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KP Suresh
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

N Sagar
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

A Jayashree
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

SS Patil
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

YB Naveesh
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

R Sushma
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

D Hemadri
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

CA Archana
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

Corresponding Author:
SS Patil
ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru, Karnataka, India

Investigating a sheep anthrax outbreak in Karkihalli Village, Karnataka, India: An integrated study of demographic, ecological, socio-economic, and risk factors

KP Suresh, N Sagar, A Jayashree, SS Patil, YB Naveesh, R Sushma, D Hemadri and CA Archana

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Abstract
Anthrax, caused by *Bacillus anthracis*, is a persistent global threat to both public health and livestock industries. This study investigates a recent outbreak of sheep anthrax in Karkihalli Village, Karnataka, India. The demographic and ecological characteristics of this region are pivotal factors influencing disease emergence, with varying outbreak years observed among sheep farmers. Socio-economic factors and Risk Exposure and Mitigation Behavior (REMB)" were found to be critical determinants of anthrax incidence, emphasizing the multifaceted nature of the disease's spread. Sheep migration and proximity to water bodies, notably the Tungabhadra reservoir, facilitated spore transfer and contributed to the outbreak in this village. The study highlights the urgency of proactive measures, including comprehensive disease surveillance, vaccine accessibility, training initiatives for local veterinarians and farmers, and the integration of AI tools for early detection and rapid response.

Keywords: Anthrax outbreak, sheep anthrax, disease surveillance, livestock trading, disease prevention

Introduction
Anthrax is an acute, infectious, non-contagious, zoonotic disease that remains a threat to public health throughout the world. The causative agent of anthrax is *Bacillus anthracis*, which is a rod-shaped, spore-forming, soil-borne bacterium that survives in the soil under suitable conditions for long periods of time. *B. anthracis* is an extracellular pathogen that replicates rapidly in the blood, conquering high density to make the host diseased. The soil pH, organic calcium, potassium, and zinc concentrations of soil are believed to be correlated with the survival of spores. Animals come into contact with the spores by grazing grass closer to the surface when the grass is low or scarce, or by moving herds to restricted areas when water is scarce (Sushma *et al.*, 2021; Suresh *et al.*, 2022) [8, 7]. The spores are very resistant to unfavourable environmental extremes of heat, cold, desiccation, chemicals and irradiation. The incidence of anthrax varies with the type of the soil and climate. It is many times restricted to a particular area where it is endemic and such areas are known as “Anthrax belts”. Cattle and sheep are very susceptible to anthrax and dogs and cats are quite resistant. There are only few reports of anthrax outbreak in domestic animals in India. Venkatesha, *et al.*, (2006) [9] reported 2 anthrax outbreaks in Hassan and Kolar districts of Karnataka State.

Over the past 12 years, anthrax outbreaks have occurred irregularly in Karnataka state's Koppal district, particularly in Karkihalli Village. These outbreaks have affected livestock and resulted in human casualties. The need for ongoing vaccination, public health education, and surveillance efforts to prevent further outbreaks remains crucial in these regions.

In a parallel scenario unfolding in Karkihalli Village, situated within Koppal district, Karnataka, a concerning report surfaced indicating a sudden upsurge in animal mortality attributed to Anthrax disease. Notably, there had been prior official communication with regional health and veterinary authorities regarding this issue. This development triggered substantial consternation and instigated widespread public discourse within the region.

In response to the emergent situation, a swift and coordinated initiative was orchestrated by the National Institute of Veterinary Epidemiology and Disease Informatics, headquartered in Bengaluru. The primary objective of this initiative was to conduct a thorough investigation into the perplexing animal fatalities and subsequently validate the presence of an Anthrax outbreak in Karkihalli Village.

The multifaceted outbreak investigation team embarked on a structured mission with distinct aims, including the assessment of the scope and magnitude of the potential outbreak, the meticulous identification of the infection source, the comprehensive evaluation of populations at heightened risk, and the systematic analysis of demographic, ecological, socio-economic, and risk-related factors that may have contributed to the outbreak.

