

Unraveling the Dynamics of the 2023 Anthrax Outbreak: Insights from Spatial and Temporal Analysis in the Kariba Ecosystem, Zambia

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ABSTRACT

The 2023 anthrax outbreak in the Lake Kariba ecosystem of Zambia, particularly in the Sinazongwe district, heralded a significant threat to both animal and human populations. This study aimed to unravel the spatial and temporal distribution of anthrax deaths, identify the sources of the outbreak, and analyze the factors contributing to its spread. Through meticulous investigation and analysis of data collected from June to November 2023, we uncovered critical insights into the dynamics of the outbreak.

Spatially, the outbreak affected 25 locations, with the highest concentration of anthrax-related cattle deaths observed in Chimonselo, Chiyabi, and Dengeza villages. Temporally, the first livestock case emerged in June 2023, with vaccination efforts commencing in August and covering over 68,000 cattle by November 2023. Concurrently, sightings of dead hippos along the shores of Lake Kariba underscored the potential role of wildlife in disseminating anthrax. Tissue samples from a hippo carcass tested positive for anthrax, suggesting a zoonotic transmission pathway.

Climate change emerged as a critical factor exacerbating the outbreak, with prolonged droughts impacting water availability and pasture quality, rendering livestock more susceptible to diseases. Additionally, illegal livestock trade across Lake Kariba and collusion between coal truck drivers and livestock traders facilitated the spread of anthrax-contaminated meat, circumventing veterinary checkpoints.

The chronology of events leading to the outbreak elucidated the cascade of factors contributing to its delayed detection and control. The contamination of Lake Kariba by anthrax-infected hippo carcasses emerged as a primary source of the outbreak, with contaminated pastures also playing a significant role. It is probable that the outbreak in Sinazongwe district was epidemiologically linked to simultaneous outbreaks in neighboring Zimbabwe.

The absence of anthrax vaccination programs and a deficient animal disease early warning system exacerbated the vulnerability of livestock populations. The outbreak spread across a wide geographical area, particularly affecting villages along the shores of Lake Kariba, highlighting the significance of waterborne transmission.

In conclusion, this study provides critical insights into the complex interplay between wildlife, livestock, humans, and the environment in anthrax outbreaks. By implementing the recommended control measures, enhancing disease surveillance, and fostering cross-border collaboration, future outbreaks can be mitigated, safeguarding public health, livestock, and wildlife in the Lake Kariba ecosystem of Zambia.



Keywords- Anthrax outbreak, Livestock, Wildlife, Zambia, Lake Kariba ecosystem, Sinazongwe district, Spatial distribution, Zoonotic transmission, Climate change impact, One Health.

I. INTRODUCTION

Anthrax, a zoonotic disease caused by the bacterium *Bacillus anthracis*, poses significant threats to both animal and human health. In 2023, an unprecedented outbreak of anthrax struck the tranquil landscapes of the Lake Kariba ecosystem in Zambia, particularly ravaging the Sinazongwe district. This outbreak, the inaugural documented occurrence of anthrax in the region, ignited concerns regarding the complex interactions between livestock, wildlife, humans, and the environment. Agents that cause zoonotic diseases are infectious (transmissible) agents that not only are confined to 1 animal host but that also cause an infection (infestation) with or without clinical disease in several hosts, including humans.

An evidence-based semiquantitative methodology, developed by 35 scientific experts in the field of animal and public health, food, and clinical microbiology and epidemiology. Scores were assigned based on five criteria encompassing public health (severity and occurrence in humans), animal health (severity of disease coupled with economic consequences and occurrence in animals), and food (occurrence in food). This comprehensive approach, previously undertaken before the emergence of anthrax in Sinazongwe district, made a pivotal moment for public health authorities, veterinarians, and conservationists. As the outbreak unfolded, rigorous scrutiny of its origins, transmission dynamics, and socio-environmental factors became imperative. Exploring the nuances of this outbreak not only yields insights into its specific circumstances but also equips stakeholders with invaluable lessons for devising effective control strategies to mitigate future occurrences.

This study embarked on a comprehensive investigation into the 2023 anthrax outbreak, seeking to unravel its enigmatic origins and shed light on the underlying mechanisms fueling its spread. As outlined in the Zambia Anthrax Situational Report No: 001 (Ministry of Health, 2023), a total of 335 cases were documented across several provinces. By delving into the depths of this calamitous event, we endeavor to elucidate the potential sources of the outbreak, delineate the contributing factors, and proffer pragmatic recommendations for bolstering future control efforts. Through meticulous inquiry and rigorous analysis, this study aims to arm stakeholders with the knowledge and tools necessary to safeguard the health and well-being of both human and animal populations inhabiting the Lake Kariba ecosystem of Zambia.

The first suspected case of human anthrax in Sinazongwe was reported on October 14th, 2022, in a man who consumed meat from a dead hippopotamus found floating in Lake Kariba. Fear of legal repercussions for

possessing wildlife meat led him to withhold this information from health authorities. This incident remained unreported until disgruntled villagers revealed it in August 2023, by which time anthrax cases were reported in 13 villages.

The first suspected case of human anthrax in Sinazongwe district of Southern Province was reported on 14th October 2022 at Dengeza Health Post in an adult male, a resident of the nearby Munengo village in Mweenda ward, who had consumed meat from a dead hippo (*Hippopotamus amphibius*). However, for fear of legal repercussions, he withheld this information from the medical authorities by representing hippo meat as cattle meat (although no cases of suspected anthrax were reported in cattle at the time anywhere in Sinazongwe district).

This episode remained a closely-guarded secret in the community until it was subsequently exposed on 14th August 2023 by a disgruntled member of the village community. By then suspected anthrax in humans had been reported in 13 out of the 18 villages in the Dengeza Health Post catchment area.

