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EDITORIAL COMMENT Open Access

Editorial-Forecasting the anthrax outbreak dynamics in Zambia

Brian Chanda Chiluba[1,2*]

[1] School of Health Sciences, University of Zambia, Lusaka, Zambia
[2]Department of Geography and Environmental studies, School of Natural Sciences, University of Zambia

Corresponding author: brian.chiluba@unza.zm

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Anthrax has deep historical roots, believed to originate in ancient Egypt and Mesopotamia. Intriguingly, some scholars suggest its presence during the biblical era, potentially associated with the fifth plague during Moses' time, affecting various animals like horses, cattle, sheep, camels, and oxen.

Ancient Greece and Rome, renowned for their intellectual heritage, contain hints of anthrax recognition. Homer's "The Iliad" from 700 BC and the works of Virgil (70-19 BC) are thought to contain references to anthrax. Some even speculate that anthrax may have played a role in the eventual decline of the Roman Empire [1].

Anthrax, commonly known as splenic fever, is a highly dangerous bacterial disease with abrupt and lethal characteristics. Primarily affecting herbivores such as pigs, sheep, chickens, and buffaloes, it leads to rapid and excruciating health decline, posing significant threats to both animals and humans. Anthrax is a zoonotic disease, persisting as a challenge in numerous countries worldwide. It's attributed to Bacillus anthracis and mainly affects herbivorous animals, spanning from domestic livestock like sheep, goats, and cattle to wild animals like camels, antelope, deer, and buffaloes. Although birds are rarely afflicted, cats and dogs can contract the disease when consuming anthrax-contaminated meat. However, not all infected animals succumb, with outcomes influenced by factors such as pathogen dosage and natural immunity [2].

Bacillus anthracis, a gram-positive, rod-shaped bacterium, exists in two forms: vegetative and resilient spores. It remains in the vegetative form within a host's low-oxygen environment, but transforms into spores in adverse conditions, featuring a robust outer shield to survive harsh environments. When spores infiltrate a host, they germinate into vegetative cells, multiplying rapidly and leading to septicemia, causing the host's swift demise. Anthrax spores can persist for decades in the environment, posing a risk for new infections [3].

Human anthrax infection results from accidental exposure during rural agricultural activities or industrial processes. Several factors influence the risk, with anthrax infections manifesting as cutaneous, gastrointestinal, or inhalation anthrax. Cutaneous anthrax occurs when spores invade skin through abrasions, typically due to handling infected animals or products like wool, hides, or hair. Symptoms include localized itching, swelling, and discoloration, with untreated cases having a mortality rate of 5-20%. It accounts for approximately 95% of reported human anthrax cases.

Gastrointestinal anthrax occurs when individuals consume meat from animals infected with vegetative Bacillus anthracis or ingest anthrax spores via mucous membranes in the mouth and intestines. Symptoms include nausea, vomiting, anorexia, mild diarrhea, and fever, with a fatality rate exceeding 50%.

Inhalation anthrax develops when individuals inhale anthrax spores, with varying incubation periods. Symptoms comprise fever, chills, sweats, fatigue, cough, shortness of breath, mental alterations, confusion, and nausea or vomiting. It's associated with an 85% case-fatality rate [4].

Anthrax maintains a global presence, with endemic regions across Southern and Eastern Europe, Central and Southwestern Asia, Sub-Saharan Africa, North and South America, and Australia. An estimated 2,000 to 20,000 human anthrax cases occur worldwide annually. Beyond natural occurrences, Bacillus anthracis is a significant bioterrorism threat, particularly in Africa and various regions where many countries still face endemic anthrax, with most experiencing at least one human outbreak yearly [5].

Anthrax outbreak in Zambia

Anthrax outbreaks in Zambia have become a recurring concern, posing threats to both livestock and human populations. These incidents are typically associated with the transmission of Bacillus anthracis, the causative bacterium behind anthrax, from infected animals to humans. These outbreaks are more prevalent in rural or agricultural areas and are often linked to activities such as handling infected animal carcasses or consuming contaminated meat [6] (Carlson et al., 2018).

