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Evaluation of the Variability and Frequency of Infectious Diseases in the Ngorongoro Conservation Area, Ngorongoro District in Arusha Region, Tanzania

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ABSTRACT: The Ngorongoro Conservation Area (NCA) frequently experiences the emergence and re-emergence of infectious diseases. However, it is unclear how emergence varies or changes in frequency. Hence, the objective of this was to evaluate the Variability and frequency of infectious diseases in the Ngorongoro Conservation Area, Ngorongoro district in the Arusha region of Tanzania using appropriate standard methods such as questionnaire surveys, field visits, documentation reviews, and focus group discussions. A total of 396 households participated in the survey from four selected villages, Nainokanoka, Endulen, Kayapus, and Meshili, within the NCA. The collected responses were analysed to determine physical and cultural practices potentially influencing the variability and frequency of infectious diseases. The results suggest a combination of environmental factors, cultural practices, and wildlife conservation measures influence the variability and frequency of infectious diseases in the study including climatic conditions, meat consumption, and scarcity of suitable land for pasture, the presence of wildlife corridors, large livestock numbers and lack of hygiene. Diseases frequently reported to occur were Anthrax, Tuberculosis, Brucellosis, Rabies, Malignant catarrhal fever (MCF), and Malaria. Mitigating pathogens transmission risk will require mapping high-risk areas precisely and public education initiatives to minimize contact between pathogens and the populace within the study area.

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The Ngorongoro Conservation Area (NCA) was established in 1959 as the first multiple land-use conservation area in the world where Maasai pastoralists could reside within a fully protected wildlife area (Linuma *et al.*, 2022; Ngorongoro Conservation Area Authority-NCAA, 2011). The Maasai have shared the area with wildlife for centuries (Veldhuis *et al.*, 2019; Homewood and Rodgers, 1991). This has resulted in the co-usage of resources by wildlife, humans, and their livestock. Despite the Maasai's ability to segregate livestock from wildlife during grazing, interactions can occur at shared water sources and salt licks (Swanson, 2007). The sharing of water leads to the transmission of infectious diseases (Linuma *et al.*, 2022). The co-utilization of water between humans and livestock and the lack of water treatment tabs caused an outbreak of cholera in 2018 (NCAA, 2011). There was an outbreak of anthrax in the Ngorongoro District in 2016 (TAWIRI, 2016). An outbreak of anthrax was also observed in the Serengeti ecosystem located closure to the NCA in 2016, which killed more than 500 goats, sheep, and cattle (Lembo

et al., 2011). Moreover, the presence of other diseases, such as rabies, where vaccination efforts are limited was observed (DED, 2019). Furthermore, the occurrence of Malignant catarrhal fever (MCF) in the NCA represents a major threat to the livelihood of Maasai pastoralists during the mass movement of wildebeests from Maasai Mara to the NCA (Hicks *et al*., 2012). The increasing emergence of infectious zoonotic diseases worldwide is anticipated to continue at an accelerating pace in the future linked to economic development, globalization of travel and trade, changes in habitation and farming systems, and climatic change with global implications (Zhang *et al.*, 2022; Tazerji *et al.*, 2022; Laurenson *et al.*, 2005; Daszak *et al.*, 2000). However, the local drivers of emergence, variability, and frequency are not well characterized. Hence, the objective of this was to evaluate the Variability and frequency of infectious diseases in the Ngorongoro Conservation Area, Ngorongoro district in the Arusha region of Tanzania.

MATERIALS AND METHODS

Study area: The study was conducted in the NCA in the Ngorongoro district in the Arusha region in Tanzania (Figure 1). It covered four villages of the Endulen (n = 118), Nainokanoka (n = 72), Meshili (n = 124), and Kayapus (n = 82) as indicated in Table 2. The NCA was selected purposively due to mainly three reasons; first, it was established in 1959 as the first multiple land-use conservation area in the world where Maasai and Datoga pastoralists and Hadzabe hunter-gatherers could reside within protected wildlife area providing an area for studying human-wildlife interactions and potential variability and frequency of infectious diseases (NCAA, 2011). Second, the NCA has a healthy resident population of most species of wildlife (Linuma *et al.*, 2022; Homewood and Rodger, 1991). Third, there is contact between humans and wildlife in all villages within this area. Ngorongoro is the only wildlife reserve in the world where human and wildlife co-exist (human activities are taking place together with wildlife conservation) (NCAA, 2011).

Criteria for selection of case study villages: A deterministic sampling approach was used to select the case study whereby specific criteria listed in Table 1 were developed and used to screen villages of interest. The criteria developed had scores ranging from 1-5, (1 = least applicable and 5 = most applicable) to guide the selection of wards and villages, and the ones which met most of the criteria with high score were sampled as summarized in Table 1. The selection of the study villages based on the consumption of carcasses, intensity of drought, cold climate, presence of mosquitoes, the increase of temperature, shared drinking water sources, consumption of raw blood, and the presence of large number of goats and sheep. Consequently, this study was carried out in the NCA, comprising nine villages namely; Nainokanoka, Irkeepus, Bulati (Nainokanoka ward), Oloirobi, Kayapus, Mokilal (Ngorongoro ward) Endulen, Nasporing (Endulen ward) and Meshili (Olbalbal ward) as shown in Table 1. The NCA is situated 180 km West of Arusha in the Crater Highlands area of Tanzania. The NCA is part of the Serengeti ecosystem, and has very high animal population densities (Niboye, 2010).