According to the National Parks and Wildlife Act No. 14 of 2015, Sinazongwe district is classified as an 'open area' and the hippos therein are a protected species. Any person found in unlawful possession of hippo meat, or any wildlife product, therefore could attract dire legal consequences in his direction.

The dead hippo had been found floating by villagers in the waters of Lake Kariba on or around 1st October 2022 and was dismembered by the villagers before sharing its meat amongst themselves.

The village of Dengeza is situated about 130 km south of Sinazongwe Boma and 7 km from the shores of Lake Kariba. Dengeza falls under Siameja veterinary camp. The camp is not manned by any member of staff from the Department of Veterinary Services, a situation attributed to a shortage of manpower in the department.

On 14th July 2023, the District Veterinary Officer Dr Shonga Chalembe reported that suspected anthrax had broken out in humans following their handling and consumption of contaminated cattle meat and hippo meat in Siatwiinda village in Mweemba ward of Kanchindu veterinary camp in Sinazongwe district. Siatwiinda village is situated about 30 km to the northeast of Dengeza village.

Anthrax is a notifiable bacterial disease caused by *Bacillus anthracis*, and samples collected from the affected humans in Siatwiinda village were submitted to Samora Machel School of Veterinary Medicine Laboratory in Lusaka; they returned positive for anthrax. By 14th July 2023, Sinazongwe district had, according to the Anthrax Situation Report from Southern Province

Health Office dated 22nd July 2023, already recorded 13 cases of anthrax in humans (from Siatwiinda and Dengeza villages) since 1st June 2023.

It is worth noting that by that time (i.e. 14th July 2023), no cases of anthrax in livestock or wildlife had been reported to the veterinary or wildlife authorities in Sinazongwe district.

Outbreak Investigation

Sinazongwe district falls under Zambia's National Parks and Wildlife Act, classifying hippos as a protected species. Possession of wildlife products carries legal consequences. This regulation likely discouraged villagers from reporting dead hippos or consuming their meat, hindering early detection and intervention.

Outbreak of Anthrax in Sinazongwe District

According to archival data held by the Department of Veterinary Services, the outbreak of anthrax in Sinazongwe district marks the first time in recorded history that anthrax was being encountered not only in Sinazongwe district but also along the shores of Lake Kariba (at least on the Zambian side of the lake).

From an epidemiological point of view, it was of utmost importance to establish and understand how and when the circumstances leading to this pioneer outbreak coalesced and blossomed. Such an undertaking is essential in order to inform future policy direction insofar as the control of anthrax is concerned not only in Sinazongwe district but the country as a whole.

The outbreak ravaged livestock, principally cattle, in Sinazongwe district for 5 months before it fizzled out at the beginning of November 2023, earning it the dubious distinction of being one of the longest outbreaks of anthrax in the country. Occurring as it did in an era of rapid information transfer, the outbreak became the subject of an exaggerated media frenzy in the country (Fig. 1).



Figure 1: Media Articles on Anthrax Outbreak in Sinazongwe District.

Risk Mapping of Anthrax Occurrence in Zambia

Though anthrax has been regularly reported in Zambia since its first reported occurrence in Luambe National Park in 1922 (Siamudala, 2003), it is only now that its risk of occurrence and transmission has been comprehensively mapped using a multi-criteria decision tool (Mataa et. al, 2023). A multiplicity of risk factors was identified, notable amongst them being 'mafisa',

proximity to wildlife anthrax hotspots, proximity to livestock anthrax hotspots, presence of alluvial soils and presence of calcareous (high calcium carbonate-containing) soils (Fig. 2).

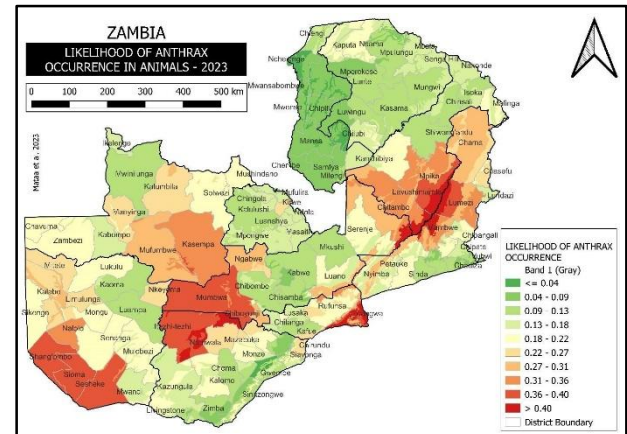


Figure 2: Likelihood of anthrax Occurrence in Zambia

Areas identified to be at high risk of occurrence of anthrax include:

- Shang'ombo district through Sioma district to Sesheke district
- Mumbwa district through Shibuyunji district and Itezhi-tezhi district to Namwala district
- Southern part of Mpika district and western part of Lumezi district through Lavushimanda district to Mambwe district
- Luangwa district

In Zambia, livestock anthrax is more frequently encountered in risk areas (a) and (b) whereas wildlife anthrax is more frequently encountered in risk areas (c) and (d).

The maintenance of anthrax spores in the environment is known to be favoured by certain types of soils (Singare et. al., 2022). A modified soil map of Zambia, taking this into consideration, is shown in Fig. 3.

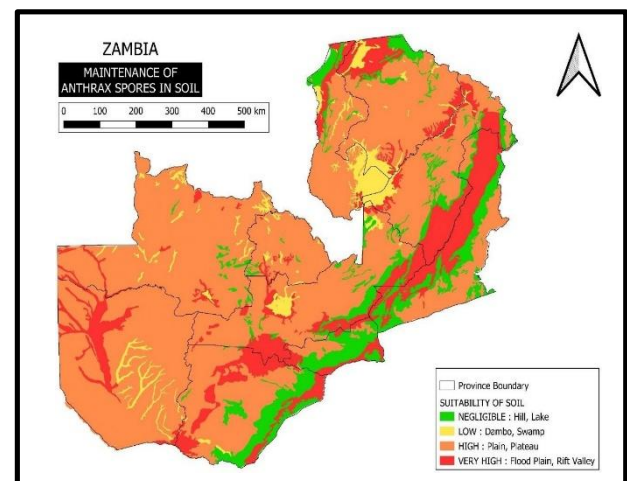


Figure 3: Modified Soil Map of Zambia.