The impact of anthrax in Zambia extends to both public health and agriculture. To control and prevent these outbreaks, a range of measures have been implemented, including the surveillance and monitoring of animal and human cases, livestock vaccination, proper disposal of infected animal remains, and public awareness campaigns to educate communities about the associated risks and prevention strategies. Additionally, efforts are being made to strengthen the healthcare system's capacity for diagnosing and treating anthrax cases promptly, as well as enhancing veterinary services to control its spread among livestock. These measures collectively aim to mitigate the impact of anthrax outbreaks on both animals and humans in Zambia [7]

It's important to note that the recurrence of anthrax outbreaks in Zambia may be influenced by seasonal variations, particularly differences in precipitation and human activities. Furthermore, interactions between Bacillus anthracis and plants may provide a potential route of transmission to grazing hosts (Ganz et al., 2014). The transmission of anthrax via necrophagous flies has also been identified as a potential mechanism for the spread of anthrax among wildlife [8,9].

Effectively managing anthrax outbreaks in Zambia necessitates a comprehensive understanding of the environmental biology of anthrax, including the dynamics of spores and soil. In addition, the use of canonical single nucleotide polymorphism (CanSNPs) has been employed to characterize outbreak strains of Bacillus anthracis in Zambia, offering valuable insights into the genetic diversity and evolution of the bacterium.

Moreover, studies have explored the lay perceptions, beliefs, and practices linked to the persistence of anthrax outbreaks in cattle in the Western Province of Zambia. Thematic analysis of interview data has revealed important insights into the cultural and social factors contributing to the ongoing presence of anthrax outbreaks in this region [10].

Over the past several months, Zambia has been grappling with another anthrax outbreak. A previous outbreak took place in Muchinga Province in late September 2016 but was successfully contained by mid-October. During that outbreak, a total of 44 people were infected, fortunately with no reported fatalities. All cases were attributed to the consumption of contaminated meat.

In this recent outbreak, the Western Province has been particularly affected, with 67 reported cases of anthrax infection and two fatalities. This outbreak commenced in November 2016, persisted throughout January, and is ongoing into February. It has affected five districts within the Western Province, namely Limulunga, Nalolo, Kalabo, Shangombo, and Sioma. Alongside human infections, 40 animals succumbed to anthrax poisoning during the first week of January alone.

As of January 11, the Western Province outbreak had reported a total of 17 cases [11]. However, this number has since surged to 67 suspected cases with two recorded fatalities [12]. Health authorities strongly advise animal vaccination and caution against consuming potentially infected meat.

To combat the outbreak, the Ministry of Fisheries and Livestock has initiated a large-scale livestock vaccination campaign, coupled with government measures to restrict cattle movement from affected regions for vaccination purposes [12]. Approximately 65,000 cattle herds in the Western province are deemed at risk of infection.[9] Given that the primary mode of human transmission in this outbreak has been gastrointestinal anthrax infections, the Ministry of Health urges the public to refrain from consuming meat from cattle suspected of contamination [12, 13] This outbreak is of greater magnitude than the previous one in September and October, necessitating proactive public health measures for effective control.

It is important to know that in Zambia, anthrax is a notifiable disease under Chapter 295 section 9 of the Zambia Public Health Act of the Laws of Zambia. It is therefore mandatory to report all suspected cases to Government Veterinary and Public Health officials as soon as they are noticed. Timely determination of the risk of infection for an outbreak is cardinal for mobilizing adequate resources to stop the spread of the disease. It helps identify the focal area of the outbreak where resources should be allocated first.

Anthrax is a big public health security threat to our country and the subregion as well. anthrax can multiply, spread, produce toxins, and cause severe illness. There is an anthrax vaccine not available in Zambia approved for use in adults 18 to 65 years of age. The vaccine is only given to those who may be at risk of coming in contact with anthrax because of their job. These include certain laboratory workers who work with anthrax and some people who handle animals or animal products.

Figure 2 (as of 3rd November 2023), depicts Anthrax cases in Zambian provinces, alongside associated game reserves. It underscores the interplay between Anthrax outbreaks and wildlife habitats, with implications for both human and animal health. The maps showcase the varying severity of Anthrax across provinces, while also highlighting the correlation between Anthrax cases and game reserves. This information informs conservation efforts, resource allocation, and the need for integrated disease management, recognizing the interconnectedness of human, animal, and environmental health in Anthrax-affected areas.