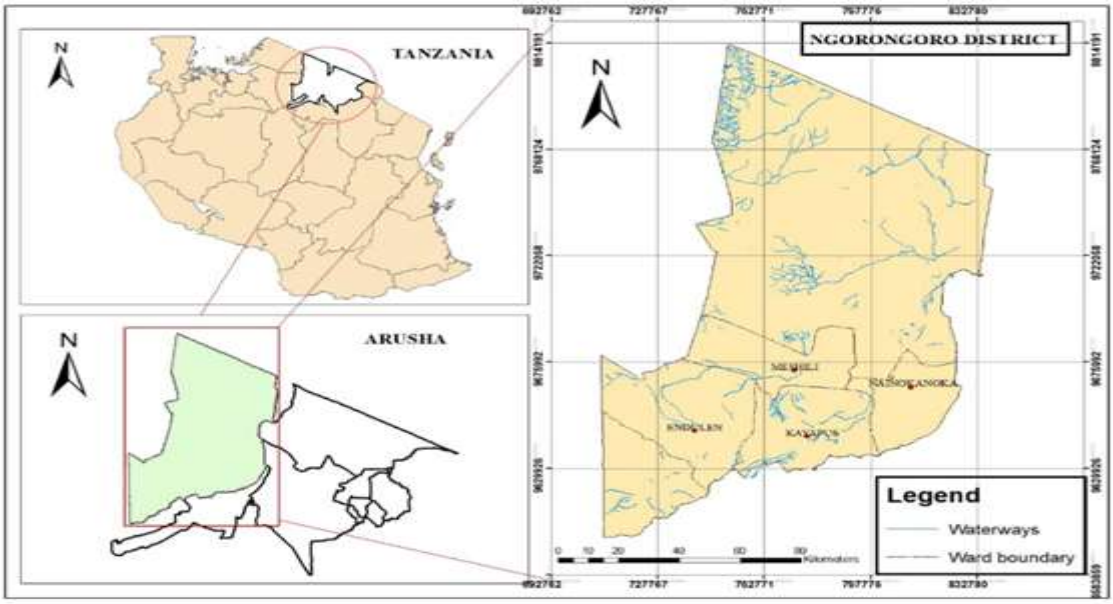

Fig 1: The study area in the Ngorongoro Conservation Area is shown relative to Tanzania. Villages surveyed are shown in the panel on the right

It lies between Longitude 36° 1' 38.7466" and 36° 1.645776' E and Latitude 3° 9' 44.8399" and 3° 9.747332' S. It is bordered by the Serengeti National Park to the North, urban and agricultural areas to the South, the Loliondo Game Controlled Area to the East, and the Maswa Game Reserve to the West (Niboye, 2010). The NCA covers an area of 8,292 km² and can be divided into the Crater Highlands, Eyasi escarpment, Salei plains and the Gol Mountains (Masao *et al.,* 2015; Niboye, 2010). The Salei plains receive little rain and as such, it is dry and dusty with winds carrying and distributing volcanic ash. The dust has a high nutrient content supporting vegetation which in turn supports mass migration of herbivores from Maasai Mara in Kenya to the NCA (NCAA, 2011).

Table 1: Selection of the study area (1 = least applicable, 5 = most applicable)

Wards	**Selection criteria**									
	High consumption of carcass	Cold climate	Presence of mosquitoes	Increase of temperature	Shared of drinking water sources	Consumption of raw blood	Large number of goats and sheep	Shared shelters	**Total score**	**Rank**
Mokilal	4	2	4	3	4	3	4	3	**27**	**6**
Oloirobi	4	1	4	3	3	4	4	5	**28**	**5**
Kayapus	4	5	0	3	5	5	4	5	**31**	**3**
Nasporing	3	1	4	3	4	3	3	4	**25**	**8**
Irkeepus	4	2	4	1	4	3	4	4	**26**	**7**
Meshili	5	1	5	5	5	5	5	5	**36**	**1**
Endulen	5	1	5	5	4	5	5	5	**35**	**2**
Bulati,	3	1	4	2	4	3	4	3	**24**	**9**
Nainokanoka	4	5	0	2	5	5	5	3	**29**	**4**

Data collection: The methods employed in the study included household questionnaire surveys, focus group discussions, documentary reviews, field observation, Key Informant (KI) interviews, and village executive officers in the study area. As argued by Rocco *et al.,* (2003), the application of different techniques in the data collection process helps to confirm information acquired among different techniques. The verification and validation of the outcomes and information in this study were done through cross-checking of data from all sources to discover if similar conclusions could be drawn to increase the reliability of the findings. A random sampling technique was used to select 396 heads of the households to participate in the interviews as indicated in Table 1. The calculated sample size based on the total households in the selected study area was determined using Yamane's formula used in Owuor and Mwiturubani (2021) as indicated in Equation (1).

$$n = \frac{N}{1 + N(e)^2} \qquad \text{Eq. 1}$$

Where n = sample size required; N = population size; e = precision desired (0.05)

Households in the villages (Kayapus, Endulen, Meshili, and Nainokanoka) were 40065.
Calculated sample size:

$$n = \frac{40065}{1 + 40065(0.05)^2} \qquad (2)$$

Where n = 396

Table 2: Distribution of the respondents

Villages	**Sample Size**	**Percent (%)**
Kayapus	82	21
Endulen	118	30
Meshili	124	31
Nainokanoka	72	18
Total	**396**	**100**

Households for interviews were randomly chosen using a list of heads of households in each village from village records. From the selected list, names were chosen randomly and without any order to get a representative sample of people that were included in the interviews from four villages. Directed sampling techniques were applied to choose people that participated in focused group discussions (FGDs) and key informants (KIs) which involved specific categories of people. The household interviews were conducted using structured questionnaires. The interviews were conducted such that the respondents were asked questions and provided answers orally. This method was used to get overall information on the household demographic characteristics of household members, the insights of people, and their inferences of variability and frequency of infectious

diseases among the study sites in the NCA. Beside the household interviews, Focused Group Discussions were conducted to discuss the questions in further depth and acquire information from a small number of individuals to supplement other sources of information. The FGDs was also conducted mainly to increase knowledge with regards to variability and frequency of infectious diseases among pastoralists in the NCA.

Two FGDs with balanced gender were conducted in each of the four villages. Each group consisted of eight respondents including a minimum of four women (each group) who in Maasai culture are more likely to be familiar with diseases affecting their children. The selection of members of FGDs included length of residence in the project area and age. Respondents over fifty years of age were preferred because of their long-term observations. Sex was also considered due to the structure of pastoralist societies and its potential impact on infectious disease. Data collected through FGDs were analyzed and compared with other data collected from other data collection methods. KIs interview was also conducted to get in depth detailed information regarding issues in the NCA particularly those which might not easily be clarified by a person without professional or specialized knowledge about a particular subject. A semi-structured checklist of questions with both closed and open-ended questions was used to ensure collection of uniform information from all KIs in the study area. This method involved knowledgeable people with the subject matter or experts with particular knowledge concerning drinking water source impact on disease transmission in the NCA and provided recommendations for solutions.