Transmission Cycle of Anthrax to Man

In general, the transmission cycle of anthrax in livestock or wildlife starts with the ingestion of an infective dose of *Bacillus anthracis* spores during grazing. Clinical disease ensues after an incubation period of 1 - 10 days and upon death, carcasses of the infected animals are defiled and contaminate the environment and the cycle repeats itself.

Broadly speaking, two main epidemiological scenarios of transmitting anthrax to humans exist in Zambia. In scenario A, where there is weak or no interphase between wildlife and livestock, only the wildlife ingests the anthrax spores from the bacteria-contaminated pastures or water reservoirs and upon succumbing to disease, their carcasses enter the human food chain as meat resulting in the emergence of positive cases of anthrax amongst the human population. This scenario is exemplified along the Luangwa valley basin (from Chama district to Nyimba district) and the Lower Zambezi river basin (Luangwa district) when anthrax strikes the hippos and elephants (Fig. 4).

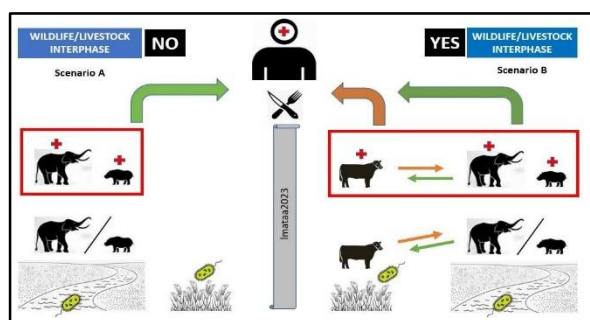


Figure 4: Transmission cycle of Anthrax to Man.

In scenario B a strong interphase between wildlife and livestock exists. Both the wildlife and livestock ingest the anthrax spores from the bacteria-contaminated pastures or water reservoirs (with contamination emanating from dead wildlife or livestock) and upon succumbing to disease, their carcasses enter the human food chain as meat resulting in the emergence of positive cases of anthrax amongst the human population. This scenario is exemplified in the Barotse Flood Plains in the Western Province when anthrax strikes cattle as well as the hippos in the Sioma Ngwezi National Park (Fig. 4).

In order to break the disease transmission cycle, intervention measures such as community sensitization, environmental decontamination of 'anthrax graves' and suspension of safari hunting would be appropriate for scenarios A and B. The inclusion of livestock vaccination to these measures would be economically reasonable for scenario B and less beneficial in scenario A. Needless to say, the interface in scenario B can be contained within the boundary of one country (as seen in the Barotse Flood Plains), or it can spill over into a neighbouring country. The presence of the Lake Kariba in Sinazongwe district has cleaved such an interphase, pitting the livestock component on the western bank of the lake against the

wildlife component on the eastern bank of the lake (Chete Safari Area in the Republic of Zimbabwe).

II. METHODOLOGY

In order to gather as much information as possible about the outbreak of anthrax in wildlife and livestock in Sinazongwe district, a number of techniques were used. Face-to-face personal interviews were held in Sinazongwe district with key value chain and sector players such as fishers along the shores of Lake Kariba, government officials (DOF, DNPW, DVS, MOH), livestock traders, butcher men and private veterinarians under the auspices of the Crocodile Consortium.

General Objective

To investigate the 2023 anthrax outbreak in the Lake Kariba ecosystem of Zambia, focusing on the Sinazongwe district, and to understand its spatial and temporal distribution, identify its sources, and analyze the factors contributing to its spread.

Specific Objectives:

1. Determine the spatial distribution of anthrax-related cattle deaths within the Sinazongwe district, focusing on identifying the locations with the highest concentration of cases, such as Chimonselo, Chiyabi, and Dengeza villages.
2. Investigate the temporal distribution of anthrax cases by analyzing the timeline of events, including the emergence of the first reported livestock case in June 2023 and the implementation and coverage of vaccination efforts from August to November 2023.
3. Examine the potential role of wildlife, particularly hippos, in the transmission of anthrax, with a focus on understanding zoonotic transmission pathways through the analysis of tissue samples from anthrax-positive hippo carcasses found along the shores of Lake Kariba.
4. Evaluate the impact of climate change on the outbreak dynamics by assessing the influence of prolonged droughts on water availability, pasture quality, and livestock susceptibility to diseases, and exploring how these factors contributed to the spread of anthrax in the Sinazongwe district.
5. Face-to-face interviews with villagers, fishers, government officials, and livestock traders. Field visits to affected locations (Fig.5)



Figure 5: Interview with Mr. D Mweetwa at Dengeza Health Post.

Structured questionnaires for fishing village committees regarding dead hippo sightings. Examination of veterinary office records.

Confirmatory field visits were also undertaken to selected localities and villages in Sinazongwe district where livestock and/or wildlife deaths were reported.

A structured questionnaire was administered to representatives of Fishing

Village Management Committees by DOF staff in Gwembe, Siavonga and Sinazongwe districts in order to elicit information on sightings of dead hippos (Fig. 6).

Ministry of Fisheries and Livestock				
HIPPO DEATHS QUESTIONNAIRE				
Name of District	GWEMBE		SIAVONGA	
Name of Fishing Camp/Village				
Stratum	I	II	III	IV
Name of Respondent				
Date of Interview				
Question 1	Did you, or any member of your fishing camp/village, see HIPPOS along the shores of Lake Kariba from January 2023 to October 2023?	YES NO	If answer is NO end the interview	
Question 2	Did you, or any member of your fishing camp/village, see DEAD HIPPOS along the shores of Lake Kariba from January 2023 to October 2023?	YES NO	If answer is NO end the interview	
Question 3	In which MONTH(S) did you, or any member of your fishing camp/village, see DEAD HIPPOS along the shores of Lake Kariba this year? (Choose all applicable months)	JAN MAY SEP	FEB JUN OCT	MAR JUL APR AUG
Question 4	Approximately how many DEAD HIPPOS did you, or any member of your fishing camp/village, see along the shores of Lake Kariba this year?			