Furthermore, the team diligently engaged in the implementation of rigorous control and preventive measures to curtail the further spread of Anthrax. Additionally, the team sought to compile indispensable questionnaire data from the local populace. These questionnaires encompassed diverse aspects, such as migration patterns, socio-economic behaviours, risk exposure, and mitigation strategies, thereby enhancing the scientific basis for their investigation and bolstering their readiness to respond effectively to this unfolding crisis.

2. Methods

2.1 Study Area

Karkihalli in Karnataka, India, falls under village location code 601779 and is situated in Koppal taluk of Koppal District. It is positioned 10.2 km away from the District and Sub district headquarters at Koppal. Karkihalli Village, located in Koppal, covers an area of 4636.13 hectares and is situated at a latitude of 15.251872° N and a longitude of 76.247060° E (Fig. 1). The village is at an altitude of 526 meters. As of the most recent data available, the population of Karkihalli Village is 2428 people, with a literacy rate of 49.59%. (Table 1). The livestock population in Karkihalli Village comprises 1070 cows, 294 buffaloes, 1569 sheep, and 643 goats, totalling 3576 animals (Table 2).

Table 1: Demography of Karkihalli Village, Koppal

Area	4636.13 ha
Latitude	15.251872 "N
Longitude	76.247060 "E
Altitude	526 mt
Population	2428
Literacy rate	49.59 %

Table 2: Livestock Populationn

Cow	Buffalo	Sheep	Goat
1070	294	1569	643
Total=3576			

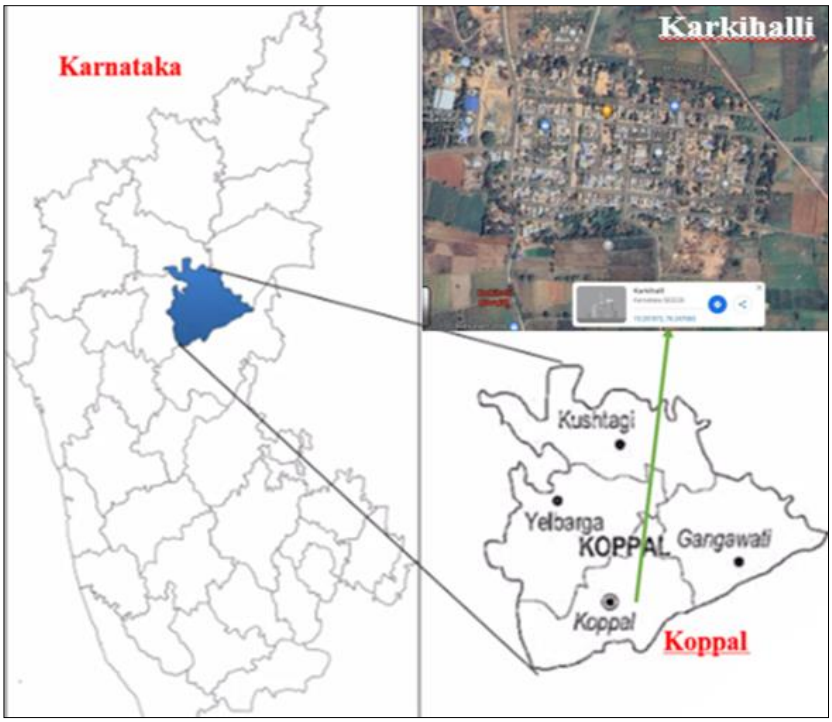


Fig 1: Google map of Karkihalli Village, Koppal

The ecology of Karkihalli village of Koppal district is characterized by its semi-arid climate, diverse vegetation, wildlife adapted to dry conditions, agricultural practices and the influence of human activities. The Tungabhadra reservoir, situated at Munirabad and bordering Karkihalli village, serves as a primary water resource for nearby villages and also tube wells are major source of water needs for both agriculture and livestock. The region experiences an average annual temperature of 27.0°C, receives around 587 mm of rainfall annually over 30-40 days, maintains an average annual wind speed of 5.67 meters per second, and sustains an average annual pressure ranging between 1008-1010 millibars (Table 3). The soil type prevalent in the area is primarily composed of Red Loamy soils, which are known for their fertility and suitability for agriculture. Agriculture in this region relies on both rainfed and irrigated methods, with tube wells being a common irrigation source. Major crops cultivated in this region include maize, sugarcane, sorghum, pigeon pea, black gram, green gram, cowpea, and groundnut, reflecting a diverse agricultural landscape that caters to various food and economic needs.

