ^2 (36) = 48.72, $p = 0.007$). No evidence of multicollinearity was detected, with low VIF values (1.022–1.375) and high tolerance values (>0.7), Supplemental Table (S8). AME denotes Average Marginal Effect, and $p < 0.05$ denotes statistical significance.

highly endemic areas, such as rural Ghana, have reported remarkably low knowledge scores, often below 50% [28]. Further evidence highlights both the variability and severity of these knowledge gaps. In northern Nigeria, a study conducted among 331 HCPs found that only 12.7% had sufficient knowledge about the use of antivenom serum [24]. Another study from northern Nigeria among 374 tertiary hospital doctors found that the mean knowledge score was 70.2%, with only 52.9% fulfilling the criteria for the definition of 'adequate' knowledge [35]. In Sudan, a study of 394 medical and HCPs showed that 58.1% had sufficient knowledge of snakes, and 45.3% had knowledge of snakebite presentation [25]. The aforementioned study in Ghana enrolled 186 HCPs and reported that the overall knowledge score was only 48.2%, with registered general nurses having the lowest scores, whereas medical doctors scored significantly higher [28]. This variation in knowledge levels highlights the need for standardized, context-specific training interventions, especially in areas where snakebites are a critical public health concern.

The modest explanatory power of the knowledge model (McFadden pseudo-R^2 value 0.179) in the current study suggests that additional unmeasured factors, such as regional differences in disease burden and healthcare infrastructure, may influence participants' knowledge and were not captured in the analysis.

The results of the current study suggest that the development of expertise in snakebite management is not simply a function of professional experience. Rather, it depends on investment in education and institutional support within healthcare settings. Knowledge levels were highest among HCPs with formal training in toxicology, those who had received recent training within the previous 3–6 years, and those practicing in institutions with established protocols and a regular, accessible supply of antivenom. This finding contrasts sharply with the 'institutionalized improvisation' that remains prevalent in healthcare systems across SSA [36].

The finding that pharmacists had a significantly lower level of knowledge is noteworthy. This disparity likely reflects systemic exclusion from clinical emergency training programs, rather than individual capability. In a decentralized healthcare setting, where pharmacists are often the first point of contact, this knowledge gap represents a critical systemic failure [37]. This professional disconnect is consistent with observations in other low-resource settings and underscores the need to reframe snakebite management as a high-priority, multidisciplinary responsibility [36].

The association between knowledge and awareness of antivenom availability suggests that knowledge is stronger in environments where antivenom is recognized as an integral component of the healthcare system, rather than merely a theoretical concept. On the other hand, the negative association between knowledge and the lack of protocols or systems for referrals demonstrated how insufficient individual preparedness was linked to a general lack of knowledge. This creates a vicious circle where the lack of protocols leads to a lack of knowledge, which in turn reduces the motivation to develop any protocols at all [38].

In this study, a median attitude score of 87.0% indicates a strongly positive professional outlook. Similarly, in rural Bangladesh, HCPs exhibited appropriate clinical perspectives, yet operated within a community context that often directed victims to traditional healers, resulting in a significant gap between attitudes and practical application [39]. In Sudan, HCPs' moderate level of knowledge did not lead to increased confidence in snakebite management, as it was undermined by inadequate training and a lack of systemic support [25].

This study showed that the positive attitudes are not just a default setting but are closely associated with specific enabling factors. The association between positive attitudes and having a doctoral degree, working in private or mixed sectors, and having prior clinical experience underscores the importance of professional autonomy and practical skills, which align with the literature [40]. Furthermore, the significant association between the absence of institutional protocols and negative attitudes observed in this study parallels and helps explain the low confidence in disease management reported in Sudan [25], highlighting a common systemic challenge.

The observed differences in country-level attitude scores in the current study from lower scores in Ethiopia to higher scores in Uganda underscore that systemic investments, such as the adoption of WHO-aligned protocols, are not optional but fundamental. Such investments appear essential for transforming provider confidence from passive uncertainty into proactive engagement in effective snakebite management [41–43].