INSTRUCTIONS

- Respondent should be a member of the Fishing Village Management Committee.
- Only **ONE** Questionnaire must be administered per Fishing Camp/Village.
- Where options are provided, circle or tick or cross your response.

Figure 6: Fishing Village Management Committee Questionnaire.

The final technique used was the examination of registry records at the district veterinary office in Sinazongwe district with a view to unearth any missed disease alerts.

Geography of the Anthrax Outbreak Area

Lake Kariba, situated in the Southern Province of Zambia, is the world's second largest man-made lake created through damming of the Kariba Gorge at Kariba in Siavonga district in 1958 for the purpose of generating hydro-electric power for the copper and coal mines in Northern Rhodesia and Southern Rhodesia respectively. At that time in history the two riparian Rhodesias were under the colonial administration of the British Empire where they formed an integral part of the Federation of Rhodesia and Nyasaland.

Lake Kariba is well known for its wonderful sunsets and serene boat trips. The topography and hydro-biography of the lake is as follows:

- Altitude: 665 m at average high water level
- Length: 280 kilometres
- Width: 40 km (at greatest)
- Area: 5,364 square kilometres
- Depth: 93 m (maximum)
- Depth: 29 m (average)
- Water temperature at surface: 22 – 35°C
- Air temperature at surface: 22.5 – 28°C
- Rainfall: 16 - 24 inches on the southern side and 24 - 32 inches on the northern side

On the Zambian side, the lake shoreline, which runs from Siavonga district (fishery stratum IV) in the north through Gwembe district (stratum III) to Sinazongwe district (strata I and II) in the south, is punctuated with over 60 fishery settlements and villages distributed thus:

- 17 in stratum I (Makunka to Siatwinda)
- 14 in stratum II (Luchinze to Chiyabi)
- 6 in stratum III (Simulilika B to Hamatuba)
- 15 in stratum IV (Jari to Lufua)

Carcass burial sites, known to retain viable spores for up to 12 months post-outbreak, pose significant concerns as potential reservoirs for *B. anthracis* and catalysts for new disease outbreaks. Conversely, on the Zimbabwean side, nearly 80% of the lake's shoreline is nestled within protected wildlife sanctuaries, such as Charara Safari Area, Chete Safari Area (opposite Zambia's Chete Island), and Matusadona National Park (Fig. 7).

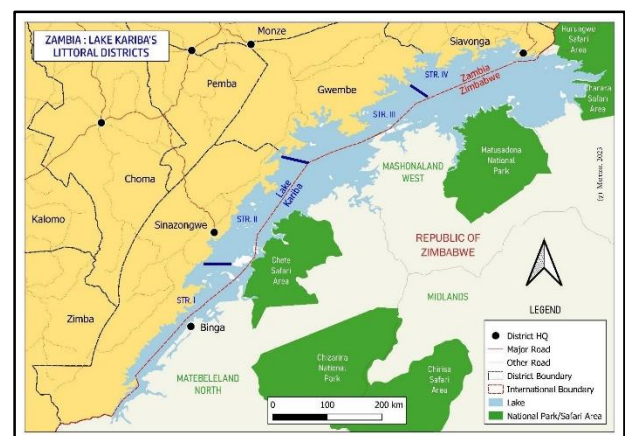


Figure 7: Zambia's Lake Kariba Littoral Districts and Fishery Strata.

III. DEMOGRAPHICS AND ECONOMICS OF THE OUTBREAK AREA

Of the three littoral districts of Lake Kariba, Sinazongwe district has the highest human population at

159,055 followed by Gwembe district (79,273) while Siavonga district is the least at 66,030 (ZamStats, 2022).

In terms of economic activity, there are 27,067 fishers in the Lake Kariba fishery, and stratum IV (Siavonga) has the largest number of fisherpersons (41% of the total) and the least is stratum II (Upper Sinazongwe) with 18%. However, with declining fish catches per boat night, livestock farming has emerged as an alternative livelihood to the fishing community of Lake Kariba (DOF, 2011).

Data from the Livestock and Aquaculture Census 2017/18, which records more goats than cattle for the littoral districts of Gwembe, Siavonga and Sinazongwe, is given in Fig. 8. On the other hand, data from the Fisheries Frame Survey (DOF, 2011), is given in Fig. 9 and shows the distribution of livestock across the Lake Kariba strata.