Table 3: Ecological, soil type and cropping pattern of Karkihalli village

1. Ave. annual Temperature	27.0 °C
2. Ave. annual Rainfall	587 mm
3. Ave. annual Rainfall days	30-40 days
4. Ave. annual wind speed	5.67 mt/sec
5. Ave. annual pressure	1008-1010 mb
6. Soil type	Red Loamy soils
8. Major crops	Maize, sugarcane, sorghum, pigeon pea, black gram, green gram, cowpea, groundnut

2.2 Study Design: The investigation adopted the One Health Approach. That is, involvement of the regional health system and veterinary service in Koppal. The Principal scientists of project, regional director of AH and VS and the regional veterinary officer took part in the investigation. The One Health Approach recognizes that the health of humans, animals and ecosystems are interconnected. The approach involves applying a coordinated, collaborative, multi-disciplinary and cross-sectoral approach to address potential or existing risks that originate at the animal-human ecosystems interface.

The investigation involved a review of past reports of outbreak investigations in Koppal district as well as an in-depth analysis of data collected between 2010-2023 as a result of the outbreak. Two Focused Group Discussions (six in each group) were held with livestock farmers and local community members. A total of seven interviews with a cross-section of the community members from grazing sites and livestock farmers were conducted to provide an account of what happened to their animals and community for the past periods about anthrax disease outbreaks for their animals. Interviews were also conducted with various stakeholders (i.e. district director of AH &VS, and regional veterinary officers).

Two case definition categories were used in the investigation to determine suspected and confirmed cases. A case is said to be suspected when it is compatible with the clinical description and has an epidemiological link to confirmed or suspected animal cases (or contaminated animal products) in and around Karkihalli village of Koppal district. A confirmed case was defined as a suspected case that is laboratory-confirmed. Veterinary records on anthrax vaccination coverage in the area and the history of anthrax outbreaks in the area as well as rainfall figures for the period were reviewed.

2.3 Data Analysis: The results of the outbreak investigation were categorized into three thematic areas which include: Animal anthrax, Veterinary records and ecological and demographic pattern. We performed descriptive analysis of the outbreak data by place and time. The findings are presented as frequency distributions, percentages, range, and attack numbers.

3. Results

3.1 Animal Anthrax: In a survey conducted in Karkihalli village, sheep anthrax cases were recorded among various farmers (Table 4 & Fig. 2). The detailed overview of the sheep populations managed by various farmers and the suspected anthrax attacks they encountered over multiple years, with a specific focus on the first attack year. Notably, Devappa and Govu Siddappa experienced a significantly high number of anthrax attacks, with 40 and 70 incidents, respectively. Devappa's first attack occurred in 2017-18, while Govu Siddappa's first attack was reported in 2018-2019. These numbers indicate the substantial challenges these farmers faced during those initial years due to anthrax outbreaks. Conversely, some farmers like Somappa reported a comparatively lower number of anthrax attacks, with only 10 incidents in 2017-18. In this case, the first attack year is also highlighted to provide insight into the timeline of anthrax occurrences. Moreover, the data shows that Jagadeesh had no recorded anthrax incidents during the specified years, suggesting a fortunate situation of minimal or no anthrax attacks. This information is particularly important for understanding regions or practices where anthrax is less prevalent. In summary, the table underscores the variable impact of anthrax on farmers' livestock and highlights the significance of knowing the first attack year to better assess the anthrax risk in a particular region or among specific farmers.