A total of 22 KIs were interviewed during this process. KIs included medical doctors (n = 5), field livestock officers in the study villages (n = 4), field livestock officer from NCAA headquarters (n = 1), veterinarians from Ngorongoro District headquarter (n = 2), conservationists (n = 6), and village executive officers (n = 4) in all villages in the study area. Other issues discussed during KIs interviews were variability and frequency of infectious diseases and their trends in the NCA and possible implications on human health and conservation of wildlife in general. The interviewed respondents in FGDs and KIs were sufficient because in collection of qualitative data the samples are not meant to represent large populations.

Field observation was undertaken to gather data independent of the feedback provided by villagers or by direct observation. During field observation, pictures of various areas and scenarios that provided confirmatory evidence for the research site which could assist to verify the information taken from the interviewees and other data sources. Field observation was made during the reconnaissance, data collection period, and post-data collection to observe direct variability and frequency of infectious diseases among the study sites. Documentary review data were collected from both published and unpublished documents. Textbooks, journal articles, internet materials, health center/hospital reports, veterinary reports, ministerial reports from villages, and wards from the NCAA were reviewed. Demographic Health Surveys (DHS) were collected from dispensaries and hospitals.

Data analysis: Data collected using interviews, focus group discussions, field observation, and documentary reviews were qualitative in nature. The nature of the data, therefore necessitated the use of qualitative data analysis techniques. Descriptive statistics were performed to obtain the nature of the occurrence of the diseases in terms of frequencies and percentages. Descriptive statistics were performed using the Statistical Package for the Social Sciences (SPSS) version 25. The inferential statistics (Chi-square) test was used to determine the significant difference in the occurrence of the diseases across the villages in the study area. Moreover, mapping areas vulnerable to infectious diseases was done to analyze distribution patterns. The researcher took coordinates from the research site, and one point of the coordinate represented the impact of one village. The coordinates were taken in the middle of the respective village after confirming that a given disease was present in the area. The coordinates were taken by using a hand GPS. The software used was ArcMap/ArcGIS. Furthermore, Content Analysis (CA) was used to analyse data collected through FGDs and KIs interviews. As argued by Lindgren *et al.*, (2020) and Stemler (2015), content analysis is a method to determine, with objectivity, correctness, and simplification, what is thought on a given topic in a given abode at a given time. The data were split into related and meaningful categories. Collaborative evidence from the household interviews was also used to authenticate interpretation. Paraphrasing and direct quotes were used to present the KIs and FGD findings.

RESULTS AND DISCUSSIONS

Frequently occurring infectious diseases according to respondents: Almost all respondents (97.6%) reported the occurrence of infectious diseases in the study area. The respondents residing in the NCA complained of infectious diseases emanating from wildlife due to co-existence. It was reported that 907 people in the NCA were affected by anthrax disease from 2018 to 2022 (URT, 2022). Furthermore, the

respondents inhabiting the wildlife corridor connecting Lake Manyara and the NCA complained about being vulnerable to diseases. People residing in wildlife corridors such as Selela in the NCA and Lake Manyara National Park have complained about the transmission of infectious diseases from wildlife (Msoffe *et al.*, 2019; Gamasa, 1998). Maa language was used to describe the diseases such as "Engeya nairorwa" anthrax, "emoyani olgoitte" tuberculosis, "engeya oloiki" brucellosis, "olotirwa loodiaini" rabies, "endimiru" malaria, "eneingati" Malignant catarrhal fever (MCF) and "enarats ongoshwak" cholera. Anthrax as described in the local language "engeya nairorwa" was reported by 48.7% of the respondents as among the infectious diseases frequently taking place in the study area, 21.5% reported tuberculosis "emoyani olgoitte", 11% brucellosis "engeya oloiki", 6.1% rabies "olotirwa loodiaini", 5.1% malaria "endimiru", 2.5% Malignant catarrhal fever (MCF) "eneingati", 1.5% cholera "enarats ongoshwak", and 3.6% reported others as indicated in Table 3. The occurrence of anthrax in Endulen and Meshili villages which poses a threat to human and animal health is exacerbated by the hot climatic conditions experienced in these villages. As noted by Carlson *et al.,* (2019) and Malkhazova *et al.,* (2019), countries such as Ethiopia, Turkey, and South Africa have experienced anthrax incidents during dry and warm periods.

Table 3: The reported frequencies of infectious diseases

Variable	Frequency	Percent (%)
Anthrax	193	48.7
Tuberculosis	85	21.5
Brucellosis	44	11
Rabies	24	6.1
Malaria	20	5.1
MCF	10	2.5
Cholera	6	1.5
Others	14	3.6
Total	**396**	**100.0**

Source: Field Survey, 2022

During field visits and discussions with key informants, it was revealed that gastrointestinal and cutaneous anthrax were reported as prevalent.

Village-by-village occurrence of reported diseases: A chi-square test was conducted to identify significant reported variations in disease occurrence in the study area (Table 4). Anthrax occurrence was significantly more commonly reported than other diseases and was particularly prevalent in Endulen village as reported by 40.5% of the respondents and 38.6% of the respondents in Meshili village ($X^2 = 183.5, P < 0.05$, df = 3). Malaria, which is also prevalent, was reported by more than half (51.2%) of the respondents in Endulen village and 48.8% of the respondents in Meshili village ($X^2 = 396.0$, $P < 0.05$, df = 3). Tuberculosis was reported to be significantly widespread ($X^2 = 30.93$, $P < 0.05$, df = 3) in the study area, as noted by 32.2% of the respondents in Meshili village, 23.5% of the respondents in Endulen village, and 23.2% of the respondents in Kayapus village. Malignant catarrhal fever ($X^2 = 63.68$, $P < 0.05$, df = 3) was reported to be predominant in Endulen village by 33.8% of the respondents, 25.5% of the respondents in Kayapus village, and 20.9% of the respondents in Nainokanoka village. A significant proportion ($X^2 = 47.24$, $P < 0.05$, df = 3) of the respondents indicated that Brucellosis was more prevalent in Kayapus village as reported by 28.7%, followed by 25.4% of the respondents in Endulen village, and 23.4% of the respondents in Nainokanoka village. Rabies also showed a significant incidence ($X^2 = 34.04$, $P < 0.05$, df = 3) being common in Meshili village, reported by 28.8% of the respondents, 27.1% of the respondents in Nainokanoka village, followed by 25.0% of the respondents in Endulen village. Cholera ($X^2 = 0.86$, $P = 0.85$, df = 3), was reported by 30.9% of the respondents in Endulen and 30.1% of the respondents in Meshili villages. Generally, anthrax, malaria, tuberculosis, and rabies were reported to be the most common diseases with a high rate of occurrence, particularly in Endulen and Meshili villages in the study area (Table 4). The variation in the occurrence of infectious diseases among the villages across the study area is caused by a number of factors as determined during FGDs discussion with the respondents. First, the hot-dry climatic conditions experienced in Endulen and Meshili villages contributed to the frequent occurrence of infectious diseases such as anthrax compared to the other two villages. This is similar to the studies by Carlson *et al.,* (2019) and Malkhazova *et al.,* (2019) which noted that countries such as Ethiopia, Turkey, and South Africa have experienced anthrax incidences during dry and warm periods. Hot-dry climatic conditions in Endulen and Meshili villages have favored the spread of malaria compared to the other two villages (Mboera *et al.,* 2005; Njunwa *et al.,* 1995). Second, the consumption of meat a common source of food in the pastoralist communities, including the carcasses has contributed to the increase of anthrax cases in Endulen and Meshili villages. According to Chubwa *et al.,* (2019) the Ngorongoro Conservation Area has widespread of anthrax, and the consumption of infected carcasses leads to high disease risk in humans. The shortage of pasture in Endulen and Meshili villages caused by hot-dry climatic conditions results in livestock browsing grass closer to the soil, which is a favorable environment for anthrax bacteria increasing livestock exposure risk. As observed by