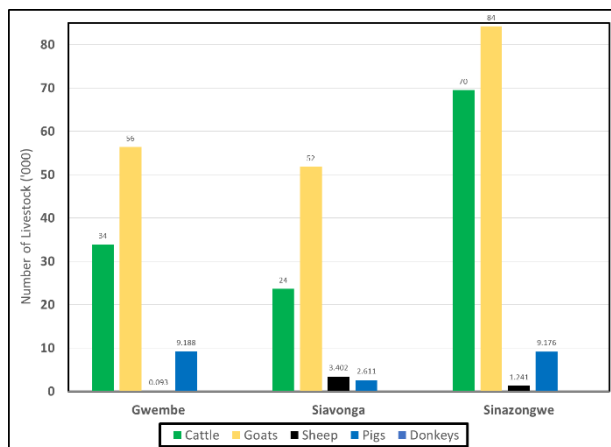


Figure 8: Distribution of Livestock across Lake Kariba Littoral Districts

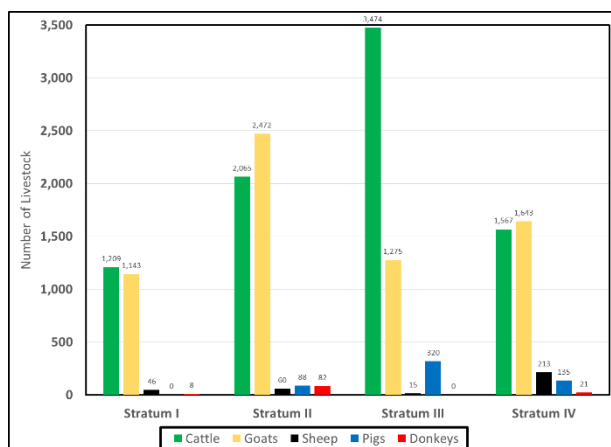


Figure 9: Distribution of Livestock across Lake Kariba Fishery Strata

IV. RESULTS

Spatial Distribution of Anthrax Deaths: During June-November 2023, 246 cattle deaths from anthrax were reported across 25 locations, with the highest concentration in Chimonselo, Chiyabi, and Dengeza

villages. During the period 6th June 2023 to 15th November 2023 a total of 246 cattle died from anthrax at 25 various locations and villages in Sinazongwe district, with Chimonselo, Chiyabi and Dengeza villages accounting for 60.2% of the deaths (Fig. 10).

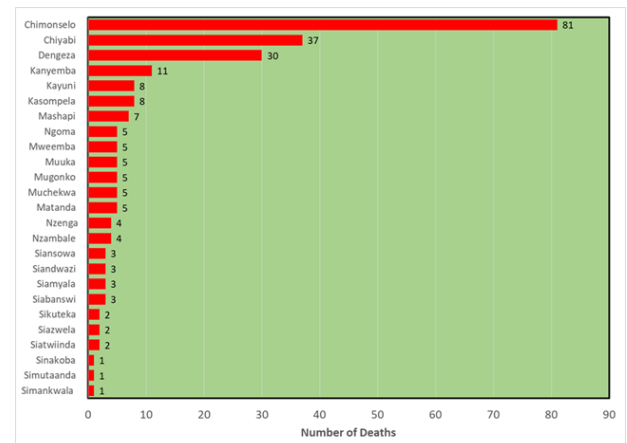


Figure 10: Distribution of Livestock Deaths by Location in Sinazongwe District

Temporal Distribution of Anthrax Deaths: The first reported livestock case occurred in June 2023. Vaccination began in August and covered over 68,000 cattle by November, 2023. The distribution of reported livestock deaths in time in Sinazongwe district is shown in (Fig.11). The first reported case in livestock occurred on 6th June 2023 at Kanyemba/Nzambale village in Kanchindu. Vaccinations began on 31st August 2023 and by 17th November 2023 a total of 68,883 cattle; 26,187 goats and 1,459 sheep had been vaccinated in the district.

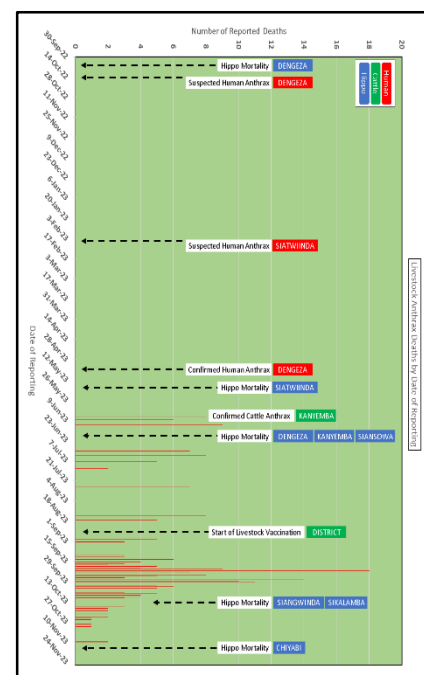


Figure 11: Distribution of Livestock Deaths by Date of Reporting in Sinazongwe District

Sightings of Dead Hippos Along the Shores of Lake Kariba (Fig.12) : Dead hippos were reported floating in various locations along the lake shore throughout the outbreak period. Tissue samples from one hippo carcass tested positive for anthrax. Lake Kariba is home to a sizeable population of hippos. A substantial anthrax outbreak in the wildlife of the Malilangwe Wildlife Reserve in Zimbabwe, occurring between August and November 2004, led to the demise of nearly all the reserve's estimated 500 kudu (*Tragelaphus strepsiceros*). Additionally, other species, including nyala (*Tragelaphus angasi*), bushbuck (*Tragelaphus scriptus*), waterbuck (*Kobus ellipsiprymnus*), and roan antelope (*Hippotragus equinus*), experienced significant losses, with approximately 68%, 48%, 44%, and 42% of their respective populations succumbing to the outbreak. Meanwhile, Mr. Evans Mubita, a Wildlife Ranger with the Department of National Parks and Wildlife (DNPW) in Sinazongwe district, observed concentrated hippo schools (groups of hippos) in specific locations such as Chiyabi, Simalilongwe, Mambova, Nang'ombe, Irrigation Area, Muntu wa Masiku, and Intake Area. Additionally, other sites frequented by hippos include Sinazongwe Main Harbour, Nzenga Fishing Camp, Simuzila Fishing Camp, Siatwiinda, Siansowa, Namafulu (bordering Binga district in Zimbabwe), and Namazambwe.

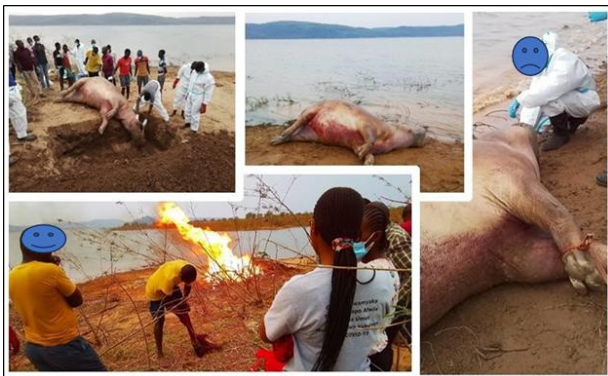


Figure 12: Incineration of Hippo Carcass on Njongolo stream in Chiyabi.