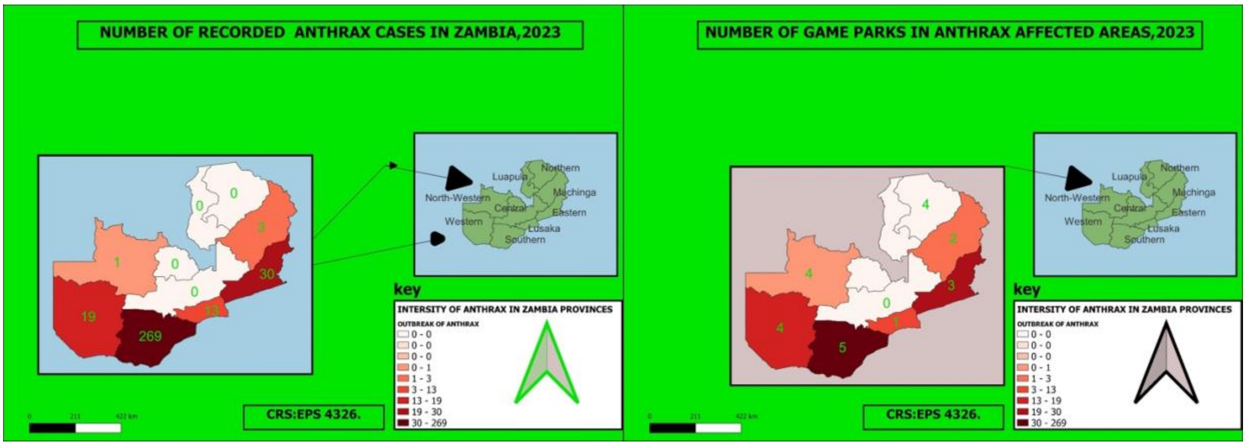

Figure 1: Case distribution and number of Game parks per case area with Anthrax (3rd November 2023)

SIR Model Specification-Anthrax context

The application of mathematical models for the investigation of infectious disease spread and control has proven to be a pivotal tool for epidemiologists and scientists [14]. The rate at which infective animals shed anthrax pathogens into the environment. The anthrax pathogen level in the environment P decays due to the practice of environmental hygiene and by natural phenomenon at rates of θP and ∈P respectively. The human population suffers a spillover transmission of anthrax from outbreaks of the disease within the animal population.

As shown in Figure 2, the susceptible human population Sh increases through recruitment at a rate of Λh. Susceptible humans become infected with anthrax through effective contact with pathogen sources (P, Ia) at a constant rate of βh. In the infective human class Ih, infected population recover from the disease due to treatment or natural recovery at a rate of φhIh and joins the recovery compartment Rh. Individuals in Rh become susceptible at a rate of πhRh due to waning of infection-acquired immunity. The Susceptible, Infected and Recovered humans die naturally at rates μhSh, μhIh and μhRh respectively. The infective human population also suffer from anthrax related deaths at rate αhIh.

During an anthrax epidemic, the general public especially farmers react behaviorally, psychologically, and socially towards the disease spread. These attitudes may have an impact on the overall infection rate or number of infectious persons as well as the susceptible human population through the incidence rate. As the number of infective individuals increases, the susceptible human population may tend to reduce the number of contacts with infective animal population per unit time due to the behavioral effect.

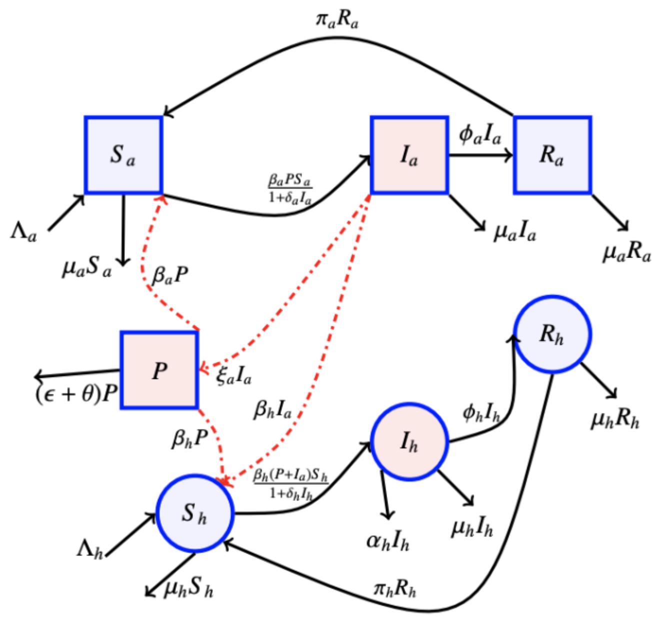

Figure 2. Schematic Diagram of Anthrax Epidemic in Animal and Human Populations.

SIR model-based forecasting of Anthrax outbreak in Zambia

Change in Susceptible Population (dS(t)/dt):

This fundamental equation within the SIR (Susceptible-Infectious-Recovered) model captures the dynamics of individuals who are susceptible to Anthrax, providing insights into how this group changes over time. Susceptible individuals are those who have not yet been exposed to the Anthrax pathogen and are thus vulnerable to infection [15]. The rate of change in susceptibility (dS(t)/dt) is governed by the transmission rate (β).