The questionnaire responses showed that most farmers strongly agreed on the influence of socio-economic factors in anthrax incidence (Likert Scale: 5). Additionally, farmers generally acknowledged the significance of Risk and Emergency Management Behaviour (REMB) in anthrax prevention (Likert Scale: 4-5). However, there was variability in responses regarding the relevance of migration patterns (Likert Scale: 1-5). Despite experiencing anthrax outbreaks in different years, their agreement levels vary significantly. While some farmers consistently express strong agreement across all domains, others exhibit mixed responses, suggesting that their perception of risk, preparedness, and migration behaviour may be influenced by individual circumstances or experiences with anthrax. Overall, the data underscores the complexity of farmer attitudes and preparedness in the face of anthrax incidents.

Table 4: Data of Anthrax of Sheep at Karkihalli village

SL. No.	Farmers Name	Total No of Sheep's	Suspected attacks	Year in which anthrax occurred/ not occurred	Questionnaire # (Likert Scale: 5 = strongly agree, 4= agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree)							
					Socio-economic		REMB		Migration		Preparedness	
					I	II	I	II	I	II	I	II
1.	Devappa	60	40	2017-18	5	5	5	5	5	5	5	5
2.	Revappa	80	70	2016-17	1	5	5	4	5	4	5	5
3.	Somappa	100	10	2017-18	1	4	5	4	5	5	5	5
4.	Govu Siddappa	100	70	2018-2019	1	4	5	5	5	4	5	5
5.	Parashuram	150	50	2018-19	5	5	5	5	5	5	5	5
6.	Nagaraj	130	30	2018-2019	2	4	5	5	5	4	5	5
7.	Nagappa	80	40	2018-19	2	5	5	5	5	4	5	5
8.	Ambarish	100	7	2023	1	5	5	5	5	5	5	5

9.	Annappa	120	40	2018	1	5	5	4	5	4	5	5
10.	Honappa	100	6	2023	4	4	5	4	5	5	5	5
11.	Bheerappa	200	4	2023	3	4	5	5	5	4	5	5
12.	Sindhogappa	70	8	2023	1	5	5	5	5	5	5	5
13.	Hanumantha	50	21	2018	2	4	5	5	5	4	5	5
14.	Jagadeesh	100	NIL	2023	5	5	5	5	5	5	5	5
15.	Shankarappa	70	30&3	2016&2023	3	5	5	5	5	5	5	5

Questionnaire [#]
Socio-economical: I. Do you think you're hesitant to dispose anthrax affected carcass in a way that goes against your religious teachings? II. Do you think you avoid social gatherings and public spaces due to fears related to the anthrax outbreak?
Risk Exposure and Mitigation Behavior (REMB): I. Do you think anthrax spores can survive in the soil for extended periods, posing a risk to grazing livestock? II. Do you think inadequate disease surveillance measures have hindered early detection of anthrax outbreaks?
Migration: I. Do you think unregulated movement of people and livestock can contribute to the spread of anthrax to unaffected areas? II.: Do you think shifting of animals or change of grazing area from infected to uninfected area is effective in avoiding occurrence of anthrax?
Preparedness: I. Do you think collecting and analysing data helps identify patterns and trends in anthrax cases? II. Do you think prior anthrax outbreak information is important for preparedness?