Localities where dead hippos were sighted floating in the lake by the local people are shown in Table 1.

Table 1: Sightings of Dead Hippos Along the Shores of Lake Kariba.

S/N	LOCALITY	EAST	SOUTH	MONTH	NUMBER
1	Siatwiinda	27.2806	-17.4288	May, June	2
2	Siansowa	27.3873	-17.4508	June, July	2
3	Siangwinda	27.5152	-17.1998	October	Not known
4	Dengeza	27.1508	-17.6722	Jun	Not known

5	Sikalamba	27.4634	-17.2601	October	1
6	Chiyabi	27.6952	-16.9586	November	1*
7	Kanyemba	27.29554	-17.45731	June	Not known

* Tissue samples collected from the hippo tested positive for anthrax on microscopy and culture.

Bacillus anthracis colonies were identified based on their distinctive features: Rapidly-growing colonies resembling a "Medusa head" with irregular edges and comma projections, exhibiting a non-pigmented, dry "ground glass" surface. These colonies displayed a sticky, tenacious consistency. Identification of bacterial isolates relied on their cultural and biochemical characteristics. (Fig.13).

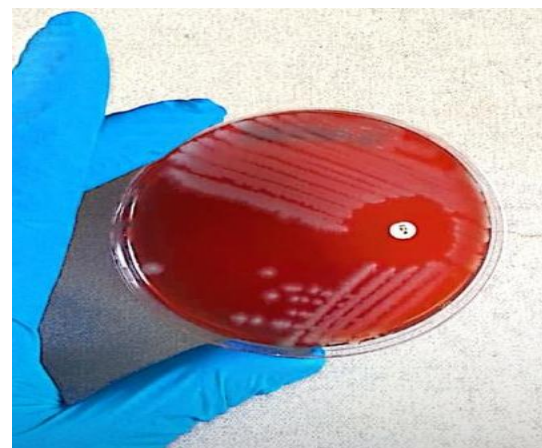


Figure 13: *Bacillus anthracis* colonies, Rapidly-growing colonies

Whilst hippos were regularly sighted by fishers along the shores of Lake Kariba in Gwembe district (stratum III) and Siavonga district (stratum IV) between January 2023 and October 2023, no reports were available to indicate that hippo deaths occurred during this period.

The distribution of cattle and hippo mortality is shown in Fig. 14.

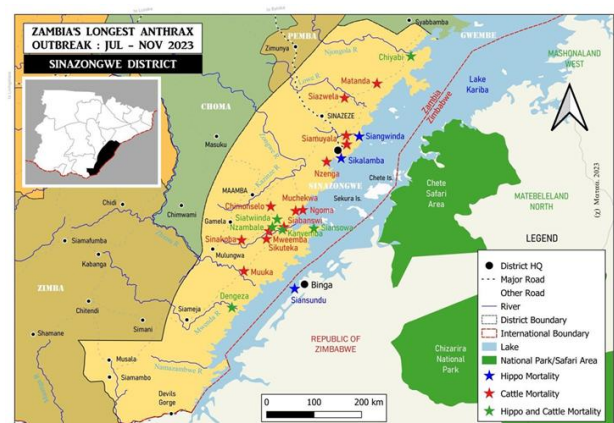


Figure 14: Cattle and Hippo Mortality in Sinazongwe District.

Climate Change and Animal Health : Sinazongwe experiences prolonged droughts, impacting water availability and pasture quality, potentially making livestock more susceptible to diseases. Sinazongwe district, lying at approximately 532 meters above sea level in Zambia's agro-ecological zone I, is one of the driest and hottest areas in the country (<https://www.weather2visit.com/africa/zambia/sinazongwe.htm>). Its rainfall and temperature pattern is given in Fig. 15 and Fig. 16 respectively.

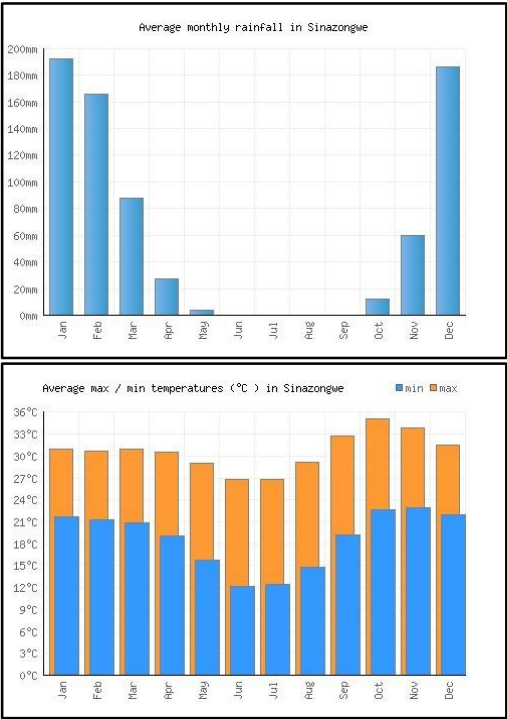


Figure 15: Average Monthly Rainfall Figure 16: Average Max/Min Temperature

It is prone to prolonged periods of drought which consequently leads to inadequate availability of water for livestock, poor quality of pastures and diminishes the animal's ability to withstand disease stress, resulting in spikes in disease incidence.

Staff at Sinazongwe Fisheries Training Institute, situated on the banks of Lake Kariba, have attested to the fact of a receding shoreline of the lake. According to them, since 2017 the lake shoreline has retracted by as much as 500 meters, thereby exposing rocks that were hitherto not visible and opening the exposed land for agricultural activity.