Chubwa *et al.,* (2019), the contamination of soils with hemorrhaged blood coupled with other body exudates due to the death of infected animals seeds the earth with *Bacillus anthracis* spores which can be ingested. The presence of wildlife corridors in Endulen and Meshili villages as reported during the focus group discussion leads to the shedding of pathogens and contact with wildlife during the search for pasture which contributes to the increase of anthrax instances in the mentioned villages. According to Msoffe *et al.,* (2019) and Gamasa (1998), the residents residing in wildlife corridors such as Selela linking NCA and Lake Manyara National Park complained about the transmission of infectious diseases from wildlife. Likewise, the respondents during the focus group discussion reported that the commonness of anthrax is associated with the unwillingness of the pastoralist communities in Endulen and Meshili villages to vaccinate their livestock.

During field visits and interviews with veterinarians and livestock field officers, the resistance of Maasai pastoralists to livestock vaccination was confirmed. Lack of education is also another factor for the pastoralist communities not to send their livestock for vaccination.

"The community is unwilling to vaccinate their livestock when the vaccines are sent out of the preferred period starting from April to July. This is the period of rainfall with enough grasses for grazing the livestock. The unwillingness to vaccinate their livestock out of this period as the following period is a dry period accompanied by a lack of grasses causing the livestock to become weak and thinking that the vaccines might affect their livestock. Lack of education among the pastoralist communities also triggered a poor response to vaccinate their livestock."
Source: A complaint from a livestock field officer, 2022

Moreover, the keeping of a large number of livestock by the pastoralist communities in Endulen and Meshili as reported during the focus group discussions, has increased anthrax prevalence. The pastoralist communities in Endulen and Meshili keep a large number of sheep as the main source of food and income. Domestic animals are vulnerable to anthrax disease, and they are the sources of disease transmission to humans through the consumption of meat of infected animals. As noted by Hicks *et al.,* (2012), most of the susceptible ruminants to anthrax disease are sheep, cattle, and goats. Furthermore, the lack of hygiene services such as water and toilets in the villages of Endulen and Meshili resulted in the occurrence of cholera. A total of 1,572 (710 males (45%) and 862 females (55%)) were affected by cholera in the NCA in 2018 (DED, 2019). Other diseases (Sleeping sickness, respiratory disease, foot, and mouth diseases) (X^2 = 3.11, P = 0.38, df = 3) were observed but were less prevalent.

Table 4: Variation of infectious diseases across villages

Diseases	Endulen	Meshili	Kayapus	Nainokanoka	X^2	df	P value
Anthrax	40.5	38.6	12.4	8.5	183.5	3	0.00**
Tuberculosis	23.5	32.2	23.2	21.1	30.93	3	0.00**
Brucellosis	25.4	22.5	28.7	23.4	47.24	3	0.00**
Rabies	25.0	28.8	19.1	27.1	34.04	3	0.00**
Cholera	30.9	30.1	20.8	18.2	0.86	3	0.85
Malaria	51.2	48.8	0.0	0.0	396.0	3	0.00**
MCF	33.8	19.8	25.5	20.9	63.68	3	0.00**
Others	21.4	42.9	7.1	28.6	3.11	3	0.38

*** Significant at 0.05;* ***Source:*** *Field Survey, 2022*

Factors influencing the frequency of reported infectious diseases: More than half (56%) of the respondents reported cultural practices such as the consumption of unprepared meat, drinking raw blood, and raw milk, the use of skin clothes, skin mattresses, and shelters constructed by using skins and animal dung among the factors influencing the frequency of infectious diseases in the study area (Table 5). Twenty-two percent reported co-usage of water, 9.3% co-grazing, 6.6% increasing temperature, 3.3% wildlife corridors, 2% shared shelters, and 0.8% others. Meat is the primary source of protein in the Maasai pastoralist communities, and it is consumed undercooked hence it contributes to the transmission of infectious diseases such as anthrax. Moreover, they consume raw blood and unpasteurized milk which in turn can increase the frequency of transmission of infectious disease such as Brucellosis. As argued by Kiringe (2006), Maasai pastoralists are affected by Brucellosis and worms due to the consumption of unpasteurized milk, undercooked meat, and the drinking of raw blood. Furthermore, exposure to wildlife corridors supports the transmission of infectious diseases to the communities living along the corridors. The search for pasture leads to exposure to pathogens shed by wildlife. As noted by Gamasa (1998), the residents residing in wildlife corridors such as Selela linking NCA and Lake Manyara National

Park complain about the transmission of infectious diseases from wildlife. Likewise, the co-usage of water among humans, domestic animals, and wildlife influences the transmission of infectious diseases. Widespread anthrax is linked to the co-sharing of water sources by humans, domestic animals, and wildlife. A study by Carlson *et al.*, (2019) revealed that livestock and people in the world are at risk of anthrax spores as they expose to contaminated soil, pasture, and water. However, the extreme heat experienced in Endulen and Meshili villages as the outcome of climate change has supported the emergence and frequency of occurrences of malaria. Previously, the NCA did not have cases of malaria as it was too cold for mosquito vectors. As argued by Mboera *et al.*, (2005) and Njunwa *et al.*, (1995), the Ngorongoro highlands until mid- 1990 were known to be free from malaria.