3.3 Veterinary records

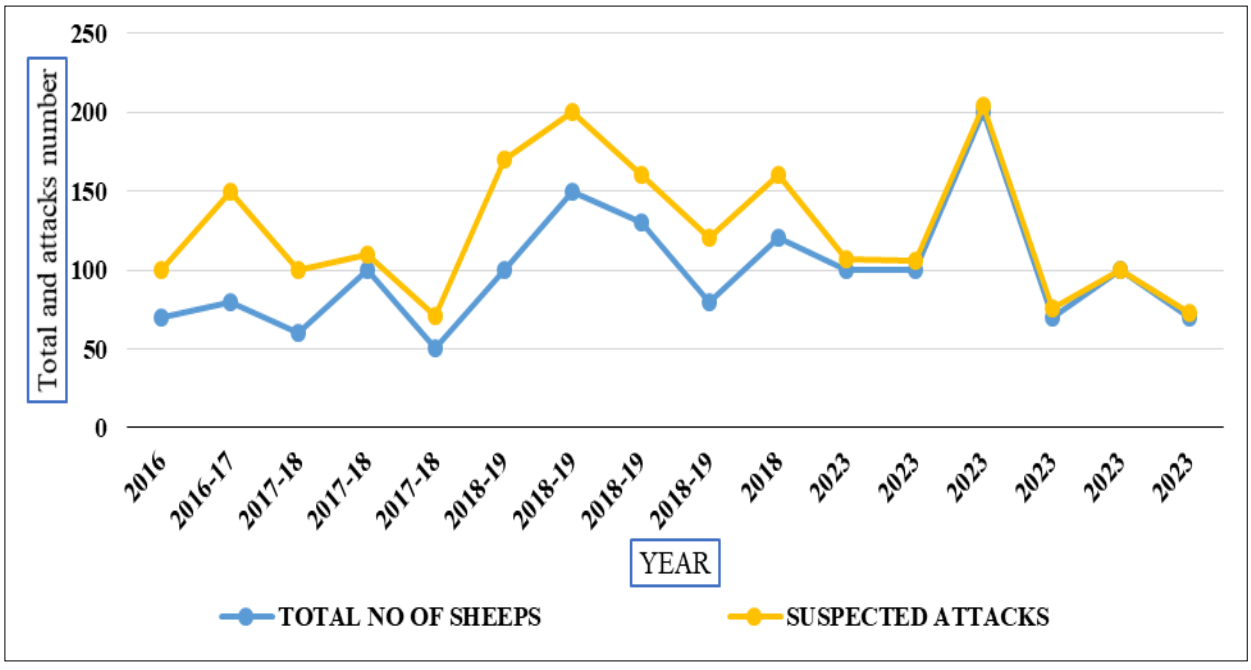
A review of veterinary records revealed that Koppal had yearly outbreaks of anthrax. There was an anthrax outbreak in 2022 in Karkihalli, a community which is about 12 km away from Koppal. The region has not had any programmed vaccination for several years except ad hoc vaccinations during outbreaks targeted at the outbreak area and its surrounding.

3.3 Focus group discussion and stakeholder interviews

During our FGD and stakeholder interviews, we observed that both health system and community-related challenges, mainly poor surveillance activities (notifications and reporting) by staff in the region which was largely attributed to low staff strength and limited capacity and lack of anthrax vaccination in animals due mainly to logistical problems. We also noticed that livestock farmers have over the years benefited from free vaccination services and thus shy away from fee payment for anthrax vaccination. Additionally, group and family ownership of animals poses a major problem for livestock when they are to be either vaccinated or treated for fee payment.

4. Discussion

Anthrax, an enduring conundrum in numerous regions, presents a significant public health peril owing to its propensity for infecting livestock. The field diagnosis hinges upon clinical manifestations, particularly the occurrence of abrupt mortality accompanied by exudation of non-coagulated blood from natural orifices. Mongoh *et al.* (2005) [4] discerned pivotal clinical indicators, encompassing the sudden demise of afflicted animals and the manifestation of haemorrhagic symptoms. Anthrax outbreaks typically arise from the ingestion of spores residing within the soil, frequently intertwined with antecedent incidents and the disposal of deceased animals. The contemporary outbreak has unveiled two distinct infection categories: the per-acute variant, characterized by unforeseen fatalities devoid of overt clinical manifestations, and the acute form, distinguished by discernible symptomatic presentations and the potential for case recovery. Bodies of water and the seasonal migration of sheep to the Tungabhadra reservoir have played a pivotal role in facilitating the transfer of anthrax spores, thereby exacerbating the outbreak dynamics within this locality.