In an earlier study (Chainda, 2020) in Siavonga district, farmers also identified these adverse outcomes as effects of climate change in livestock production and included the emergence of 'new' livestock diseases to the list. Though the 'new' diseases are not specifically identified in the study, the emergence of anthrax in Sinazongwe district is a new phenomenon.

Elsewhere, for example in the Luangwa valley in Eastern Province, outbreaks of anthrax are often

associated with alternating heavy rainfall, drought and high temperatures.

Illegal Trade in Livestock

It emerged that there is booming illegal trade in livestock between Zambia's Namafulu area and Binga district in Zimbabwe. This is a point where the width of Lake Kariba is at its narrowest. Granted this, it is likely that in the event of hippo die-offs in Binga or Namafulu, hippo meat from either side of the lake can find a market on the other side of the lake.

The risk is further increased by the prevalence of cattle rustling which is rife in the area. The rustlers, locally known as 'bakanjani' in the local dialect, are armed robbers who ply their illegal trade on both sides of the international border.

Coal Mining and Anthrax

Sinazongwe district is home to Zambia's only coal mines, principal among them being Collum Coal in Nkandabbwe, and Maamba Collieries and Sezi Resources in Maamba. Most of the coal is transported outside the district by road using trucks (Fig. 17).

In addition to fulfilling this economic function, some unscrupulous truck drivers were also conniving with livestock traders to transport anthraxcontaminated meat from Sinazongwe district to Batoka in Choma district and beyond; the modus operandi used was to bury sacks of dried meat in the heaps of coal to evade detection at veterinary checkpoints.



Figure 17: Trucks ferrying coal from Sinazongwe District.

Chronology of Events Leading to Anthrax Outbreak

The chronology of events (and extenuating factors) leading to the outbreak of anthrax in Sinazongwe district is given in Table 2.

Table 2: Chronology of Events Leading to Anthrax Outbreak

DATE	EVENT	FACTORS
1 st October 2022 (approx.)	Dead hippo found floating on Lake Kariba near Munengo village, Dengeza.	Hippo died of unknown cause.
1 st October 2022 (approx.)	Villagers dismember the hippo carcass and share the meat.	High prevalence of hunger

		amongst people in the area.
14 th October 2022	First probable case of anthrax in humans recorded at Dengeza Health Post. It was misdiagnosed as cellulitis.	Consumption of hippo meat in Munengo village.
4 th Feb 2023	First probable case of anthrax in humans recorded at Siatwiinda Rural Health Centre.	Consumption of hippo meat in Munengo village.
5 th May 2023	First confirmed case of anthrax in humans recorded at Dengeza Health Post.	Consumption of hippo meat in Munengo village.
May-23	Dead hippo found floating on Lake Kariba at Siatwiinda village.	Hippo died of unknown cause.
Jun-23	Dead hippo found floating on Lake Kariba at Dengeza village.	Hippo died of unknown cause.
Jun-23	Dead hippo found floating on Lake Kariba Kanyemba at village.	Hippo died of unknown cause.
Jun-23	Dead hippo found floating on Lake Kariba at Siansowa village (near Zongwe Crocodiles).	Hippo died of unknown cause.
Jun-23	Probable cases of anthrax in cattle (and humans) recorded at Kanyemba village in Kanchindu.	
27 th Jul 2023	First probable case of anthrax in humans recorded at Sinazongwe Health Centre.	
5 th Aug 2023	First probable case of anthrax in humans recorded at Muuka Health Post.	Consumption of cattle meat
15 th Aug 2023	First probable case of anthrax in humans recorded at Siameja Rural Health Centre.	Consumption of hippo meat or cattle meat?
31 st Aug 2023	Start of anthrax vaccinations in cattle, goats and sheep	Livestock mortality
13 th Sep 2023	First probable case of anthrax in humans recorded at Sikaneka Rural Health Centre.	
13 th Sep 2023	First probable case of anthrax in humans	

	recorded at Namafulu Rural Health Centre.	
Oct-23	Dead hippo found floating on Lake Kariba at Maiya village (Siangwinda).	Hippo died of unknown cause.
Oct-23	Dead hippo found floating on Lake Kariba at Sikalamba village.	Hippo died of unknown cause.
14 th Nov 2023	Dead female hippo aged 4-5 years old, with blood oozing from nostrils, found floating on Njongola stream leading into Lake Kariba at Chiyabi village.	

Illegal Trade: The investigation revealed illegal livestock trade between Zambia and Zimbabwe across the narrowest point of Lake Kariba. This raises concerns about the potential spread of anthrax-contaminated meat.

Coal Mining: Some coal truck drivers reportedly colluded with livestock traders to transport contaminated meat, bypassing veterinary checkpoints.

Chronology of Events

The study presents a timeline of events leading to the outbreak, highlighting factors that contributed to its delayed detection and control. This includes the initial unreported human case, followed by subsequent human and livestock deaths throughout 2023.

V. DISCUSSION

The investigation by this study identified two potential sources for the outbreak: Contamination of Lake Kariba: Infective blood from dead hippos with anthrax likely contaminated the lake, leading to livestock ingesting spores while drinking.

Contaminated Pastures: Anthrax spores in pastures could have infected livestock grazing near the lake shore.

The study estimates that the lake water contamination accounted for approximately 75% of the cases, with contaminated pastures contributing to the remaining 25%.

Source of Anthrax Outbreak

Two likely sources of the outbreak of anthrax in Sinazongwe district were postulated. The major one, thought to account for close to 75% of the reported cases, was the contamination of the waters of Lake Kariba by infective blood from dead hippos with anthrax spores. In the quest by the livestock to hydrate themselves, the livestock invariably ingested the spores, triggering the commencement of the disease process in the livestock.