Although this study revealed generally high levels of knowledge and positive attitudes, practices related to snakebite management were frequently inadequate. Marked discrepancies were observed across different countries and professional groups, highlighting a substantial gap between theoretical knowledge and its application in clinical practice among HCPs. For example, Uganda and Sierra Leone achieved median knowledge scores of 100%; however, their median practice scores were only 0% and 50%, respectively. This gap is most probably due to systemic unpreparedness, including inadequate clinical training, unclear protocols, and inconsistent availability of antivenom [44].

In this study, HCPs reported several inappropriate practices, such as applying a tourniquet above the bite site, trying to suck out venom, cutting through the wound, and advising patients to run to the nearest health facility, which may accelerate the systemic dissemination of snake venom. Comparable harmful first-aid measures, including the use of tourniquets and other traditional interventions, have also been documented among HCPs in rural settings, contributing to avoidable complications [45]. In Sri Lanka, these harmful first-aid practices are common among caregivers and parents; however, targeted training has been shown to reduce these harmful practices [46]. Notably, better clinical practices in some LMICs appear to be linked with higher formal education and well-organized in-service training courses. Structured educational programs, such as the Snakebite Life Support training course in India, have significantly enhanced knowledge, self-efficacy, and clinical decision-making [47].

The practice scores were higher among HCPs holding diplomas or fellowships than those with master's or doctoral degrees, suggesting that hands-on experience and clearly defined clinical responsibilities may be more valuable than academic qualifications alone. Although very few toxicologists were included, they showed excellent practice performance, underscoring the value of specialized training. However, pharmacists demonstrated the poorest practice performance, which may reflect limited exposure to medical toxicology during their training [36]. Previous experience in managing snakebite cases did not predict better practice performance; rather, knowledge and the ability to perform appropriate steps, managing patients correctly, and seeking help when needed were the strongest predictors of practice performance. These findings reinforce the need for confidence supported by well-structured protocols, clear guidance, and well-equipped healthcare systems, which remain absent in many SSA countries.

The present study identified a substantial gap between knowledge and practice among HCPs across SSA, irrespective of country income level. Although participants had good knowledge and positive attitudes toward snakebite management, their clinical practices were consistently inadequate, independent of specialty, education, or prior training. Thus, knowledge and positive attitudes alone do not ensure effective care. This gap appears to be driven mainly by systemic and contextual barriers, including limited formal training, absent institutional protocols, unreliable antivenom supply, and weak referral systems. Practical application of care and consistent use of protocols predicted better practice more strongly than academic credentials alone, as shown by the stronger performance of diploma holders, fellows, and toxicologists compared with pharmacists and emergency physicians. These results underscore the importance of strengthening health systems through mandatory training, incorporation of toxicology into medical and nursing education, implementing standardized management protocols, and guaranteeing consistent antivenom. Creating more opportunities for supervised hands-on experience and structured in-service training is essential for narrowing gap between knowledge–practice and improving patients' outcomes across the region.

Strengths and limitations of the current study

The study has several strengths; including the application of a validated instrument (KAPSE-HCPQ), the large sample size, and reliable data, all together supporting a robust analysis of KAP predictors across SSA countries from diverse income levels. However, several limitations should be acknowledged. The cross-sectional design, self-reported data, and use of online surveys methods may have introduced potential bias, although mixed survey approaches can still yield valid insights [48]. Furthermore, the observed low practice scores may partly reflect limitations of the measurement scale rather than actual clinical performance, highlighting the need for more detailed assessment tools and complementary methods such as clinical audits or simulations. Additionally, contextual differences between countries such as variations in the healthcare systems and resource availability, were not comprehensively explored, possible residual confounding can be still detected. The current findings reflect the data of nine sub-Saharan countries that are more likely to have better-resourced and more developed connection settings. The sample may not represent all SSA settings or healthcare roles, as physicians were disproportionally represented in comparison with nurses. Consequently, future research should interpret the results cautiously when attempting to generalize them across the broader sub-Saharan region. Self-reported practices are also prone to biases including social desirability bias, wherein respondents tend to select answers that align with noms and expectations rather than their actual thoughts and acts. Added to this Hawthorne effect, in which survey participation itself can influence reported behaviors; to be professionally acceptable the respondents choose the correct answers. Together, these factors suggest that the actual adherence to clinical guidelines in routine practice may be even lower than that reported in the current study.