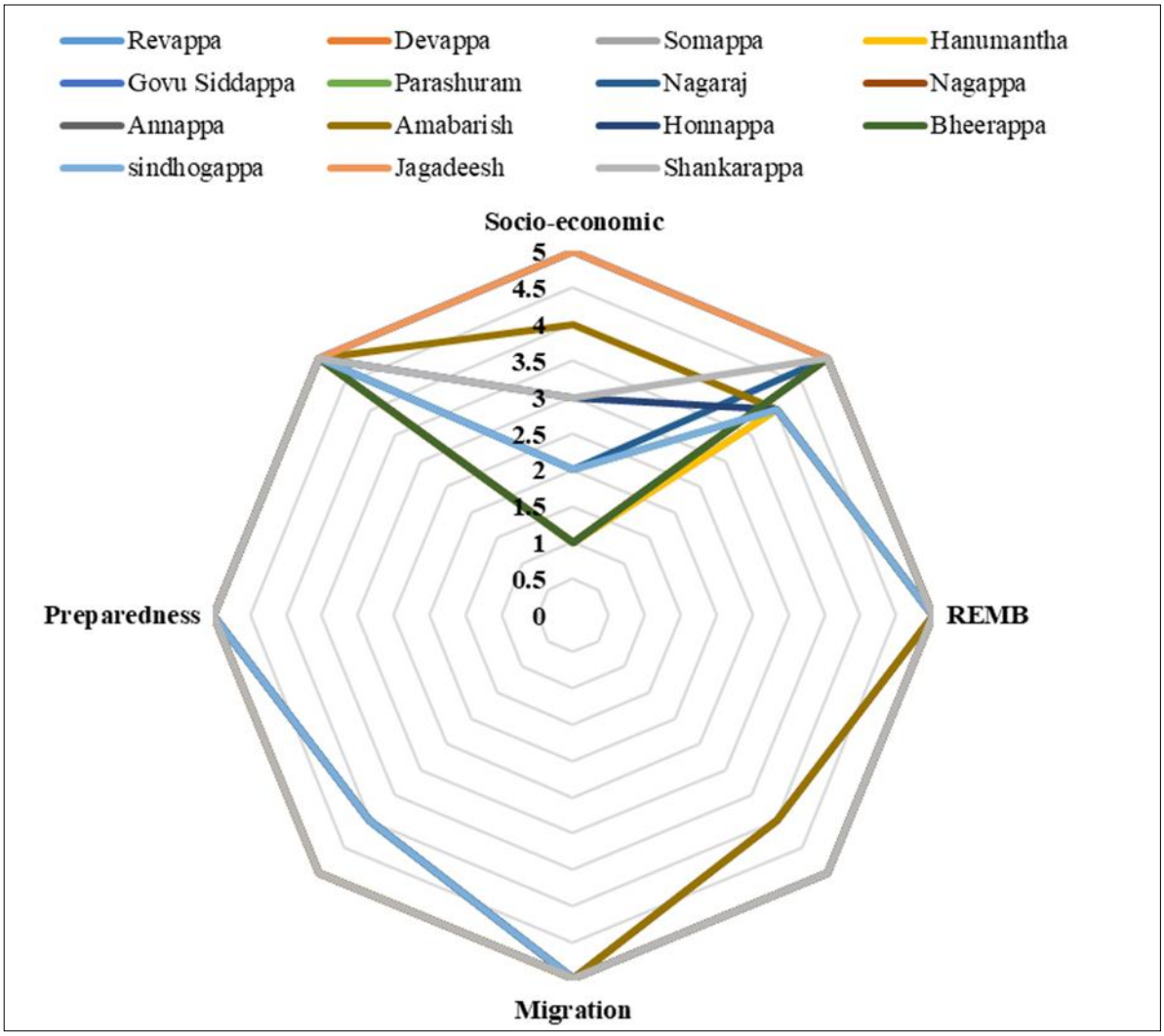


Fig 2: Data of anthrax of sheep and questionnaire details of farmers at Karkihalli village

In the environs of Karkihalli Village, livestock husbandry and commerce constitute integral components of the local econ14.omic fabric, albeit they concurrently pose formidable disease transmission risks within the precincts of local markets. These risks are further compounded by the inadequacies in veterinary oversight and the persistent adherence to traditional practices. To mitigate the proliferation of disease through the marketing of animals, an imperative call for the dissemination of knowledge, implementation of quarantine measures, and collaborative engagement with authorities to uphold the well-being of both animals and humans alike.