The transmission rate (β) is a critical parameter in infectious disease modeling, signifying the likelihood of transmission from infected individuals to susceptible ones. It is influenced by factors such as the frequency of contact between susceptible and infected individuals, the efficiency of transmission, and the characteristics of the pathogen. A higher β indicates a more contagious pathogen, leading to a faster depletion of the susceptible population [16].

Change in Infected Population (dI(t)/dt)

This equation pertains to the number of individuals who are actively infected with Anthrax at a given time. It is pivotal for comprehending the rate of new infections and the progression of the disease within the population. Infected individuals, while in this state, have the potential to transmit the disease to susceptible individuals and can eventually recover [15].

The change in the infected population (dI(t)/dt) results from two main factors: the transmission of the pathogen, which increases the number of infected individuals, and the recovery of infected individuals, which reduces this population. The transmission component is associated with the transmission rate (β), which represents the probability of infection spread [16]. The recovery component is governed by the recovery rate (γ), which defines the speed at which infected individuals transition into the recovered state [15].

Change in Recovered Population (dR(t)/dt)

This equation tracks the number of individuals who have successfully recovered from Anthrax infection, thus becoming immune to further infections. The rate of change in the recovered population (dR(t)/dt) is governed by the recovery rate (γ) [14].

The recovery rate (γ) signifies the rate at which infected individuals clear the infection and enter the recovered category [9]. It encompasses various factors, including the effectiveness of medical treatment, the strength of the individual's immune response, and the inherent characteristics of the Anthrax pathogen. A higher γ indicates a faster recovery rate, shortening the duration of time an individual remains infectious [14].

As shown in Figure 3, in the context of Anthrax modeling, these dynamic equations are crucial for understanding how the infection spreads, the impact of intervention measures, and the overall progression of the disease within a population.

Figure 3: SIR model

The sir model prediction of the outbreak of anthrax based on province in Zambia

The SIR (Susceptible-Infectious-Recovered) model is used to project the number of Anthrax cases for the next 6 months in various provinces of Zambia. This model is commonly employed in epidemiology to understand the spread of infectious diseases and predict how outbreaks might evolve.

Eastern Province

Over the next 6 months, the SIR model predicts the following number of Anthrax cases: 30, 60, 85, 110, 130, and 140. These projections indicate a gradual increase in the number of cases as the outbreak progresses. The model assumes that there is ongoing transmission within the population.

Southern Province

In Southern Province, the SIR model projects a higher number of Anthrax cases compared to Eastern Province, with projections of 269, 410, 560, 710, 760, 787, and 799 over the next 6 months. These numbers suggest a more significant outbreak in this region, possibly due to various factors such as population density or transmission dynamics.

Muchinga Province

Muchinga Province is experiencing a relatively low number of cases, as projected by the SIR model: 3, 3.20, 3.52, 3.88, 4.29, and 4.74 over the next 6 months. The lower-case numbers may be attributed to factors like lower population density, effective control measures, or less favourable conditions for Anthrax transmission.

North-western Province

The SIR model forecasts a gradual increase in Anthrax cases in North-western Province, with projections of 2, 2.3, 2.6, 3.0, 3.4, and 3.8 over the next 6 months. This suggests a relatively small outbreak, possibly due to early containment efforts or lower susceptibility in the population.

Western Province

Western Province is experiencing a moderate outbreak, as projected by the SIR model with the following cases over the next 6 months: 19, 40.5, 50.6, 57.3, 62.0, and 65.5. These numbers indicate an increasing number of cases, suggesting the need for public health measures to contain the outbreak.

Lusaka Province

Lusaka Province is projected to have a relatively high number of Anthrax cases over the next 6 months, with projections of 13.234, 39.674, 66.135, 92.596, 119.057, and 145.518. The higher numbers may be due to factors such as population density, movement, or transmission dynamics. It's important to note that these projections are based on the SIR model and its associated assumptions.

CONCLUSION

Anthrax remains a significant concern in Zambia, with varying outbreak projections across different provinces. These forecasts, generated using the SIR model, shed light on potential trends in the disease's spread. Effective control measures, public awareness, and timely interventions are essential to manage and mitigate the impact of Anthrax outbreaks in Zambia.

***Disclaimer**: The projections are based on the SIR model and are subject to change based on real-world factors and intervention strategies*

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