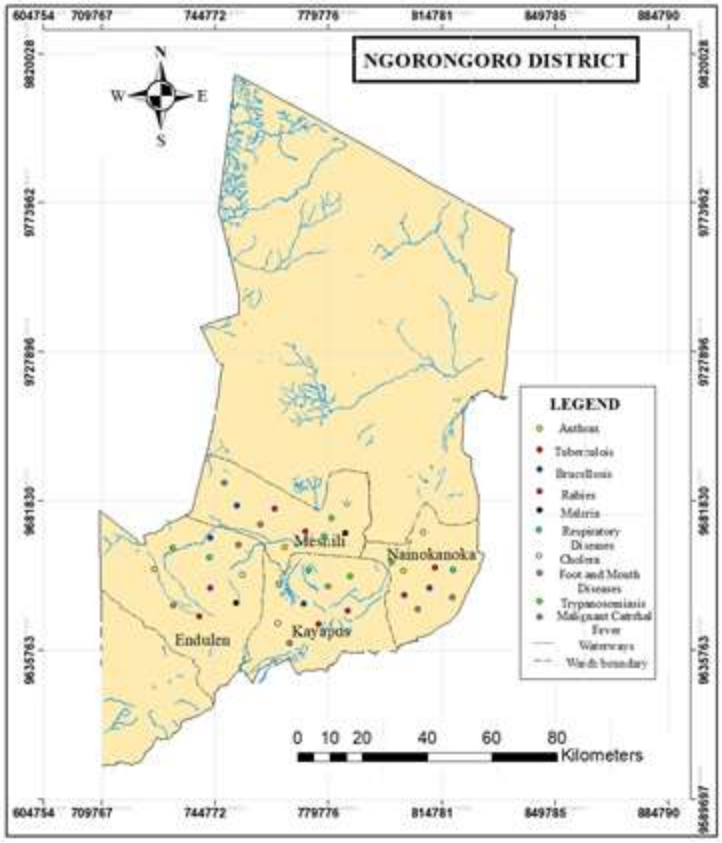

Fig 2: Distribution of reported infectious diseases is shown in the right panel. Each colour represents different reported disease in the study villages as shown in the legend.
Source: Field Survey, 2023

Shared human and livestock shelters, particularly sharing with calves, promote the transmission of infectious diseases by inhalation. The presence of tuberculosis disease results from the co-sharing of shelters with calves that are co-grazed with buffalos during the daytime. A total of 655 people (315 men (48.1%) and 340 women (51.9%)) suffered from tuberculosis-related disease in the NCA over a period of six years from 2018 to 2023 (URT, 2023). Dog bites were also another factor reported by the pastoralist communities to influence occurrences of rabies disease in the study area. The pastoralist communities in the NCA keep dogs for security purposes against wildlife, however, the same dogs can be infected. It was reported that 124 people (79 men (63.7%) and 45 women (36.3%) were bitten by dogs in the NCA over six years (2018 to 2023). Out of 124 people bitten by dogs, 5 people (4%) died due to rabies disease over a period of six years starting in 2018 to 2023. As argued by Blanton *et al.*, (2009), almost 90% of rabies transmission is through dog or cat bites. Additionally, Malignant catarrhal fever was reported by the respondents as a fatal disease to livestock particularly the cattle in the study villages. The livestock interact with the wildebeests as they have shared water, grazing, and salt-licking areas hence the frequent occurrences of infectious diseases posing a threat to livestock and wildlife. Such interactions happened during the great mass movement of wildebeests from Maasai Mara to the NCA each year in December.

According to Katale *et al.,* (2013) and McCabe *et al.,* (1997), the interactions between livestock and wildlife coupled with the semi-nomadic style of livestock production aftermath in distinctive and intricate disease transmission in the NCA.

Table 5: Factors influencing the frequency of infectious diseases

Variable	Frequency	Percent (%)
Cultural practices	222	56
Co-usage of water	87	22.0
Co-grazing	37	9.3
Climate change	26	6.6
Wildlife corridors	13	3.3
Shared shelters	8	2.0
Others	3	0.8
Total	**396**	**100.0**

Source: *Field Survey, 2022*

During field visits, the researchers observed calves entering unventilated human shelters at night (Figure 3). As calves share water sources and salt licks with the wildlife which are the main sources of infectious diseases transmitted to humans, cohabitation is likely a source of infectious disease risk.

Fig 3: The picture shows a typical example of a shelter shared by calves and humans
Source: Field Survey, 2022

The influence of livestock on the variation and frequency of reported infectious diseases: More than half 202(51%) of the respondents reported goats as the main livestock kept in the study area, 103(26%) sheep, 77(19.4%) cattle, and 7(1.8%) donkeys. Among companion animals 5(1.3%) of respondents kept dogs, and 2(0.5%) cats (Figure 4). The livelihood of Maasai pastoralists relies on livestock as their sole core sources of food and income. As noted by Mshida *et al.,* (2018) and Nestel and Geissler (1986), the traditional diet of Maasai involves raw milk, fat, raw blood, tree bark, meat, and honey. As explained previously, the mentioned livestock is highly vulnerable to diseases such as anthrax while browsing for pasture which is also affected by climate change. According to Hicks *et al.,* (2012), the most susceptible ruminants to anthrax disease are goats, cattle, and sheep.

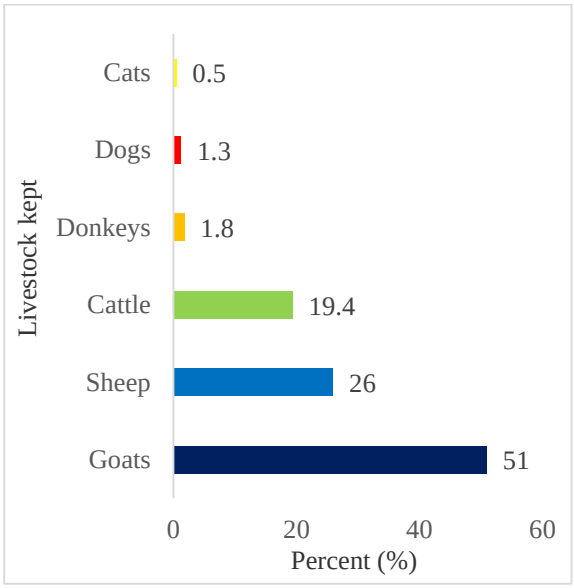

Fig 4: Livestock kept in the study area
Source: Field Survey, 2022

During field visits, the researchers observed that shelters were constructed of animal skins and livestock dung (Figure 5). The use of skins and livestock dung in the construction of shelters could transmit anthrax to humans, particularly during the rainy season when the skins become wet and are water carries bacteria into the enclosure.