The importance of educating farmers to take livestock as a business and learn to invest in it through routine treatment and vaccination especially against anthrax disease must be stressed. The poor attitude of livestock farmers to avail their animals for vaccination was evident in the Focus Group Discussions (FGDs) and is one of the factors that militated against the control of the disease. In addition, the unwillingness of cattle farmers to pay for vaccination of their livestock was also noted. Since anthrax disease affects animals, it should be seen as a health development priority that requires a multisectorial approach, a strategy that requires the collaboration of various ministries and other international agencies. This is because elimination of anthrax in Karkihalli village of Koppal district using the One Health Approach is only effective if there is better sectorial balance among existing groups and networks, especially between veterinarians and physicians, and increased participation of environmental and wildlife health practitioners, as well as social scientists and development actors (Opare *et al.*, 2000 and Patocka *et al.*, 2002) [5, 6]. It is imperative for the strengthening of veterinary and medical services by including relevant stakeholders in policy formulation and priorities in the decision making process towards control and prevention measures. Consistent with previous studies by Hampson and his colleagues [37], we observed that the outbreak in Karkihalli village has affected domesticated sheep of all ages and sexes and has caused 100% deaths in all livestock that were known to be infected.

Ingestion is thought to be the most common route by which herbivores contract anthrax (Dragon *et al.*, 2011) [1]. Livestock in this community are free range and thus are highly exposed to anthrax spores. We observed that even though some forms of anthrax respond well to antibiotic treatment, the cases were not reported to the veterinary services for attention which could have prevented some deaths. Epidemics tend to occur in association with periods of marked climatic or ecological changes such as heavy rainfall, flooding or drought [WHO, 2008 and Hugh-Jones *et al.*, 2009] [10, 2]. We observed that Karkihalli recorded different rainfall patterns as shown in Table 3. This could have caused a change in the climate causing grasses to sprout out and with animals grazing so close to the soil thereby ingesting or inhaling anthrax spores and getting the infection. It is therefore important that community members are educated on

the dangers of anthrax and its prevention. We also observed that even though there seem to be collaboration between the the veterinary services, this is weak and needs to be addressed. During the outbreak, there was a ban on slaughtering and movement of livestock in the region to prevent further spread.

5. Study Limitations
The outbreak investigation had some limitations as only sheep were considered and presented here where other animals could have also done.

6. Conclusion
The case report of the sheep anthrax outbreak in Karkihalli Village, Koppal, Karnataka, highlights the complex interplay of factors contributing to the disease's emergence. The demographic and ecological characteristics of the region, coupled with traditional livestock trading practices, pose significant challenges in disease prevention and control. To mitigate future outbreaks, it is imperative for the government to take proactive measures. This includes allocating resources for comprehensive disease surveillance, ensuring a consistent supply of anthrax vaccines, conducting regular training sessions for local veterinarians and farmers, and establishing robust early detection and rapid response mechanisms using Artificial intelligence (AI). Engaging with the community, dispelling myths, and fostering trust is crucial, as is collaborating with international organizations to strengthen disease management efforts. Addressing these aspects holistically is essential for safeguarding the health and livelihoods of both the community and their livestock in Karkihalli Village and similar regions.

7. Acknowledgement
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8. Authors Contribution
The study on the anthrax epidemic in Hatti Village, Karnataka, was a collaborative effort led by Suresh K P, who served as the corresponding author and played a pivotal role in designing and executing the research. Sagar N, Jayashree A, Naveesh Y B, Archana C A and Sushma R contributed significantly to data collection and analysis, particularly in gathering vital demographic and ecological information about the village. They also assisted in the analysis of collected data while providing support in manuscript editing. Suresh K P brought an international perspective, lending expertise in analyzing ecological factors and their influence on the anthrax outbreak. Hemadri D and S S Patil, experts in veterinary epidemiology contributed to identifying the anthrax-prone area in Koppal and provided brief information regarding the preparation of the questionnaire, in addition to editing the manuscript.

9. Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

10. Consent from Farmers
We've recorded videos of each farmer with their clear and transparent consent, signifying their willingness to participate in activities involving their land and data, all in adherence to agreements ensuring transparency and respecting their rights and interests.

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