5. Conclusion and recommendations

This study highlights a pronounced gap between HCPs' knowledge, attitude, and practice. Although the HCPs demonstrated adequate theoretical understanding and generally favorable attitudes toward snakebite management, the translation of this knowledge into practice remains markedly deficient. Tourniquet application above the bite site, incising the wound, advising patients to run immediately to the nearest health facility, and attempting to suck out the venom are the commonly reported harmful practices. Improved outcomes were associated with higher levels of education, recent training, formal toxicological education, antivenom availability, and the presence of well-established institutional protocols. The generalizability of our results is confined to HCPs who were accessible *via* professional and digital networks, rather than to all HCPs across sub-Saharan Africa. Future studies should combine online surveys with an in-person 'face-to-face' data collection strategy to enhance representativeness across the diverse settings of the SSA region, in addition stratified probability sampling are encouraged. Marked differences between countries further reflect unequal levels of health system preparedness. To address the identified gaps, targeted interventions are recommended for HCPs in snakebite-endemic regions. These include mandatory simulation-based training paired with quarterly competency assessments; the display of standardized WHO-aligned visual algorithms in local languages; the use of bedside checklists to eliminate harmful practices and ensure timely patient transport; routine audits to monitor protocol adherence; linking antivenom distribution to verified team readiness supported by just-in-time training; and tailored education for nurses and pharmacists in contexts where physicians are limited. The goal of these measures is to translate awareness into consistent life-saving practice, beginning in high-burden areas and among professions with the greatest deficiencies.

Informed consent statement

An initial mandatory question was added to obtain the informed consent of the participant 'Do you agree to participate in the survey?' with 'Yes' or 'No' options; only those selecting 'Yes' could continue. Each subject gave their informed consent before the beginning of the research.

Author contributions

CRediT: **Fatma Mohamed Magdy Badr El Dine**: Conceptualization, Supervision, Visualization, Writing – original draft, Writing – review & editing; **Sarah Hamed N. Taha**: Conceptualization, Writing – original draft; **Suzan Abdel-Rahman**: Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Fatma Elnaggar**: Writing – original draft, Writing – review & editing; **Maryam Fasfous**: Data curation, Formal analysis, Software, Writing – original draft; **Assem Gebreal**: Supervision, Writing – original draft, Writing – review & editing; **Nathan Ezie Kengo**: Investigation; **Gori Gaitano**: Investigation, Writing – original draft; **Ukamaka Gladys Okafor**: Investigation; **Aschalew Benti**: Investigation; **Maram Mahmoud**: Investigation; **Sandra Konadu Bonnah**: Investigation; **Saaid Jama**: Investigation; **Alhaji Turay**: Investigation; **Okot Michael**: Investigation; **Abdul Mohsin Mohammad**: Investigation; **Ramy Mohamed Ghazy**: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Supervision, Visualization, Writing – review & editing.

Submission declaration

Institutional Review Board Statement: The Ethics Committee of the Faculty of Medicine, Alexandria University, Egypt, approved the study (IRB No 00012098: serial number 00018699) and it was carried out in accordance with the principles of the Declaration of Helsinki.

Disclosure statement

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Data availability statement

Upon reasonable request, the first author will make available the datasets used and analyzed in the current work.

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