Fig 5: A photograph of a typical structure constructed with animals' skins is shown.
Source: Field Survey, 2022

The influence of co-usage of habitat in the occurrence of reported infectious diseases: Habitat is reported by 100% of the respondents interviewed as the foremost factor influencing the frequency of occurrence of

infectious diseases. The NCA is a co-existence area inhabited by humans, livestock, and wildlife.

The indigenous Maasai have co-shared the area with wildlife for several years while benefitting from pasture for their livestock, food supplies, traditional herbal medicines, and shelter (TAWIRI, 2016). Water was reported by 273(69%) of the respondents interviewed as the major factor influencing the frequency occurrence of infectious diseases, 99(25%) reported pastures, and 24(6%) reported shelters (Figure 6). The co-usage of water sources due to limited supply of tap water, the co-grazing of livestock together with wildlife coupled with the co-shared of shelters trigger the frequent occurrence of infectious diseases. The occurrence of anthrax and tuberculosis in the NCA is linked with the sharing of water sources among humans, livestock, and wildlife. Both fecal coliform and coliform bacteria are present in sampled water (URT, 2021).

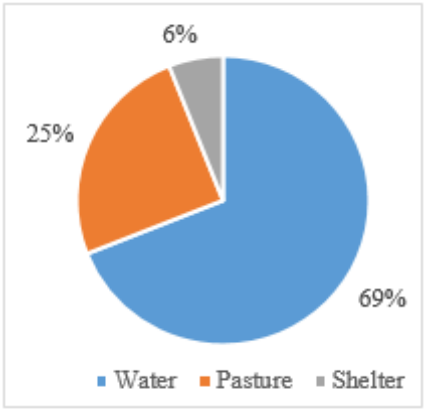

Fig 6: A breakdown of reported shared resources is shown.
Source: Field Survey, 2022

Respondent reported challenges caused by infectious diseases: Drug-resistant pathogens were reported by 222(56%) of the respondents (Figure 7). 107 (Twenty-seven percent) reported traditional herbal medicines, 27(7%) inappropriate use of drugs, 20(5%) overuse of antibiotics, 16(4%) insufficient infection control measures, and 4(1%) ineffective drugs and vaccines as contributing factors.

The inappropriate prescription by doctors and misuse of antimicrobial drugs by patients, including the Maasai pastoralist communities, is known to increase microbial drug resistance. Traditional herbal medicines interfere with the metabolism of drugs used to treat other infectious diseases. The Maasai pastoralists entirely rely on traditional herbal medicines that have no data regarding efficacy for the treatment of diseases. For example, *Hypoxis* has the possibility to interact with HIV drug-metabolizing enzymes which leads to drug resistance, treatment failure, and drug toxicity (Mills *et al.*, 2005).

Human anthrax cases: Questionnaire interviews and discussions with key informants revealed the frequency of occurrence of anthrax in the NCA. Results (Figure 8) show 907 (521 men (57.4%) and 386 women (42.6%) were affected by anthrax in the NCA in a period of five years (2018 to 2022). Men were more susceptible to anthrax infection than women as they were more likely to engage in the slaughtering of livestock such as sheep (ingerah), cows (ingishu), and goats (ingineji). Likewise, men in the pastoralist communities might be infected with anthrax through handling animal products or during grazing, which puts them in contact with the livestock.

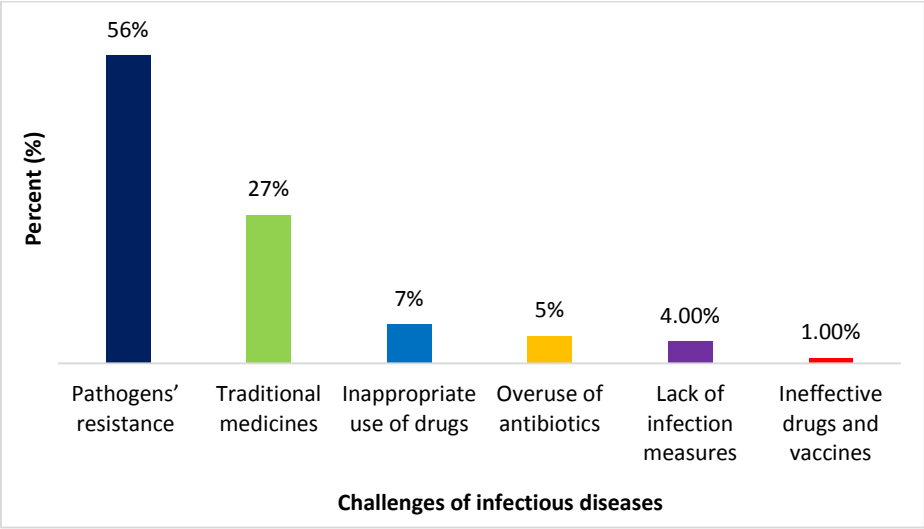

Fig 7: The most common respondent reported challenges as a result of infectious diseases.
Source: Field Survey, 2022

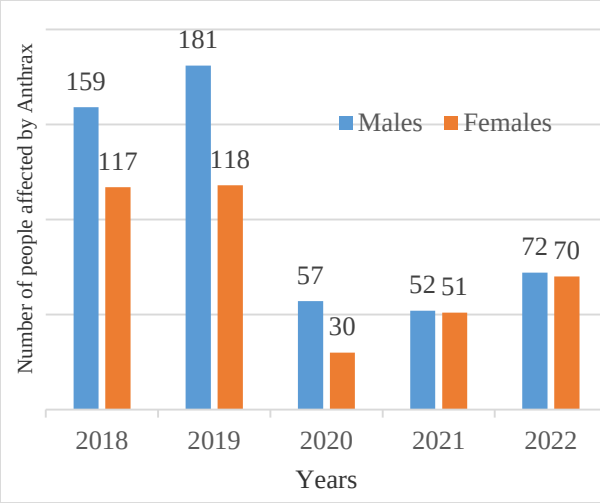

Fig 8: The number of anthrax cases requiring treatment from 2018-2022 is shown.
Source: Demographic Health Surveys (DHS) data, 2023