The minor source, accounting for about 25% of the reported cases, was the contamination of the pastures along Lake Kariba shores with anthrax spores from dead hippos during the process of scavenging of the hippo carcasses. The contaminating anthrax spores would come

from blood and ruminal contents during fraying of meat. Needless to say, villagers scrambling for hippo meat played a significant role in this process. For fear of crocodile attacks, which are numerous in the lake, the villagers would always drag the carcasses out of the water before dismembering them.

In the absence of a more detailed enquiry, which the current investigation did not have the luxury of time to consider, it is difficult to decipher where the hippos got the anthrax from in the first place. Suffice to mention, however, that notwithstanding, anthrax is endemic in neighbouring Zimbabwe, with outbreaks reported annually in livestock in high risk areas. Outbreaks of the disease in game parks, affecting a wide variety of wild animal species are also not uncommon (Clegg et. al. 2007). In a recent publication, Mukarati et. al (2020) has observed that anthrax appears to be establishing endemic status along the Zambezi River basin, with Chete Safari Area being a known anthrax hotspot.

In the recent past a number of hippo deaths, suspected to be due to anthrax, have been recorded not only on Zambia's Chete Island (1 hippo) but also on other islands on Lake Kariba such as Muzozo (4), Umbrella (1) and Wenzu (1). The anthrax hotspot Chete Safari Area is separated from Sinazongwe's Chete Island by a narrow strait of water.

In June 2023, **The Herald**, a Zimbabwean state-owned newspaper, reported the deaths of 16 hippos along the banks of Lake Kariba at Siansundu village in Binga, a poor rural district on the Zimbabwean side of the lake in Matebeleland North Province. The deaths were confirmed as anthrax by the country's national veterinary authorities. The disease later spread to humans. It is therefore probable to assume that the outbreak of anthrax that ravaged livestock and wildlife in Sinazongwe district in July 2023 has epidemiological links to the events that occurred on the islands as well as in Binga district in June 2023.

The occurrence of simultaneous outbreaks of anthrax (i.e. occurring at about the same time in the same ecosystem) in the Zambezi valley are a common phenomenon. This pattern has repeated itself time and time again especially in the stretch of the Zambezi river between Chirundu and Luangwa districts. In the last three decades, for instance, anthrax has been reported in hippos in Zambia's Lower Zambezi National Park on a number of occasions (i.e. September 1989, March 1997, October 2011 and December 2018) and these events have mirrored themselves in Zimbabwe's Mana Pools National Park across the Zambezi River. Insofar as the epidemiology of anthrax is concerned, however, only time will tell whether the 'anthrax twinning' of Sinazongwe district in Zambia and Binga district in Zimbabwe, both littoral districts on either side of Lake Kariba, will be sustained. The role of the informal trade in livestock between Sinazongwe district and Binga district in anthrax epidemiology has not been established.

Factors Promoting Spread of Anthrax Outbreak

Three factors were found to be critical in ensuring that the disease rapidly spread from its initial foci to other localities. First, anthrax has never been reported in Sinazongwe district before, and in line with Statutory Instrument No. 24 of 2014, farmers in the district are not compelled to, and therefore do not, vaccinate their livestock against the disease. Largely because of this, the livestock population resident in the district was immunologically naïve and when the disease came, it was relatively easy for it to sweep through the highly susceptible and nutritionally-stressed livestock.

Secondly, the district lacked an animal disease early warning and response mechanism which could have helped in risk assessment and analysis and in turn assist in prescribing an appropriate course of action. Arising from this shortcoming, the anthrax risk in Sinazongwe district was not graded and the district, oblivious to the consequences of their inaction, found itself overwhelmed as the events unfolded in rapid succession.

Thirdly the district lacked disinfection materials and equipment, thereby leading to a delay in instituting decontamination measures of the environment where animals died. These neglected anthrax graves were important sources of the spores that ultimately infected other animals.

Spatial Extent of Anthrax Outbreak

The outbreak of anthrax in Sinazongwe district was spread over a large swathe of the district, stretching from Chiyabi in the north to Dengeza in the south (refer to Fig. 16). The majority of cases appeared to be confined to villages along the shores of Lake Kariba or its tributaries, lending credence to the water contamination theory alluded to earlier.

The cattle mortalities were reported in all the wards of Sinazongwe district except Maamba, Mabinga, Nkandabbwe, Siameja and Tekelo.

VI. CONCLUSION

The 2023 anthrax outbreak in Sinazongwe district highlights the complex interplay between wildlife, livestock, humans, and the environment. The lack of early detection due to fear of legal repercussions and the potential role of illegal trade emphasize the need for improved public awareness, community engagement, and cross-border collaboration for effective disease control.

Recommendations

- 1) **Livestock Vaccination:** Implement regular anthrax vaccination programs for all livestock in the region.
- 2) **Wildlife Monitoring:** Collaborate with wildlife authorities to monitor hippopotamus populations and investigate unusual mortalities.
- 3) **Cross-Border Collaboration:** Enhance communication and collaboration with neighboring Zimbabwe to address illegal wildlife trade and livestock trafficking.

- 4) Review of Legal Frameworks: Review wildlife and environmental regulations to strike a balance between conservation and public health concerns. Consider creating designated reporting channels for dead wildlife sightings without legal repercussions.

Future Research

- 5) The outbreak highlights the need for further research on: Environmental Reservoirs: Identify specific environmental reservoirs of anthrax spores in the Lake Kariba ecosystem.
- 6) Climate Change Impact: Investigate the relationship between climate change, drought, and anthrax outbreaks in the region.
- 7) One Health Approach: Develop a "One Health" approach for anthrax surveillance and control, integrating human, animal, and environmental health sectors.
- 8) Concerted measures to eliminate the disease should be introduced as soon as possible, including improved cattle movement monitoring, strengthened epidemio-surveillance networks, and mass vaccination.

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Declarations

Availability of data and materials: All data generated or analyzed during this study are included in this

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Ethical Approval: Not applicable.

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