People hospitalized due to Tuberculosis from 2018 to 2023: During questionnaire interviews and discussions with key informants, it was reported that tuberculosis was frequent and widespread in almost all the villages in the NCA (Figure 9). Results show that 655 people (315 men (48.1%) and 340 women (51.9%) suffered from tuberculosis disease in a period of six years (2018 - 2023) (URT, 2023). Women were more likely to report tuberculosis infection than men. Studies by Office International des Epizooties (OIE) (2009) and Thoen and LoBue (2007) showed women were more responsible for milking cows and caring for them putting them in contact with a known reservoir (cattle are considered to be the primary host for Bovine Tuberculosis) which can infect humans and other animals. As a consequence of tuberculosis outbreaks in the NCA, the Endulen hospital was constructed in part to combat tuberculosis affecting the Maasai pastoralist communities. Endulen hospital in the NCA, According to Mbugi *et al.*, (2017), Waso district hospital, Bunda, and Mugumu district hospitals perform Tuberculosis (TB) screening.

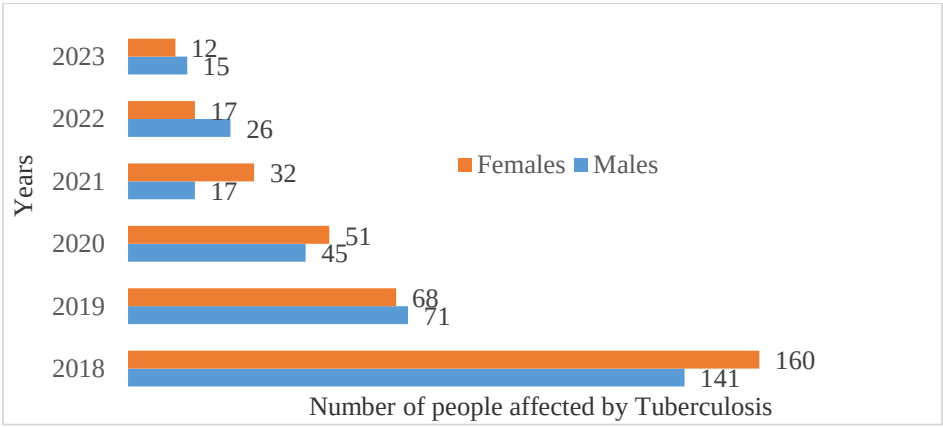

Fig 9: Tuberculosis cases by gender 2018-2023
Source: Demographic Health Surveys (DHS) data, 2023

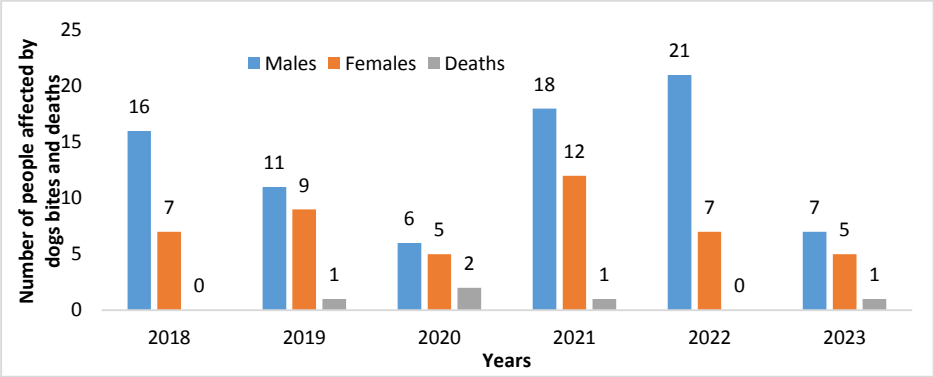

Fig 10: Reported cases of dog bites by gender 2018-2023
Source: Demographic Health Surveys (DHS), 2023

Rabies as an example of zoonotic disease transmission from 2016-2019: Questionnaire interviews and discussions with key informants showed the frequency of occurrence of rabies in the NCA. Results (Figure

10) show that 124 people (79 men (63.7%) and 45 women (36.3%) were bitten by dogs in the NCA for a duration of six years (2018 to 2023). Of these 124 people bitten by dogs, 5 people (4%) died due to rabies over six years. These are the cases reported to dispensaries/hospitals; however, the number of deaths could be more than reported to health centers as the limited availability of rabies vaccines and the use of traditional herbal medicines might contribute to low reporting of rabies cases. Men were more vulnerable to dog bites in the NCA compared to women. This could be partially explained by men's roles in the pastoralist communities, such as grazing the livestock and safeguarding the community, keeping them in frequent contact with dogs. A study by Blanton *et al.*, (2009) noted that dogs are kept by the community for security against wildlife. Likewise, during physical field visits and discussions with key informants, it was confirmed that unreported rabies cases were treated using traditional herbal medicines.

Hospitalizations due to Brucellosis from 2018 to 2023: Questionnaire interviews and discussions with key informants indicated brucellosis-associated health problems (Figure 11). Results show that 32 people (20 men (62.5%) and 12 women (37.5%)) suffered from brucellosis in six years (2018 - 2023). Unpasteurized milk is commonly consumed in the pastoralist communities, followed by meat and then vegetables. The milk used by the pastoralist communities is unpasteurized, which encourages the transmission of brucellosis when raw milk from an infected cow is consumed. With regard to the results, men are the most vulnerable compared to women. This could be partially explained by their position in the community as the decision-makers concerning all matters pertaining to family issues, including the consumption of food. As reported by Udokanma and Emeahara (2017) and Nkhoma-Wamunza *et al.*, (1989), in Tanzania women's participation in decision-making at both the household and community level is minimal.

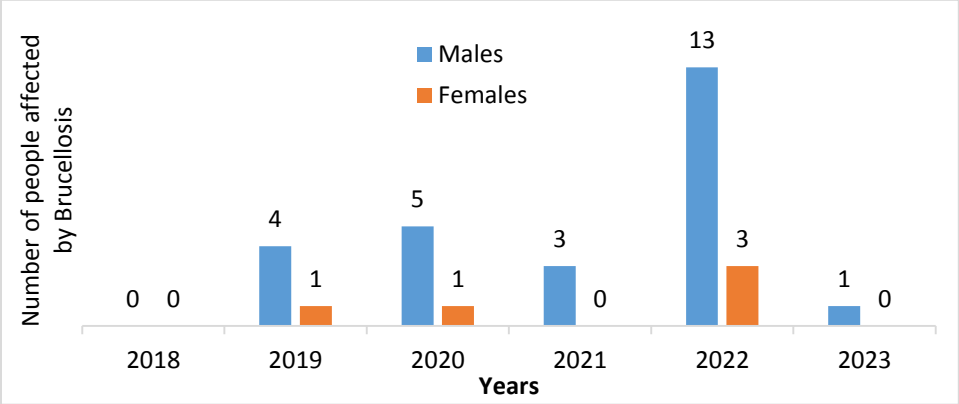

Fig 11: Reported Brucellosis cases from 2018 -2023
Source: Demographic Health Surveys (DHS) data, 2023

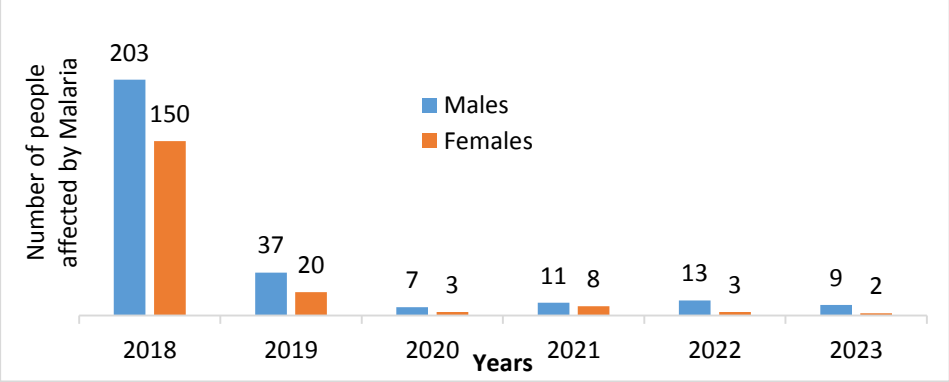

Fig 12: Reported malaria cases by gender 2018 -2023
Source: Demographic Health Surveys (DHS) data, 2023

Hospitalizations due to Malaria from 2018 to 2023: During questionnaire interviews and discussions with key informants, the frequency of occurrence of malaria in the villages that are characterized by hot climatic conditions such as Endulen and Meshili was reported. Results show that 466 people (280 men (60.1%) and 186 women (39.9%) suffered from malaria in a period of six years (2018 - 2023) (Figure

12). Previously, the NCA did not experience hot climatic conditions. As stated by Mboera *et al.*, (2005) and Njunwa *et al.*, (1995), the Ngorongoro highlands until mid- 1990 were known to be free from malaria. The frequency and occurrence of malaria in Endulen and Meshili are associated with climate change in these villages. The occurrence of malaria might increase due to an unfavorable environment for the use of mosquito nets. The skin mattresses used by the pastoralist communities do not support mosquito nets as there is no place to fix the nets. Moreover, traditional and cultural practices of the pastoralist communities do not favor mosquito nets usage. The pastoralist communities are nomadic, involving constant movement with their livestock in search of water and pasture. As noted by Kushoka (2011) and Mtengeti (1994), the Maasai pastoralists live under difficult conditions; hence they are in constant movement in response to unpredictable water availability and forage and escaping drought conditions affecting their livestock.

Questionnaire interviews and discussions with key informants revealed the awareness of climate change in the NCA (Table 6). A significant climate change was observed in the NCA. Temperature change indicates the annual increase of temperature of 0.4°C (maximum) and 0.6°C (minimum) with a 0.5°C mean temperature under the use of a Representative Concentration Pathway (RCP 4.5) (Mwabumba *et al.*, 2022). The NCA was characterized until recently by cold climatic conditions. The Ngorongoro highlands until mid- 1990 were known to be free from malaria (Mboera *et al.*, 2005; Njunwa *et al.*, 1995). The highest occurrence of malaria is in hot highland areas of Ngorongoro, such as Endulen and Meshili. During field visits, the researchers observed mosquitoes and the use of mosquito nets in the Endulen and Meshili villages. Climate change is associated with the existence of mosquitoes in the study area consequent to the presence of malaria.

Table 6. Temperature (2021-2050) under RCP4.5 and RCP8.5 as compared to the past (1982-2011)

Temp.	Historical (1982-2011)	RCP4.5 scenario	RCP8.5 scenario
Maximum	26.9	27.3 (+ 0.4) ∗	27.5 (+ 0.6) ∗
Minimum	14.3	14.8 (+ 0.6) ∗	14.9 (+ 0.5) ∗
Mean	20.6	21.1 (+ 0.5) ∗	21.1 (+ 0.6) ∗

•*Projected changes,* ***Source:*** *Mwabumba et al. (2022). Temp. - Temperature*

Conclusions: The results have shown the reported factors influencing the variability and frequency of infectious diseases were hot-dry climate, consumption of meat of infected animals, pasture shortage, wildlife corridors, livestock, lack of hygiene. Challenges identified threatening human health were drug-resistant pathogens, traditional medicines, overuse of antimicrobial drugs, and insufficient infection control measures. Mapping high-risk areas and developing public education to minimize contact between pathogen sources and the populace is critical. There is a need for prompt measures to be taken for intervention in areas with frequent occurrence of infectious diseases. Reinforcing education about cultural practices risky to community health will be necessary. Sensitizing communities to climate change leading to emergence of infectious diseases, evacuating communities in wildlife corridors, using mosquito nets, discouraging co-shared shelters, vaccination of dogs against rabies, avoid animal skin and dung in shelters' construction will also need to take place.

Declarations

Conflicts of interest: All authors have declared that they have no conflict of interest

Data availability: Data will be provided upon request

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Compliance and Ethical Clearance: The study obtained ethical clearance from Ardhi University, United Republic of Tanzania Commission for Science and Technology (COSTECH), with research permit number 2020-295-NA-2020-123, Tanzania Wildlife Research Institute (TAWIRI) and the Ngorongoro Conservation Area Authority (NCAA) before data collection. The respondents were also informed of the purpose of the research, and confidentiality was assured before conducting interviews. In addition, the National Institute for Medical Research (NIMR) read and approved the final manuscript, with reference number NIMR/HQ/R.8a/Vol./3474 before it was submitted for publication. All procedures performed in this study that involved human participants were in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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